Vol. 10, No. 02, July 2026, pp. 29-41

INTERNATIONAL JOURNAL OF INNOVATION IN ENTERPRISE SYSTEM

Journal homepage: https://ijies.sie.telkomuniversity.ac.id
e-ISSN: 2580-3050, DOI: https://doi.org/10.25124/ijies.v10i02.10514

Diagnosing Defects and Waste in an SME Bakery Using Lean Six Sigma

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ARTICLE INFO

Article history:
Received 09 January 2026
Accepted 05 August 2026
Published 09 August 2026

Keywords:
Lean Six Sigma; defect diagnosis; production waste; bakery SME; exploratory case study

ABSTRACT

Product-quality problems create material losses and operational inefficiencies for resource-constrained food SMEs. This study diagnoses product defects and production waste at Ronalee Bakery, an Indonesian bakery SME, using selected Lean Six Sigma tools. Aggregate production and defective unit records from January to March 2024 were analyzed together with process observations and operational accounts. The DMAIC framework was used to organize the diagnostic process: the Define, Measure, and Analyze stages were applied to identify problems and their potential causes, whereas the Improve and Control stages were limited to proposed actions. Of the 101,421 units produced, 3,367 were recorded as defective, corresponding to an aggregate defective-product rate of 3.32%, which exceeded the company's target of 2%. The assessment identified burnt bread, under-risen bread, torn or hollow texture, filling leakage, and non-standard weight, along with several relevant waste categories, including waiting, overproduction, overprocessing, inventory, and transportation. Potential causes were associated with operator capability, raw material and formulation consistency, oven condition, production planning, and facility layout. Proposed actions include standardized operating procedures, operator training, preventive maintenance, demand-based production planning, and layout adjustments. These findings provide a structured diagnostic basis for the future implementation and evaluation of quality-improvement actions in resource constrained bakery SMEs.

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1. INTRODUCTION

For many manufacturing companies, and especially for small and medium-sized enterprises (SMEs) in the food sector, the ability to keep product quality consistent strongly influences customer satisfaction and repeat purchases. When defects occur frequently, firms face higher production costs, material waste, and the risk of losing customers to competitors [1]. In this context, quality improvement can be viewed as a systematic effort to reduce process variation and to remove activities that do not contribute to customer value [2].

Lean and Six Sigma have been widely promoted as complementary approaches for improving processes. Lean thinking seeks to shorten lead times and smooth the flow of materials by eliminating non-value-adding activities, whereas Six Sigma focuses on reducing variation and defects through a structured, data-driven methodology. When the two approaches are combined into Lean Six Sigma, organizations can simultaneously address efficiency and quality issues. Several empirical studies [2] [3] [4] [5] report that Lean Six Sigma projects have led to shorter lead times, lower defect rates, and higher process sigma levels in various manufacturing and service settings.

One example is the study in [6] which examined "Quality Control Analysis to Reduce Product Defects and Increase Production Speed Using the Lean Six Sigma Method." The authors reported that the project reduced process lead time to 22.01 minutes per cycle and increased both process efficiency and cycle speed by 7.80% and 0.0008 processes/hour, respectively through the implementation of 5S and other Lean Six Sigma tools. Furthermore, research [5], [7] on defect reduction using the DMAIC (Define, Measure, Analyze, Improve, Control) framework also showed substantial improvement, with the rejection rate reduced to below 7% in the die-casting process and below 1% in the machining process, and an increase in the combined sigma level from 3.4σ to 4σ over time.

Previous studies have demonstrated the application of Six Sigma and Lean Six Sigma to quality problems in Indonesian bakery operations. These studies have examined defective bread products, calculated process sigma levels, identified potential causes, and proposed corrective actions using tools such as DMAIC, quality-control tools, and Kaizen [1], [8], [9], and [10]. Therefore, the research gap addressed in the present study is not the absence of Lean Six Sigma applications in bakery SMEs. Instead, this study examines how product-level nonconformities and process-flow wastes can be diagnosed within the same resource-constrained bakery setting and linked to a prospective improvement and monitoring plan.

Ronalee Bakery is an SME engaged in bread production that still experiences a relatively high rate of defective products. Based on production records from January to March 2024, the monthly defective-product rate ranged from 3.17% to 3.57%, exceeding the company's internal target of 2% (Table 1). The main types of defects included burnt bread, under-risen bread, torn or hollow bread, filling leakage, and products with non-standard weight. These nonconformities resulted in rework or product disposal.

Table 1 - Monthly Production and Defective-Product Data at Ronalee Bakery

No	Period (month)	Units Produced	Customer demand (units)	Number of defective products (units)	Defective product rate (%)
1	January	37,125	35,699	1,192	3.21
2	February	30,216	27,304	958	3.17
3	March	34,080	28,142	1,217	3.57
Total		**101,421**	**91,145**	**3,367**	**3.32**

This study was conducted to diagnose product defects and production waste in the bread production process at Ronalee Bakery using selected Lean Six Sigma tools. Specifically, the study aims to: (1) determine the defective-product rate based on the available production records; (2) identify relevant waste categories and examine their potential causes; and (3) formulate feasible improvement and control actions for a resource-constrained bakery SME.

The contribution of this study is empirical and analytical rather than methodological. Empirically, the case documents the coexistence of product nonconformities and process-flow wastes in a bakery SME operating with limited formal quality-management resources. Analytically, the study links three levels of diagnostic evidence: product-level CTQs and baseline performance, process-level waste and potential-cause analysis, and preliminary failure-mode screening used to formulate proposed improvement and control actions. This linkage provides a traceable explanation of how the proposed actions were derived from the observed production conditions. The study does not propose a new Lean Six Sigma method or demonstrate a causal reduction in defects; rather, it provides a transparent case for comparison, replication, and future intervention testing in similar resource-constrained SMEs. The remainder of this paper is organized as follows: Section

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2 presents the theoretical background and research methods. Section 3 presents the results and discussion. Section 4 concludes the study and outlines its managerial implications, limitations, and directions for future research.

2. METHOD

2.1. Waste

In Lean thinking, waste refers to any activity that consumes time, space, or resources but does not increase the value perceived by the customer [10]. Along a production value stream, some steps transform the product in a way that customers are willing to pay for, while others only create delays or additional handling. As summarized in [11], waste in manufacturing systems is often grouped into seven main categories: overproduction, waiting, transportation, overprocessing, motion, inventory, and defects. Recognizing these forms of waste is an important first step in redesigning processes and improving overall efficiency.

2.2. Lean Six Sigma

Lean Six Sigma combines the principles of Lean and Six Sigma into a unified improvement philosophy. Lean provides concepts and tools for creating smooth, fast-flowing processes with minimal waste, whereas Six Sigma offers a disciplined methodology for reducing variability and defects. Together, they offer a comprehensive framework for continuous improvement that addresses both efficiency and quality. According to [12], [13], the DMAIC cycle define, measure, analyze, improve, and control serves as the core roadmap for executing Lean Six Sigma projects and guiding teams through problem definition, data collection, analysis, solution design, and sustainability. According to [14], DMAIC is also described as a structured approach that helps organizations understand how materials and information move through their processes and where the most critical improvement opportunities lie.

2.3. Value Stream Mapping (VSM)

Value Stream Mapping is a visualization technique used to describe how materials and information flow through a production system [15]. A VSM typically shows each process step, its cycle time and waiting time, inventories between steps, and key information flows such as scheduling signals. By distinguishing value-adding from non-value-adding activities, VSM helps identify bottlenecks, excessive inventories, and unnecessary movement [16].

2.4. Study Location Profile

SME Ronalee Bakery is a bread-producing industry that manufactures 21 types of bread products. SME Ronalee Bakery has 41 workers divided into three main groups, namely operators, packaging staff, and sales staff. This SME has several dedicated areas, including storage rooms, workstations for dough preparation, oven workstations, bread molding workstations, and packaging workstations. In the production process, several stages must be carried out, namely the dough making process, dough forming process, dough kneading process, bread printing process, bread proofing or developing process, bread baking process, and finally the packaging process. The overall production flow can be seen in Figure 1.

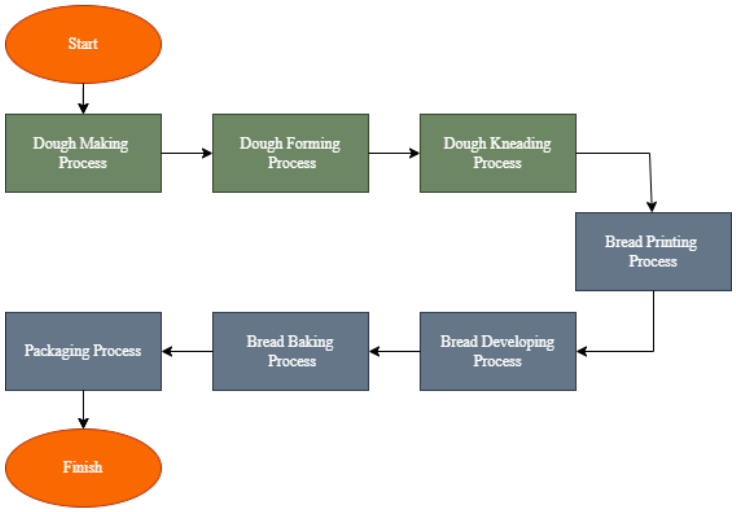

Figure 1 - Bread Production Process

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2.5. Methods

2.5.1. Research Design and Site

This study adopted a descriptive single case study design with a diagnostic focus, structured using selected Lean Six Sigma tools. The research was conducted at Ronalee Bakery, a small bread-producing enterprise that manufactures 21 types of bread products and employs 41 workers in production, packaging, and sales. The unit of analysis was the bread production process, from dough preparation to final packaging. The study focused on diagnosing product defects and production waste, examining their potential causes, and formulating feasible improvement actions.

2.5.2. Data Collection

The study used production and defect records from January to March 2024 as secondary data, including the number of units produced and the number of defective units. Primary information was obtained through direct observation of the production process and informal interviews with the owner, production supervisor, and operators to identify existing operating practices and potential sources of defects and waste. Summary process-time values retained from the original field observations were used as descriptive inputs for constructing the current-state VSM. The original cycle-level time-study records and instrument specifications were not retained; therefore, the number of measurement cycles, instrument precision, and measures of variability could not be retrospectively verified. Consequently, the reported process-time values were used only to describe the production flow and were not treated as statistically validated estimates of workstation performance.

The seven-waste categories were identified qualitatively from process observations and operational accounts. Because separate category-level data on duration, frequency, and cost were not retained, percentage contributions and quantitative rankings of the waste categories were not calculated.

2.5.3. Use of the DMAIC Framework

The DMAIC framework was used to organize the diagnostic study and does not represent a completed improvement cycle. The Define, Measure, and Analyze stages were conducted to characterize process conditions and examine potential causes. Improve was limited to formulating proposed corrective actions, while Control was limited to prospective monitoring measures. Neither component was implemented or evaluated, and no post-intervention data were collected.

2.5.4. Performance Measurement and FMEA

Process performance was evaluated using defects per million opportunities (DPMO) and the corresponding sigma level. In this study, a defect opportunity refers to a product-level Critical to Quality (CTQ) dimension against which each unit can be evaluated. The observed defect modes were mapped into three CTQ dimensions: baking conformity, form and structural conformity, and weight conformity. The mapping was based on the product characteristic being assessed and the production stage at which the nonconformity could arise, as presented in Table 2.

For the existing production records, each defective unit was treated as one recorded nonconformity event, while each unit had three opportunities to meet the specified CTQ requirements. Simultaneous multiple defects within the same unit were not recorded separately in the available aggregate data. DPMO was therefore calculated as follows:

$$\text{DPMO} = \frac{\text{Number of recorded nonconformity events}}{(\text{Number of units} \times \text{CTQ opportunities per unit})} X\ 1{,}000{,}000$$

The corresponding sigma level was calculated from the DPMO using the conventional 1.5-sigma shift, as follows:

$$\text{Sigma level} = \Phi - 1\left(1 - \frac{\text{DPMO}}{1{,}000{,}000}\right) + 1.5$$

Using 3,367 recorded defective units, 101,421 units produced, and three CTQ opportunities per unit, the calculated DPMO was 11,066.1 corresponding to a sigma level of 3.79. These measures represent the baseline diagnostic performance of the case company. The proposed improvement actions were not implemented; therefore, no post-intervention CTQ, DPMO, or sigma-level measurement was conducted. Moreover, the CTQ mapping is specific to this bakery and should be redefined before applying the calculation to other bakery settings.

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Table 2 - Mapping of CTQ Opportunities and Observed Defect Modes

No	CTQ opportunity	Operational product requirement	Associated defect modes	Relevant process and rationale
1	Baking conformity	The bread is baked to an acceptable condition without excessive burning	Burnt bread	Primarily associated with oven temperature, oven speed, baking time, and operator monitoring
2	Form and structural conformity	The bread rises adequately and maintains the expected shape, internal structure, and filling enclosure	Under-risen bread; torn or hollow bread; filling leakage	These defects represent failures in dough development or structural formation arising during mixing, kneading, forming, and proofing
3	Weight conformity	The finished bread meets the unit-weight standard specified by the bakery	Non-standard weight	Primarily associated with dough portioning and weighing before forming and baking

FMEA was used as an exploratory screening tool to examine potential failure modes associated with the identified defects and waste categories. Potential failure modes, effects, and causes were identified from the diagnostic findings and operational information obtained from the owner and production supervisor. Severity represented the anticipated consequence of a failure mode, Occurrence represented its reported recurrence, and Detection represented the likelihood that the existing practices would detect the failure before the product proceeded to the next process or reached the customer. Higher Detection scores indicated lower detectability.

The owner and production supervisor served as key informants rather than independent FMEA assessors. The researcher assigned the final Severity, Occurrence, and Detection scores on a 1–10 scale by synthesizing the information obtained from the interviews. Consequently, no mean, median, or group-consensus aggregation was applied, and separate individual ratings were not available for calculating inter-rater agreement. The RPN was calculated as Severity × Occurrence × Detection and was interpreted only as a preliminary screening indicator within this case, not as an independently validated risk ranking.

3. RESULTS AND DISCUSSION

3.1 Define

The Define phase is the initial stage of the DMAIC methodology. At this stage, the bread production process flow is identified and mapped, and problems related to product quality and waste are defined. Data collection was carried out for three months, from January to March 2024. During this period, the defective-product rate was 3.21% in January, 3.17% in February, and 3.57% in March, all of which exceeded the company's target of 2% (Table 1). These results establish a product-quality gap relative to the company's internal target and justify further diagnostic analysis.

The observed defect modes included burnt bread, under-risen bread, torn or hollow bread, filling leakage, and non-standard weight. These defects resulted in rework or scrap, thereby increasing production costs and reducing process efficiency. These conditions indicated the need for a structured diagnosis of product defects and production waste. Accordingly, the subsequent stages focused on identifying the relevant waste categories, examining their potential causes, and formulating feasible improvement actions.

3.2 Measure

Within the Measure stage, the retained production and process time records were used to describe current process performance, construct the current-state VSM, and identify potential non value adding activities.

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3.2.1 Recorded Process Time

Table 3 presents the recorded process-time values used as descriptive inputs for constructing the current-state VSM. The proofing and oven stages showed the longest recorded durations, at 120 and 102.52 minutes, respectively. However, because the original cycle-level observations and variability measures were unavailable, these values are interpreted descriptively and do not establish statistically verified bottlenecks or significant differences among workstations.

Table 3 - Recorded Process Time

No	Activity	Recorded process time (minutes)
1	Kneading	21.96
2	Formation	31.95
3	Rounding	16
4	Printing	35.36
5	Development	120
6	Oven	102.52
7	Surveillance	41.95

The values in Table 3 represent summarized process times retained from the original field observations and are used solely as descriptive inputs for process mapping.

3.2.2 Current Value Stream Mapping

The current-state map illustrates a sequence of production activities comprising dough preparation, forming, kneading, molding, proofing, baking, and packaging. Process observations and operational accounts indicated work-in-process accumulation and waiting before the proofing and baking stages. These conditions were associated with limited oven capacity, workload imbalances, and occasional machine stoppages. However, because separate waiting-time records were unavailable, the duration and percentage contribution of waiting to the total lead time could not be quantified. Layout observations also indicated additional movement of semi-finished products between the molding and proofing areas because of their separation and physical barriers, although the movement distance was not measured. Therefore, the current-state VSM was used to identify potential non-value-adding conditions and inform proposed improvement actions rather than to establish a quantitative ranking of waste categories in Figure 2.

The current state map shows that the production flow at Ronalee Bakery consists of a series of sequential steps starting from dough preparation, dough forming, kneading, printing, proofing, baking, and finally packaging. Although the main value-adding activities are concentrated in the mixing, kneading, proofing, and baking stages, the map also reveals several points where work-in-process (WIP) accumulates and waiting occurs, particularly before proofing and baking. These waiting periods are typically caused by limited oven capacity, unbalanced workloads between workstations, and occasional machine stoppages. As a result, the total lead time experienced by a batch of bread becomes substantially longer than the sum of the pure processing times. In addition, the current layout requires operators to move semi-finished products over relatively long distances between stations, which contributes to transportation waste and increases the likelihood of handling-related defects. By visualizing these conditions in the current state VSM, it becomes clearer where non value added activities are concentrated and which parts of the process may be considered in formulating future improvement actions.

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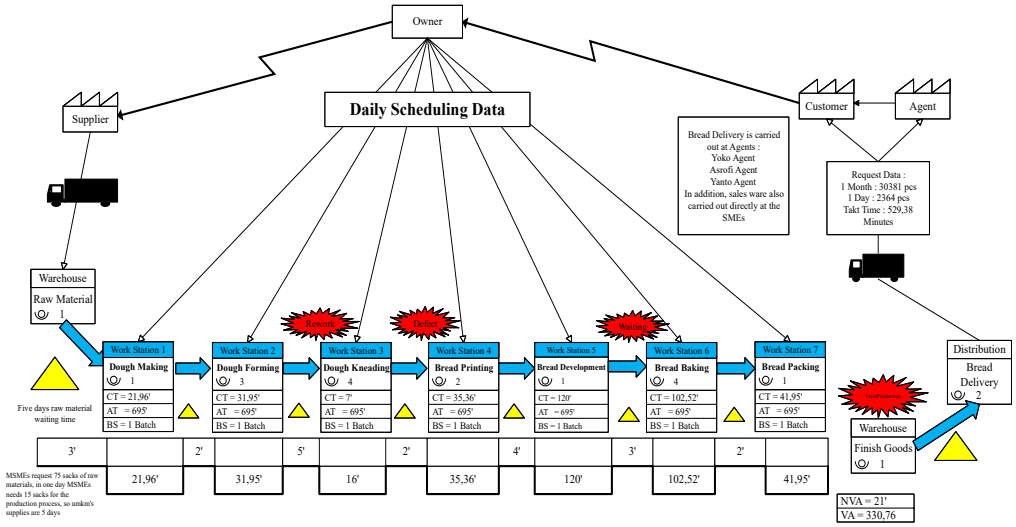

Figure 2 - VSM Bread Production

3.2.3 Identification of Seven Wastes, DPMO, and Sigma Level

The assessment based on the seven-waste framework qualitatively identified six relevant waste categories: defects, waiting, overproduction, overprocessing, inventory, and transportation. Defect waste included burnt bread and other nonconforming products. Waiting was observed when production stopped because of machine failures or spare-part replacement. Overproduction arose from producing more bread than required to anticipate uncertain customer demand, while overprocessing involved repeated dough processing due to holes or tears. Inventory waste was associated with excessive raw-material stock, whereas transportation waste resulted from physical barriers between the molding and proofing areas that caused unnecessary movement and delays. These categories were identified from process observations and operational accounts. Because separate measurements of their duration, frequency, and cost contribution were unavailable, their relative percentage contributions were not calculated, and no waste category is claimed to be quantitatively dominant.

Product-defect performance was calculated as presented in Table 4. During the observation period, 101,421 units were produced, of which 3,367 units were recorded as defective. Using the three CTQ opportunities defined in Table 2, the DPO was 0.0110661, corresponding to a DPMO of 11,066.1.1 and a sigma level of 3.79. These measures quantify recorded product nonconformities only and do not represent the relative contribution of the other waste categories. They describe the baseline diagnostic performance of the case company and should not be interpreted as evidence of statistical process stability or post-intervention improvement.

Similar Lean Six Sigma applications in the food sector also use DPMO and sigma level to evaluate process capability and report that, prior to improvement, process performance is typically still far from world-class levels, indicating substantial potential for further waste reduction [17], [18], [19].

Table 4 - Baseline DPMO Calculation

Step	Action	Information
1	Total number of products	101,421
2	Number of defective products	3,367
3	Defective unit rate = Step 2 / Step 1	0.0331983
4	Number of CTQs	3
5	Defects per opportunity (DPO) = Step 3 / Step 4	0.0110661
6	DPMO = Step 5 × 1,000,000	11,066.1.1
7	Conversion of DPMO to sigma level	3.79
8	Baseline sigma level of the process	3.79

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3.3 Analyze

The Analyze stage examined the potential causes of the identified product defects and waste categories using cause and effect analysis.

3.3.1 Defect

Product defects frequently arise during the bread-making process and are mainly associated with man, material, and machine factors. From the manpower perspective, operators often work in a hurry, leading to negligence and lack of attention during critical tasks such as kneading and baking. Some workers are not sufficiently skilled in handling the dough, resulting in non-uniform shapes and textures. From the material perspective, non-standard dough composition and inconsistent raw material quality can cause the dough to fail to rise properly. From the machine perspective, inadequate maintenance of the oven, such as worn or broken chains, can lead to unstable temperature conditions and result in burnt bread.

This pattern, in which human, material, and machine factors jointly drive critical defects, is consistent with previous Lean Six Sigma studies in the food industry that also highlight operator skills, raw material consistency, and equipment reliability as key determinants of defect rates [17], [18], [19]. Filling leakage was associated with an inappropriate ratio between the dough casing and filling and inconsistent adherence to filling procedures.

3.3.2 Waiting Time

Waiting was associated with operator- and equipment-related conditions. Differences in operator experience potentially slowed the transition between process stages, while insufficient preventive maintenance increased the likelihood of oven breakdowns and repair-related delays.
Waiting waste is mainly caused by human and machine factors. Workers' limited skills and lack of understanding of the production process can slow down operations and cause delays between process steps. On the machine side, insufficient preventive maintenance on the oven leads to breakdowns and unplanned downtime, forcing operators to wait while repairs are carried out.

3.3.3 Overproduction

Overproduction occurs because SME Ronalee Bakery produces more bread than customer orders to anticipate fluctuating demand. From a method perspective, the absence of accurate demand forecasting and production planning leads to the practice of producing additional quantities "just in case." Although this may reduce the risk of stockouts, it also increases the risk of unsold products, rework, and waste.

3.3.4 Over Processing

Overprocessing waste appears when processes are repeated unnecessarily. From the manpower perspective, workers' lack of skill in handling and rolling the dough can cause holes or tears, requiring additional processing. From the material perspective, poor dough quality due to improper mixing or formulation can cause defects during kneading and shaping. From the method perspective, the absence of clear and standardized procedures for baking can result in inconsistent outcomes and rework.

3.3.5 Inventory

Inventory waste occurs mainly due to method-related factors, particularly the lack of raw material planning and production capacity planning. Without proper planning, raw material purchases may exceed the actual needs of production, increasing storage costs and the risk of material deterioration.

3.3.6 Transportation

Transportation waste is caused by environmental and layout factors. The long distance and physical barrier between the printing (molding) area and the proofing (development) area cause unnecessary movement of semi-finished products and increase the time required for material handling.

3.3.7 Preliminary FMEA Based Screening

Following the cause analysis, a researcher-led FMEA screening was conducted to examine the relative importance of the identified failure modes. The Severity, Occurrence, and Detection scores were assigned by the researcher based on information obtained from the owner and production supervisor, who served as key operational informants. The resulting RPN values therefore represent preliminary, researcher-derived screening indicators rather than inter-rater-validated risk rankings.

Within this preliminary screening, burnt bread received the highest RPN of 140, followed by oven-related waiting with an RPN of 126 and repeated dough processing with an RPN of 120. These values indicate issues that may warrant managerial attention within the present case. However, the numerical differences should not be interpreted as statistically

validated evidence that one failure mode is definitively more critical than another. The summarized screening results are presented in Table 5.

Table 5 - Preliminary FMEA Based Screening of Identified Failure Modes

Waste	Failure mode	Potential causes	S	O	D	RPN	Proposed actions
Defect	Filling leakage	The composition between the skin and the contents of the bread is not suitable	3	3	4	36	Operators should adjust the bread filling according to the established SOP and ensure proper understanding of the machine operating procedures.
	Under-risen bread	Poor raw-material quality.	4	4	2	32	Carry out raw material receipt inspections from each delivery made by the supplier and determine raw material quality standards that must be met by the supplier
	Burnt bread	The worker's lack of dexterity in moving the pan and the worker's negligence in setting the standard speed of the oven machine and the size of the fire during the oven resulted in burnt bread.	7	5	4	140	Provide clear performance guidelines to workers and foster a mindset that emphasizes not only completing tasks but also consistently monitoring product quality during baking.
Waiting	Production stops because the oven chain is broken	Inadequate preventive maintenance of the oven	7	6	3	126	Implement a routine inspection schedule and preventive maintenance program for the oven and its chain components, so that potential failures can be detected early and unplanned downtime can be minimized.
Overproduction	Overproduction of bread (producing more than demand)	To anticipate fluctuating customer demand	4	3	3	36	Plan bread production based on actual customer orders and simple demand forecasts, and review daily production targets regularly to avoid unnecessary overproduction and the risk of unsold products.
Overprocessing	Repeated dough processing due to holes or tears	Poor dough quality	6	5	4	120	Standardize dough preparation procedures and provide skill-equalization training for operators in dough handling and molding, so that defects such as holes or tears are reduced and reprocessing can be avoided.
		Insufficient operator skills	6	4	2	48	Providing training to equalize worker skills.
Inventory	Excess raw material inventory	Lack of planning in purchasing raw materials	4	3	5	60	Use historical customer order data to determine appropriate raw material order quantities, and align purchasing decisions with production planning to prevent excessive inventory and storage waste.
Transportation	Long and obstructed material movement between molding and proofing areas	A physical barrier obstructs the transfer of semi-finished products from the molding area to the proofing area.	2	4	3	24	Improve the facility layout by reducing the distance and physical obstacles between the molding and proofing areas, so that material handling becomes shorter, smoother, and requires less unnecessary movement.

3.4 Proposed Improvement and Control Actions

Based on the diagnostic findings, a researcher-led preliminary FMEA screening was used to examine potential failure modes and support the formulation of proposed improvement actions. The final Severity, Occurrence, and Detection scores were assigned by the researcher by synthesizing operational information obtained from the owner and production

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supervisor together with process observations. The resulting RPN values were interpreted only as preliminary, case-specific indications of potential managerial attention and not as validated risk rankings or evidence of implemented improvements.

For burnt bread, the proposed actions include standardizing oven temperature, speed, and baking-time settings; introducing a pre-operation oven-setting checklist; and providing operators with guidance on tray handling and product monitoring. Oven-related waiting may be addressed through scheduled inspection of the oven chain and other critical components, supported by a preventive-maintenance log. Repeated dough processing may be addressed by standardizing dough preparation, forming, and proofing procedures and providing practical operator training. Demand-based production planning and raw-material purchasing are proposed to address overproduction and excess inventory, while the removal of physical barriers between the molding and proofing areas is proposed to improve material flow.

A proposed control plan was also formulated to guide monitoring if the improvement actions are subsequently implemented. The plan specifies the indicators, monitoring frequency, responsible roles, and corrective responses for each identified issue, as presented in Table 6. This plan represents a prospective monitoring framework and should not be interpreted as evidence that the Control phase was executed during the present study.

Table 6 - Proposed Improvement and Control Plan

Target issue	Proposed improvement action	Proposed monitoring indicator	Proposed frequency and responsibility	Corrective response
Burnt bread	Standardize oven temperature, speed, and baking time; provide operator guidance	Number or percentage of burnt units and oven-setting checklist compliance	Each batch by the oven operator; daily review by the production supervisor	Adjust oven settings, inspect affected products, and provide additional operator guidance
Under-risen, torn, hollow, or leaking bread	Standardize dough preparation, forming, filling, and proofing procedures	Number of nonconforming units and rework cases per batch	Each batch by the operator; daily review by the production supervisor	Check material composition and proofing conditions, isolate affected products, and repeat operator training when required
Non-standard weight	Standardize portioning and verify weighing equipment	Number or percentage of units outside the specified weight standard	Sample checking for each batch by a designated operator; daily review by the supervisor	Recheck the scale, correct dough portions, and inspect the affected batch
Oven-related waiting	Implement scheduled oven and chain inspection and preventive maintenance	Number of breakdowns, downtime duration, and maintenance-schedule compliance	Pre-operation inspection and weekly maintenance review by the responsible worker and supervisor	Stop the equipment, when necessary, inspect or replace defective components, and record the maintenance action
Repeated dough processing	Standardize dough-handling procedures and provide operator training	Number of repeated processing or rework cases per batch	Each batch by the operator; weekly review by the supervisor	Identify the reason for reprocessing, correct the procedure, and provide targeted retraining
Overproduction and excess inventory	Align production and purchasing with confirmed orders and historical demand	Difference between production quantity and confirmed demand; unsold products and excess raw materials	Daily production review by the owner and production supervisor	Adjust subsequent production quantities and raw-material purchases
Inefficient transportation	Remove physical barriers and improve the route between molding and proofing areas	Presence of route obstructions and unnecessary handling movements	Weekly workplace and layout inspection by the production supervisor	Remove the obstruction and revise the material-transfer route

The proposed actions are consistent with interventions frequently discussed in previous Lean Six Sigma studies, particularly operating-procedure standardization, operator training, preventive maintenance, and production planning [17], [18], [19]. However, their effectiveness in the present bakery cannot be inferred from previous studies and must be evaluated through future pre- and post-implementation measurements.

As prospective control measures, the bakery is recommended to record the defective-product rate and defect type for each production batch, oven downtime and breakdown frequency, the number of reprocessing events, and the difference between production quantities and actual demand. These indicators should be reviewed periodically by the owner and production supervisor to monitor process performance and identify recurring problems. These control measures were not implemented or evaluated during the study.

3.5 Comparative Discussion and Practical Implications

The diagnostic findings are broadly consistent with previous Lean Six Sigma studies in bakery and food production settings, which identify product defects, operator capability, raw-material consistency, equipment reliability, and process discipline as recurring quality concerns [1], [9], [11], [18], [19], [20]. However, the present study focuses on diagnosing these conditions and formulating feasible actions rather than evaluating post-intervention performance.

The present study should be interpreted as a case-bounded empirical extension of the existing literature rather than as a methodological innovation. Its analytical contribution lies in documenting product nonconformities and non-defect process wastes within the same diagnostic structure and tracing how CTQ based baseline performance, process observations, potential-cause analysis, and preliminary FMEA screening informed the proposed improvement and control actions. This traceability is particularly relevant to a resource-constrained bakery SME that relies primarily on aggregate production records, direct observations, and operational knowledge.

From a practical perspective, the findings provide several potential starting points for SME managers, including standardized operating procedures, operator training, preventive maintenance, demand based production planning, and facility layout improvement. The effectiveness of these actions should subsequently be evaluated using predefined performance indicators, such as the defective-product rate, equipment downtime, rework time, and material-movement distance.

4. CONCLUSION

This study diagnosed product defects and production waste at SME Ronalee Bakery using the Lean Six Sigma framework, supported by VSM, seven-waste analysis, cause and effect diagrams, and FMEA. The analysis focused on mapping the existing production process, assessing its current performance, identifying waste categories and their potential causes, and formulating proposed improvement actions.

During the January - March 2024 observation period, SME Ronalee Bakery produced 101,421 units, of which 3,367 units were classified as defective. Based on the calculation assumptions applied in this study, the process performance corresponded to a DPMO of 11,066.1 and a sigma level of 3.79. These results indicate a gap between the observed defect rate and the company’s internal defect target, thereby establishing a baseline for subsequent quality-improvement initiatives.

The diagnostic analysis identified six waste categories in the production process: defects, waiting, overproduction, overprocessing, inventory, and transportation. Product defects included burnt bread, under-risen bread, torn or hollow bread, filling leakage, and products with non-standard weight. The cause and effect analysis suggested that these conditions were potentially associated with limited operator skills, inconsistent work practices, non-standard material composition, inadequate oven maintenance, insufficient production and inventory planning, and an inefficient facility layout.

The researcher-led preliminary FMEA screening assigned the highest RPN to burnt bread, followed by oven-related waiting and repeated dough processing. These results were used to identify issues that may warrant managerial attention and to formulate proposed actions involving operator training, standardized procedures, preventive maintenance, demand-based material planning, and facility-layout improvement. However, the RPN values should be interpreted as exploratory screening indicators rather than inter rater validated priorities.

The study contributes case bounded empirical evidence on how product nonconformities and process-flow wastes coexist in a resource-constrained bakery SME. Its analytical contribution lies in establishing a traceable connection between CTQ-based baseline performance, process mapping, potential cause analysis, preliminary failure-mode screening, and proposed monitoring indicators. From a managerial perspective, this diagnostic structure provides a basis for determining

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where future improvement efforts may be directed. However, the contribution should not be interpreted as a new Lean Six Sigma methodology or as evidence that the proposed actions have reduced defects, improved the sigma level, or enhanced organizational performance.

This study is limited to a single bakery SME, a three-month observation period, and the available internal production data. Only summarized process-time values were retained in the archived dataset; therefore, the number of measurement cycles, instrument specifications, and variability measures could not be retrospectively verified. Consequently, the process time values were used solely as descriptive inputs for constructing the current-state VSM and not as statistically validated estimates of workstation performance. Moreover, the proposed improvement and control actions were not implemented or evaluated through pre- and post-intervention measurements. Future research should implement and evaluate the proposed actions, extend the observation period, involve multiple bakery SMEs, and employ more robust time-measurement and assessment procedures.

The FMEA assessment was also limited by its researcher-led scoring process, which was informed by only the owner and production supervisor as key informants. Because independent assessor scores were not collected, no consensus aggregation or inter-rater agreement analysis could be performed. Future studies should conduct a new FMEA assessment involving three to five cross-functional members, including operators, supervisors, and personnel responsible for quality inspection and equipment maintenance. The assessment should collect individual ratings, specify the aggregation method, evaluate inter-rater agreement, and, where appropriate, consider fuzzy FMEA to accommodate uncertainty in the ratings.

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