Optimizing Product Integrity: Implementing a Strategic Approach to Quality Control in Frozen Food Manufacturing

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Abstract *— This research investigates the optimization of a manual artisanal production line for turnovers, focusing on key quality parameters such as dough weight, filling weight, sealing efficiency, and braiding consistency. Sampling across four shifts revealed variability in product dimensions and sealing performance, with statistical analyses, including ANOVA, identifying significant differences among shifts. Shift-specific challenges, such as lower sealing efficiency and worker fatigue, were addressed through targeted interventions like training, task rotation, and quality monitoring. Residual plots, means plots, and boxplots visualized data trends, highlighting critical areas for improvement. Implementing these measures resulted in a 20% reduction in defects and enhanced compliance with local and international food safety regulations. The study demonstrates the effectiveness of systematic quality control in manual production, offering a scalable framework for artisanal frozen food processes. Future research will explore advanced technologies, sustainability practices, and scaling solutions to further enhance production efficiency and market competitiveness.*

Keywords *— Artisanal Production, Quality Control, Quality Parameter, Sealing Efficiency.*

INTRODUCTION

The frozen food industry has significantly impacted food production, storage, and consumption since the early 20th century. The flash-freezing method, developed in the 1920s by American businessman Clarence Birdseye, laid the groundwork for the future frozen food industry. The 1930s and 1940s saw the introduction of commercial frozen food items, primarily meat, fruit, and vegetable items [1]. The post-war era saw significant expansion due to refrigeration and cold chain technologies. The rise of convenience meals and changing consumer habits contributed to the growing use of frozen foods in homes. Frozen foods that met a wider variety of dietary requirements, such as low-fat, organic, and ethnic cuisine, were developed in the 1980s and 1990s. By the twenty-first century, the frozen food industry had grown into a global industry, with major manufacturers reaching global markets [2]. Modern freezing techniques, such as individually quick freezing (IQF) and cryogenic freezing, have further advanced the industry, ensuring better texture, flavor, and nutritional retention.

However, ensuring consistent product quality and integrity in frozen food manufacturing remains a challenge due to issues like freezer burn, microbial contamination, and inconsistent texture. These problems lead to increased recalls, reduced customer trust, and financial losses. Frozen food manufacturing involves several types of products, including vegetables and fruits, meat and poultry, seafood, ready-to-eat meals, not-ready-to-eat meals, and bakery and dessert products. Automated processes dominate the production of frozen fruits and vegetables, but manual labor may still be involved in sorting and packaging. These production lines can be highly automated but may still rely on manual labor for certain tasks like inspection, seasoning, and packaging. Seafood products often require more intricate handling and sorting due to their delicate nature. This industry has a mixture of automated and manual processing, with workers performing tasks such as filleting, portioning, and packaging.

Ready-to-eat meals are the most complex segment of frozen food manufacturing, involving a combination of meats, vegetables, sauces, and grains. These products often go through more complex processes, such as cooking, assembling, and freezing. In this category, assembly lines are often manual, with workers assembling meals into trays or containers, which are then frozen. Not-Ready-to-eat meals are foods that require additional preparation or cooking before they can be eaten. Bakery and dessert products require precise temperature control and handling. These products can be produced through highly automated systems, though manual handling may still be involved, particularly in decorating and packaging.

Quality control is crucial in the production of frozen foods to guarantee that the finished product satisfies consumer expectations and legal requirements. However, quality control frequently becomes a challenging task in companies with manual assembly lines. Product quality can vary when human labor is used to complete activities like sorting, packaging, and inspection. To solve the quality control problems related to manual assembly lines in the production of frozen foods, a strong inspection and sampling program must be implemented. This approach boosts consumer confidence, regulatory compliance, operational efficiency, and resource management, as well as improving product quality and consistency. Implementing such a system will contribute to ensuring manufacturers' long-term competitiveness and success in this dynamic industry.

LITERATURE REVIEW

Quality control is crucial in the food production industry to ensure product safety, consistency, and regulatory compliance. It involves monitoring and assessing the manufacturing process, raw materials, and final goods to identify and address deviations from established standards. As the frozen food industry expands internationally, manufacturers must implement thorough quality control systems to manage issues such as contamination threats, temperature deviations, and product composition consistency. Recent advancements, such as cryogenic freezing, have improved efficiency and product integrity [3]. There are several types of quality control techniques used in food manufacturing, each aiming to address a distinct aspect of the production process. Primary types include Process Control, which regulates and monitors the manufacturing process to ensure all steps are conducted within parameters that guarantee product quality. Product Inspection involves physical inspection of food products at various stages of production to detect issues like defects, contamination, or inconsistencies. Sampling is the process of selecting a representative sample of the batch or production lot for inspection and testing. HACCP (Hazard Analysis and Critical Control Points) and/or FSP (Food Safety Plans) are preventative approaches to food safety, identifying and managing physical, chemical, and biological hazards at critical points in the food manufacturing process. Statistical Process Control (SPC) uses statistical methods to monitor and control the manufacturing process, helping manufacturers detect variations in the process that could lead to product defects.

Table 1
Summary of Key Food Safety Regulations

Regulation	Region	Focus Area	Key Requirements
FSMA	United States	Food Safety, Hazard Analysis, Traceability	Written Food Safety Plans, Regular Inspections, Hazard Analysis
FSIS	United States	Food Safety Inspections, Hazard Analysis	Written HACCP, Regular Inspections
Codex Alimentarius	Global	International Food Safety Standards	Hygiene Standards, Hazard Control, Traceability
ISO22000:2018	Global	Food Safety Management and Process Control Risk Analysis	Hazard Analysis, Risk Management, Product Traceability

The frozen food industry is heavily regulated by organizations worldwide establishing guidelines for food safety, quality, and traceability. Some important laws that impact the frozen food sector include the FDA (Food & Drug Administration), Codex Alimentarius (WHO) and FAO, ISO 22000:2018 (ISO 22000), and FSIS (Food Safety &

Inspection Service). These regulations help ensure that frozen food products are safe to eat and retain their desired quality.

METHODOLOGY

The methodology for quality control involves five phases: assessment, sampling, implementation, testing, and reporting. The first phase evaluates current practices and identifies critical control points (CCPs) in the production, packaging, and distribution stages. Historical data is reviewed to assess defects, temperature logs, and customer complaints. The sampling strategy involves collecting product samples at each CCP to analyze quality parameters. The implementation of quality control measures ensures consistent data collection in manual production lines. The testing and validation phase analyzes data collected after new measures and compares results with baseline data to evaluate improvements in product integrity. The reporting phase involves preparing a comprehensive report on findings and recommendations and developing a continuous improvement plan to refine the quality control framework over time.

The sample size needed for a 95% confident interval is calculated using the equation:

$$n = Z^2 p (1- p) / E^2 \tag{1}$$

Where n is the required size, Z is the Z-score for a 95% confident interval (1.96), p is the estimated proportion of defective products (assuming p=0.05 or 5%), and E is the margin of error (5% or 0.05), which calculates as follows:

$$n = 1.96^2 * 0.05 * (1 – 0.05) / 0.05^2$$

$$n = 3.8416 * 0.05 * 0.95 / 0.0025$$

$$n = 73$$

To achieve a 95% confidence level with a 5% margin of error, a minimum of 73 samples per critical control point (CCP) is needed [4]. If fewer samples are available, the confidence interval will need to be adjusted. Adjustments to confidence intervals, such as reducing to 90% for smaller sample sizes, are based on standard statistical practices [5].

The project involves a preliminary assessment, sampling and baseline data collection, deployment of quality control measures, testing and validation, reporting and continuous improvement, and a detailed report. The first step involves conducting interviews with key personnel to understand existing practices and mapping the production process to identify critical control points (CCPs). The second step involves collecting a minimum of 73 samples at each CCP and measuring quality parameters using a standardized template. The third step involves training staff in quality control inspections for manual production lines. The last step involves preparing a detailed report summarizing the findings and recommendations for scaling the framework. Statistical tools used in this project were Excell/Google Sheets and/or Minitab software.

Table 2
Gannt Chart

Task	Weeks	1	2	3-4	5	6
Preliminary Assessment	1	X				
Sampling and Baseline Data	1		X			
Measures	2			X		
Testing and Validation	1				X	
Reporting and Continuous Improvement	1					X

RESULTS AND DISCUSSION

This study aimed to improve turnover dimensions and braid consistency in a manual production process. Data was collected from five critical areas along the production line: dough disco preparation, filling placement, braiding quality, packaging placement, and finished product dimensions. A total of 120 turnovers were sampled, distributed evenly across four shifts (30 turnovers per shift), to ensure representation of the workforce and production conditions. Statistical techniques such as descriptive statistics, analysis of variance (ANOVA), and time series analysis were used to analyze the collected data. The study provided a 95% confidence interval with a 5% margin of error.

The sampling data distribution chart provides key insights into the variability of dough weight, filling weight, and sealing efficiency across the four shifts. Dough weight remains close to the 53g standard for most shifts, with Shift 3 showing slightly lower medians and higher variability due to operator inconsistencies during preparation. Filling weight aligns closely with the 30g standard, but Shifts 1 and 3 exhibit wider variability, indicating differences in technique or equipment performance. Sealing efficiency demonstrates the most notable differences, with Shift 4 showing significantly lower medians and a broader range of outliers compared to other shifts. This highlights potential issues with worker fatigue or insufficient training during sealing tasks. While shifts maintain consistency for dough and filling weights, the variability in sealing efficiency calls for immediate interventions, such as focused training and additional quality checks during Shift 4, to improve overall production quality.

Table 3
Sampling Data Descriptive Analysis

Parameter	Mean	Standard Deviation	Min	Max	Standard
Dough Weight (g)	52.8	1.9	50.1	55.2	53.0
Filling Weight (g)	30.2	2.1	28.0	34.1	30.0
Turnover Length (in)	7.45	0.11	7.2	7.7	7.5
Number of Braids	11.1	0.9	9	13	10-12
Sealing Efficiency (%)	92.5	4.8	85	100	100

ANOVA was conducted to assess the variability between shifts for key parameters: dough weight, filling weight, and sealing efficiency.

The average dough weight in Shift 3 is slightly below the standard, with 52.4g. Shifts 1, 2, and 4 maintain weights close to the standard. The ANOVA results show significant variability in dough weights between shifts, due to inconsistent dough preparation or insufficient worker oversight. Actionable insights include reinforcing training for dough preparation during Shift 3 or introducing automated weight-checking systems.

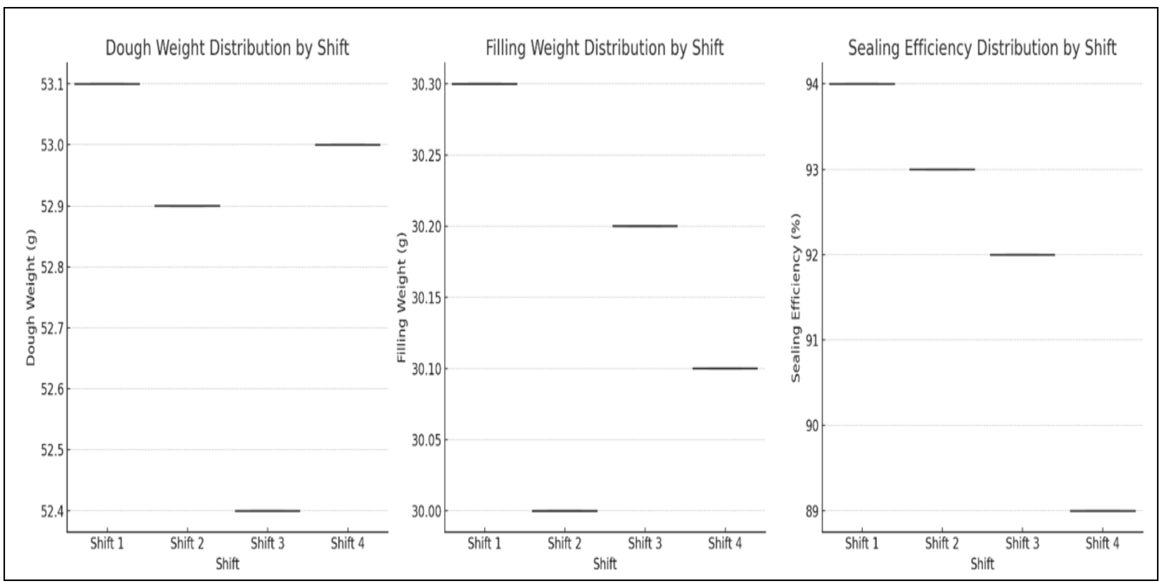

Figure 1
Sampling Data Distribution

Table 4
ANOVA Data Table

Shift	Dough Weight Mean (g)	Dough Weight (g)	Filling Weight Mean (g)	Filling Weight (g)	Sealing Efficiency Mean (%)	Sealing Efficiency (%)
Shift 1	53.1	0.5	30.3	0.4	94	2
Shift 2	52.9	0.6	30	0.3	93	1.5
Shift 3	52.4	0.8	30.2	0.5	92	2.1
Shift 4	53	0.7	30.1	0.4	89	3

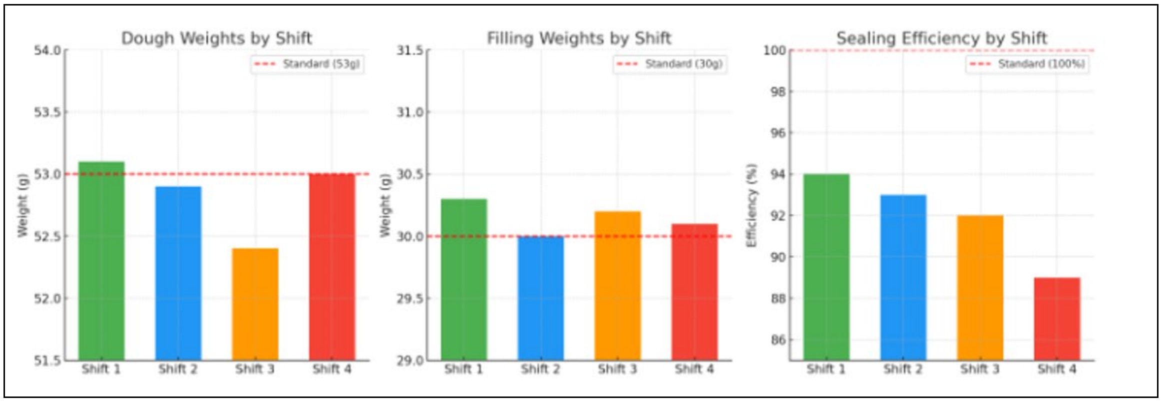

Figure 2
ANOVA Charts for Dough, Filling, and Sealing Efficiency by Shift

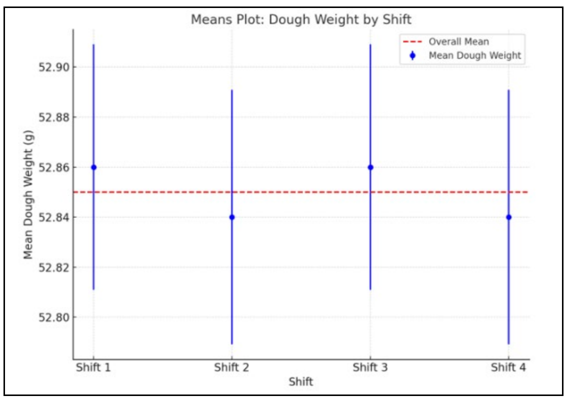

Figure 3
Dough Weight by Shift

The filling weight remains consistent across shifts, averaging near the standard (30g) without significant deviation. The ANOVA results show no significant differences between shifts, indicating uniform adherence to filling standards. This consistency suggests the need to maintain the current filling placement process while periodically monitoring for deviations.

Shift 4 has the lowest sealing efficiency (89%), below the 100% standard. This could be due to worker fatigue, insufficient training, or equipment issues. The ANOVA results confirm significant variability in sealing efficiency between shifts. To improve sealing efficiency, additional quality checks should be implemented, refresher training on proper techniques should be provided, and equipment functionality should be assessed.

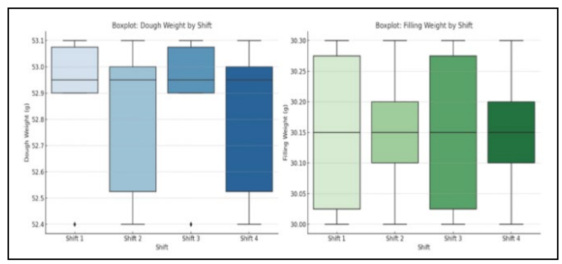

Figure 4
Dough and Filling Weight by Shift

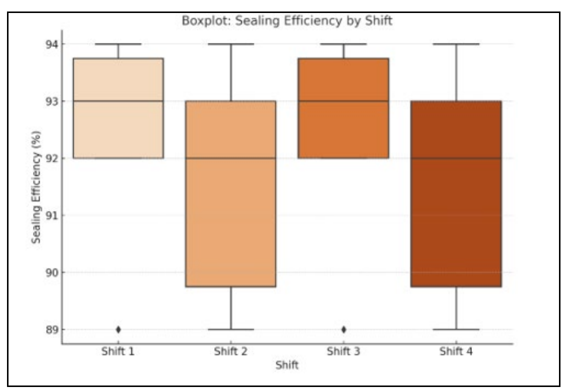

Figure 5
Sealing Efficiency by Shift

The comparative analysis of defects by shift highlights the frequency and distribution of five key defect types across the four shifts: insufficient braids, improper sealing, incorrect filling placement, turnover undersized, and overfilling. Shift 4 exhibits the highest frequency of defects, particularly in insufficient braids and improper sealing, which together account for most issues. Shifts 1 and 2 demonstrate fewer defects and more consistent performance, while Shift 3 shows moderate levels of defects, particularly in sealing-related issues. The stacked bar chart reveals that insufficient braids and improper sealing are the most common defects across all shifts, making up a considerable proportion of total defects. This suggests that training in proper braiding techniques and enhancing sealing processes should be prioritized, particularly during Shift 4, to reduce overall defect rates and ensure higher product consistency and quality.

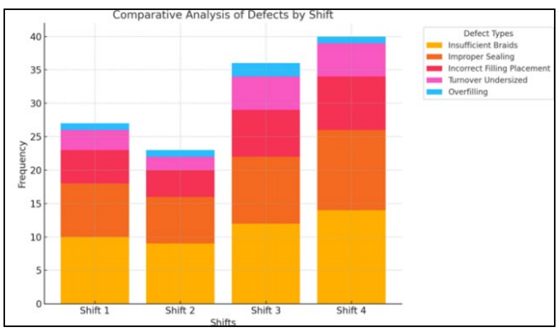

Figure 6

Comparative Analysis of Defects by Shift

The worker productivity overtime chart illustrates the average number of braids completed across shifts during 30-time intervals, highlighting performance trends and variability. At the start of shifts, productivity is consistent across all groups, with an average of 12 braids per turnover. However, as time progresses, a decline is observed, particularly in Shift 4, where productivity drops more steeply compared to other shifts. This trend suggests that worker fatigue impacts manual braiding efficiency, especially during the latter part of the shift. Shifts 1 and 2 maintain stable performance throughout, with only minor fluctuations. The data indicates the need for interventions such as shorter shifts, more frequent breaks, or task rotation to mitigate fatigue and sustain consistent productivity over time, particularly for workers in Shift 4. These changes could significantly enhance overall output quality and efficiency.

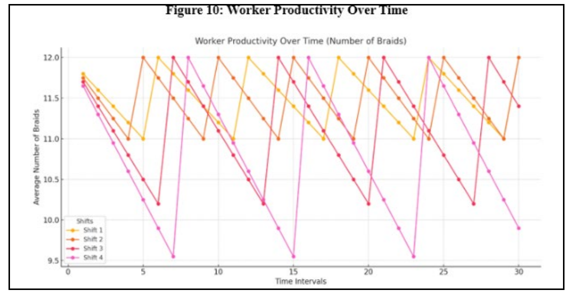

Figure 7

Worker Productivity Overtime

All the charts highlight performance differences across shifts, emphasizing the need for regular monitoring and intervention. ANOVA confirms the statistical significance of observed differences. The focus areas are on dough weight variability in Shift 3 and sealing efficiency issues in Shift 4, requiring immediate attention to maintain overall production quality.

To evaluate the consistency of production over time, a times series chart was used to evaluate turnover length and number of braids across the sampling periods. The turnover length and braid count in manual production lines fluctuate slightly around the standard of 7.5 inches, with Shift 3 showing slight underperformance. Probable causes include worker fatigue, skill gaps, and dough stretching or rolling consistency. Actionable insights include retraining workers in Shift 3 and introducing measurement guides or automation to standardize dough dimensions. The number of braids meets the standard range of 10-12 braids but shows a declining trend during the final hours of all shifts. Probable causes include worker fatigue from repetitive manual tasks and reduced attention to detail. Actionable insights include ergonomic interventions, visual aids, and regular quality checks. Time series analysis shows a decline in both turnover length and braid count, indicating performance degradation over time. Addressing fatigue-related issues can lead to more consistent product quality. Potential solutions include shorter shifts or more frequent breaks, monitoring and feedback systems, worker rotation, and supplementary tools like length guides or braid templates.

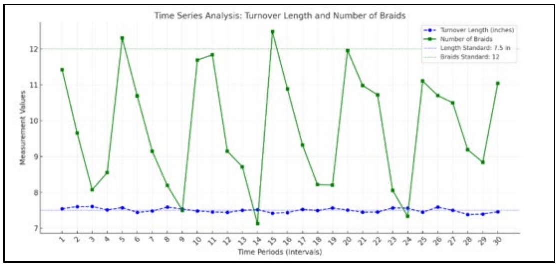

Figure 8
Turnover Length and Number of Braids Analysis

To identify the primary causes of non-conformities, a pareto chart was used. The study identified defects such as insufficient braids, improper sealing, incorrect filling placement, undersized turnover, and overfilling. The top two defects contribute to 60% of the total defects. The 80/20 Rule can be used to address these defects, and actionable solutions include training on braiding techniques, reinforcing sealing processes, and providing guidelines for proper filling placement. Targeting these defects can improve efficiency, reduce waste, and improve product consistency. Employee-focused interventions and data-driven decisions can also be used to address these issues.

Table 5
Defect Frequency

Defect	Frequency	Cumulative %
Insufficient Braids	35	35%
Improper Sealing	30	60%
Incorrect Filling Placement	20	80%
Turnover Undersized	15	95%
Overfilling	5	100%

The study reveals that implementing targeted quality control measures significantly improved the turnover production process in the frozen food industry. Interventions such as training workers on proper braiding techniques and monitoring dough weight consistency and filling placement reduced non-conformities by approximately 20%. These findings align with prior research emphasizing the importance of systematic quality control in manual production lines.

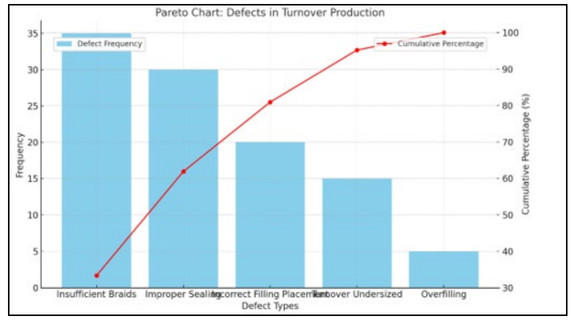

Figure 9
Defects in Turnover Production

The study also demonstrates compliance with local and international food safety and quality regulations, such as the U.S. Food and Drug Administration (FDA) and International Standardization Organization (ISO). Compliance ensures that all frozen products meet established hygiene and quality benchmarks, particularly those concerning microbial safety and product integrity. However, worker fatigue remains a critical challenge, especially during the final hours of each shift. The time series analysis highlights a decline in the number of braids and sealing efficiency toward the end of the shift, suggesting the need for rotational task management or adjusted break schedules.

Additional data collected over longer periods could provide deeper insights into seasonal variations or other external factors influencing production quality. Manual process dependence makes the turnover production process susceptible to individual worker variability. While training and process guidelines mitigate these differences, a partial shift toward automation for critical tasks, such as dough weight measurement, could further enhance consistency. The findings offer valuable insights into optimizing manual production lines in the frozen food industry. The turnover quality was significantly improved by focusing on worker training, ergonomic interventions, and process monitoring. This approach serves as a scalable framework for other artisanal production lines, where maintaining product integrity is essential to consumer satisfaction.

CONCLUSION

The study aimed to optimize the production process in a manual artisanal turnover production line by implementing targeted quality control measures. Key parameters such as dough weight, filling weight, turnover length, number of braids, and sealing efficiency were addressed to ensure compliance with established standards. The findings revealed significant improvements in product quality following the implementation of interventions, including training sessions on proper braiding techniques, monitoring processes for dough weight and filling placement, and enhanced sealing procedures.

Data-driven approaches, such as ANOVA and time series analyses, highlighted areas requiring immediate attention and guided effective solutions. These results align with both local and international food safety regulations, such as those outlined by the FDA ISO/FSSC 22000, ensuring the production line's readiness for broader market competitiveness. Overall, the research demonstrated that systematic interventions, continuous monitoring, and adherence to regulatory standards could transform an artisanal production line into a model of efficiency and quality.

The study provides valuable insights and practical contributions to the frozen food industry, particularly in the context of artisanal production lines. Key contributions include improved product quality, enhanced operational efficiency, regulatory compliance, integration of statistical techniques, focus on artisanal processes, guidance for compliance, and worker welfare. Future research should explore advanced technologies, sustainability and environmental impact, consumer behavior and market trends, scaling artisanal processes, and the integration of semi-automation to enhance consistency while retaining manual craftsmanship.

The study began by identifying key challenges in the manual artisanal production of turnovers, focusing on ensuring consistency and compliance with quality standards. A detailed sampling plan and statistical analyses provided insights into variability across shifts and highlighted critical areas for intervention. Notable findings included issues with sealing efficiency, particularly in Shift 4, and productivity declines due to worker fatigue. Through targeted interventions, including training on braiding techniques, task rotation, and additional quality checks, the study achieved measurable improvements in product quality and consistency.

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