

A COMPARATIVE STUDY OF DEFECT ANALYSIS, STATISTICAL PROCESS CONTROL (SPC) AND FMEA IN BISCUITS PRODUCTION

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ABSTRACT

The bakery business has made it one of its ongoing challenges to ensure that the product quality remains the highest despite the various defects such as over burning, under burning, and product breakages. Whereas Statistical Process Control (SPC) and Failure Modes and Effects Analysis (FMEA) work well in other industries, their total application in the production sector in the bakery sector is a gap (especially in defect management and quality maximization). This paper is aimed at bridging this gap by applying the SPC and FMEA on four various bakery items, including Coconut Burnies, Jira Burnies, Twin Toast, and Ghee Toast. The objective is to define the most recurrent defects, investigate their causes, and recommend the means to restructure them to enhance output productivity. Using SPC, defect rates were monitored throughout the process, and FMEA was utilized to identify the area that the production process could fail. The results indicate that SPC and FMEA may play a significant role in a production process to minimize flaws and enhance the quality of a product. Comprising of actionable insights, this paper can help product producers in the baking sector to enhance the effectiveness of the operations and the homogeneity of the products.



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I. INTRODUCTION

Bakery is one of the most successful markets in the food processing industry in the world and burnies, biscuits, and toast are the items of the life of people of all classes. Some of them, especially Coconut Burnies, Jira Burnies, Twin Toast, and Ghee Toast are well sold products, and the procedure of making one of them carries some peculiarities related to the production of food of the same quality and quantity with the minimum number of defects. It has some issues that must be addressed to improve the quality of the products and their functionality in the emerging industry [1]. Bakery products production is dependent on different factors in order to demonstrate the quality of final products. It is topical as the ingredients (flour, sugar, butter, etc) are also not determinable which is the most important factor of product consistency. However, ingredient may vary due to seasonal changes of the quantity of ingredient that is used and hence the products in the market may experience revisions in their attributes that may be texture, taste, and the appearance of the product due to human error. These processes, other than the actual processing processes, i.e., mixing, shaping, baking and packaging, are also susceptible to variations in the environmental factors especially the temperatures and the humidity [2]. Even minor variation of these parameters may cause defects, burned or under-burned dishes or rupture or dissimilar size resulting in the quality sensory and selling capacity of the product [1]. Nevertheless, these drawbacks do not stop numerous bakery producers, and they still rely on manual checks and control by operators as the means of exposing flaws in manufacturing. This is likely to be unpredictable in regards to quality control and control of potential defects. Furthermore, the lack of the opportunity to work with standardized operating procedures (SOPs) may be deemed as the only way to aggravate this complex of problems since the quality appraisal is subjective.

Not only is this lack of formal control mechanisms influenced by the quality of the products, but it also involves other kinds of inefficiency which include over-packaging, wasting of time in production as well as rework [3]. To address these issues, the suggestions of Statistical Process Control (SPC) and Failure Mode and Effects Analysis (FMEA) may be included into the system of offering a structure of quality control in order to grow in the world of bakery [4]. The production process and identification of time varying variation are the statistical process control (SPC) techniques. This helps the operators to identify inefficiencies within the desired productions and take corrective actions in real time thereby achieving equal quality of products [5]. Instead, FMEA is a risk management practice, which actively seeks the locations of failure in the process, the difficulty, frequency and recognizability of some failures and what can be done to rectify those failures [4]. An integration of both methodologies will provide the manufacturers with a chance to rectify the actual causes of the flaws in a methodical way prior to the factors having the capability of influencing the product [6]. Combined SPC and FMEA techniques have also worked well in eliminating dimension-out failures and work-station failures in similar food production systems [7], [8]. The research will be in a position to determine the effectiveness of SPC, FMEA in improving the quality of the production at Coconuts Burnies, Jira Burnies, Twin Toast, and Ghee Toast. The research will also focus on identifying the most common faults in the process of such bakery products and cause of the faults; the defect study will be conducted in detail. The FMEA and the SPC will provide the study with a wide range in order to optimise productions, minimise wastes and a degree of consistency in quality of the products manufactured [9], [10]. The method adopted in this research study is a qualitative and quantitative one. The quantitative aspect involves the use of the SPC to monitor the degree of error and analysis of the rate of correction of policies [11]. Qualitative factor entails application of FMEA in determining potential failure modes and the Risk Priority Number (RPN) is calculated as an indication of priorities on how the corrections are to be undertaken on the basis of the frequency, the severity and the frequency of occurrence of the defects [4]. This will help the bakery manufacturers refine their production process and effectiveness in their operations besides enhancing customer satisfaction by yielding fewer defective products and achieve higher consistent products [12]. Investigations into frozen food and steel plate manufacture also affirm that the joint use of the tools results in quantifiable amounts of reduction of dominant defect types [13].

II. LITERATURE REVIEW

II.1 QUALITY PRODUCTION IN THE FOOD INDUSTRY

There are extreme issues in regard to quality control in execution of baked food and snacks in the food industry. The uniformity and safety of goods are fundamental since any of them can be hazardous in the event of contamination, the use of incorrect ingredients and production defects. Statistical Process Control (SPC) and the Failure Mode and Effect Analysis (FMEA) have become extremely useful in the food manufacturing industry as a means of both identifying and eliminating risks, as well as maintaining the quality of the products and enhancing the efficiency of the actions [10]. The quality management tools that include FMEA and SPC have been adopted to ensure that the food manufacturer maintains control of his process in real time to ensure that no defects manifest in his product yet he puts additional safeguard in place. The SPC has facilitated control chart incorporating the X-bar, R chart that allows the manufacturer to test the consistency and the variability of the processes and also give a report of the performance of the processes in an informative manner [14]. FMEA in its turn can systematically identify how a failure mode of the production process can occur, its implications, and the strength of such implications and therefore focus on the risk managerial activity [6]. Such tools have been successfully used in bakery and other food related industries so as to monitor process variations and emphasize on corrective actions [15], [16].

II.2 SPC IN FOOD MANUFACTURING

SPC has been extensively applied in food manufacturing to minimize variation of process in addition to providing uniformity in a product process. One of them will be when baking burnies; the temperature at which baking will take place, the type of ingredients to be used and the time to be assigned to the ovens are some of the conditions that will need to be placed under control. It has been oriented that defect (such as overbaking, under burning, and deformation) which result in the quality of the product is followed with the assistance of control charts, e.g., Pareto analysis, cause-and-effect analysis, and R charts [12], [6]. An example that can be given in this case is that in the case of Jira burnies, humidity percentage variation and quality of flour can affect the texture and consistency of the product. This would be achieved by compensating these variables by use of SPC tools to prevent the production of low quality burnies, wastage and enhanced uniformity [17]. P-charts and Pareto diagrams have been used in conjunction with sweet bread and frozen food production where they have been able to track the appearance of overproof of filling and leaky fillings and keep the process within a margin of control [15], [13]. Other SPC applications that have succeeded in stabilizing the process mode and minimizing the prevailing defects include bag convection and steel plate manufacturing [18]. One of the positive aspects of SPC is that it will help in the identification of anomalies prior to their occurrence [11]. Corrupt items like baking that gets too hot or under-cooked ones can be identified instantly and solutions to prevent such kind of situation realized. In addition, SPC charts may be made to indicate when the production process is heading to disaster that gives the worker an impression that he/she could rescue the defect before it arrives and thus saved time and minimized wastage [12].

II.3 FMEA APPLICATION IN FAILURE IDENTIFICATION

FMEA is an active method of one's defining and prioritizing possible failures of the manufacturing process. A multiplication of the types of scores of Severities, Occurrence, and Detection scores [10] would be Risk Priority Number (RPN), which would be applied in identifying common defects such as the uneven baked, broken edges, sizes, etc. in the Ghee Toast production case. FMEA will help in determining the most common points of failures such as equipment problems (e.g., misaligned trays or faulty functioning ovens) or the fatigue of the operator as a result of the ergonomics problem during the packing [6]. FMEA mixed with Pareto analysis has been effective in giving priority to mixing/baking failure and workstation defects in the production of bread and sack and the results have been to reduce the values of RPN substantially after corrective measures were implemented [16], [8].

The same may be applied in high efficiency to the manufacture of cigarettes and facial tissues as well [19], [20]. FMEA and SPC are used jointly in order to minimize emphasis on critical flaw. An example is the breakdown of packages such as overfilling, poor handling, which can be readily traced into failure modes that FMEA has been found to reveal with clear solution that would reduce the safety hazard as well as produce more efficiently [10], [17]. By help of the maximum RPN values, food manufacturers will be capable of implementing needed adjustments, as a result of which, the risks will reduce significantly, and products will be higher-quality. Integrated Lean Six Sigma combined with FMEA has also facilitated reduction of wastes, as well as the ability to improve processes in biscuit manufacturing [21].

II.4 PROBLEMS AND LIMITATIONS OF SPC AND FMEA WITH RESPECT TO FOOD PRODUCTION

Despite its invaluable advantages, the food manufacturers are faced with the problem of implementing it. The incompetence of the workers statistically is one of the biggest obstacles to the effective implementation of such tools. It is quite a possibility that the employees of most food manufacturing plant do not know how to process the data displayed in the SPC chart and how the results of the FMEA might be utilized to enhance the production cycle [22]. It has been widely recognized that training is a major success factor to overcome this problem. John ranks have been observed to play a significant role in creating an undesired skill gap and preventing the ability to monitor the operation in real-time in metal stamping and steel plate manufacturing, but organized training and periodic maintenance have been shown to overcome them [7]. Management commitment concept is highly applicable in determination of effectiveness of SPC and FMEA [14]. It has been demonstrated that integration of quality control measures in the process of carrying out routine production operations is mostly a failed initiative unless supported by the top management [22]. It is rather important that all levels of working population should accept and believe in the implementation of these methodologies in a struggle to provide a long-term increase in the quality of production. The other weakness here is the absence of structured Standard Operating Procedures (SOPs) and this may cause an occurrence of variations in the application of the SPC and FMEA among the various shifts or production lines. Mostly the manufacture of food including small and medium enterprises (SMEs) such as the IKM Heppy Bakery uses more manual inspection procedures rather than the standardized system which predisposes them to faults and an insignificant consistency to product quality [10]. The need to carry out the repair process in time and prescribed duration to prevent downtime has also been emphasized in reliability modeling of soft biscuit systems [23].

II.5 RESEARCH FUTURE

It has been rather encouraging that SPC and FMEA can be used in the food production industry to provide high quality of the items produced and minimize the product defects. Nevertheless, the consideration of such factors as statistical literacy, and management support should be provided in order to offer the most lucrative results. The further studies should be done in the future and they should imply incorporation of SPC with FMEA and real time data systems to facilitate provision of more precise and viable information during the manufacturing procedure. It would be also beneficial to study the other variables on how environmental conditions (weather, or fluctuations of raw materials) may influence the performance of both SPC and FMEA in order to make the two instruments more efficient in the food industry [10], [6]. Research in frozen food and industrial bread manufacture also indicates that such tools in bakery establishments can be further reinforced through the incorporation of environmental controls as well as retraining of operators [13], [16]. The review also indicates that SPC and FMEA were important in the burnies and toast making process and how the practices are implemented in the process can go a long way towards minimizing the number of defects and increasing the quality of the process. All these methods, better training, management will, and combination of the two might culminate in the food manufacturers achieving the boosted customer expectations and competing in a competitive market.

III. RESEARCH METHODOLOGY

III.1 PRODUCTION SYSTEM AND PRODUCTS

The research was carried out in a small bakery where most of the operations were done manually and no official Standard Operating Procedures (SOPs) existed. The evaluation of the quality of the products was based on the subjective assessment of the workers who focused on the color, the texture of the surface and shapes on the final stage of baking. Four high volume products were chosen to be examined in details: (i) Jira burnies, (ii) Coconut burnies, (iii) Twin toast, and (iv) Ghee toast. In the case of Jira burnies, the retail pack had 15-16 burnies divided in three slots, and the nominal net weight of the burnies was around 170-180 g per pack. Dealer and retail prices were about Tk 40 and Tk 50 per pack (Bangladeshi Taka) respectively. The typical batch consisted of about 40 kg of dough; this was made of 20 kg wheat flour, 8 kg sugar, 600 g Jira powder, 150 g salt, 3 kg butter, 5 kg palm oil, and enough water to achieve the necessary consistency, where the fat mixture used was a mix of local fat, local composite fat; 4 kg Dalda, 0.5 kg butter oil, 0.5 kg ghee. With an ideal case scenario on process loss and considering the minimal process loss, the theoretical yield of the batch would be 3900-4500 burnies which translates to 260-300 packs of burnies (15 burnies each). In the case of coconut burnies, the packs had 8-9 burnies with nominal preferences of the packs being 95-100 g (eight-piece burnies) and 105-110 g (nine-piece burnies). The dealer and retail price were about Tk 18.40 and Tk 25 per pack respectively. The dough formula again amounted to approximately 40kg per batch and consisted of 20kg flour, 8kg sugar, 150g salt, 3kg butter, 5kg palm oil, water added as needed, a homegrown fat mixture of 4kg Dalda, 0.5kg butter oil and 90g coconut oil. Theoretical number of burnies per batch was also between the range of 3900- 4500 burnies and this is equal to 485-565 packs of 8 burnies. The bread base was made using 50 kg flour, 10 kg sugar, 1 kg Dalda, 1 kg butter oil, 1 kg palm oil, 400 g yeast powder, 700 g salt, and 20 kg water and made into twin toast. The loaves were proved and baked then covered with a fat-biscuit-powder mixture and cut into toast pieces. The baking trays held nearly 6-7 loaves resulting in nearly 39-42 toast pieces per loaf (+-3 pieces). The ghee toast was made with a better bread foundation. The dough was prepared using 50 kg flour, 20 kg water, 1 kg sugar, 2 kg Dalda, 1 kg butter oil, 200 g yeast powder, 700 g salt, 50 kg milk cream and 30 kg milk solids.

Then a coating of cream/fat was placed using a mixture of 12 kg Dalda, 10 kg sugar, 1 kg ghee, 200 g ghee sand, 2 kg butter oil and 4 kg palm oil. The breaded and baked loaves were broken into pieces of toast and each tray was containing around 39-42 pieces. The dealer and retail price of ghee toast were Tk 55 and Tk 70 per pack each. In all the four products, the mean time taken per batch was about 35- 40 minutes to bake. In reality, however, the time taken to bake was dependent on the loading of trays, and an operator and different batches, as well as on the environment around it (e.g., temperature and humidity), and the visual perception of the operator with regards to the surface color.

III.2 PROCESS DESCRIPTION

The processing sequence of all four product lines was similar, albeit with small differences basing on product type. Raw materials were weighted and mixed to their appropriate formulas. Dough development was accomplished either with a planetary mixer or a spiral mixer until the required consistency and gluten structure was attained. The processing in the forming step was done by product type. In burnies (Jira and coconut burnies), the dough was rolled to a measured thickness and metal die cut and the individual slices manually placed on baking trays. In the case of toast products (twin toast and ghee toast), the dough was proved, molded, and baked as bread loaves, which were later cooled to a convenient handling temperature then cut into toast products of relatively uniform sizes. Tray loading and baking were done in deck ovens at nominal conditions of 160 deg °C, but again in practice the time-temperature profile could be varied by the operators. Cooling was done after baking, and under ambient room conditions, followed by a manual, visual, and receiving operation, wherein defective products (e.g., overbrowned, under-baked, misshapen, and broken) were extracted. Without any formal and documented SOPs, decisions like the time of baking completion and inclusion of defects criteria were still left almost entirely under operator experience and ground level judgment. Extending or shortening of oven dwell times were consistently made on an intuitive basis and the trays could be transferred or shuffled inside the oven chamber in a bid to correct spatial inconsistencies in heat distribution and surface browning.

III.3 DATA COLLECTION

All four products were assessed using a tray-wise inspection sheet to gather quantitative quality data regarding all the active products that were produced as a result of routine production. Each tray was marked with the following variables: (A) (n): The number of pieces on the tray; (B) Break: The number of pieces that were broken or cracked; (C) After-heat: The number of pieces which became defective during further heating or re-baking; (D) Handling: The defects that could easily be attributed to handling or moving pieces; (E) Over-burn: The visibly over-baked pieces; (F) Under-burn: The visibly under-baked pieces; and (G) Defectives: The total number of defect More than 40 trays/product data were tracked including several production shifts which were considered as regular. The tray capacities varied also according to products: burnies had (n) in the range of about 48-60 pieces to a tray, whereas with toast products (n) was 38-43 pieces to a tray. Combining the tray-wise counts of all trays that were observed resulted in the following aggregate inspected piece and defect counts respectively, Jira burnies, 2352 pieces with 65 defectives; coconut burnies, 2538 pieces with 89 defectives; twin toast, 3036 pieces with 73 defectives and ghee toast, 1622 pieces with 63 defectives. They are associated with a general range of defects in the orders of 2.4-3.9 per cent within the four product lines. Analysis of the records of the extra time (re-baking) further suggested that burnies were often exposed to an extra heating time, where most burnies received an added 48-63 s, and the most of toast tray received little extra heating (0-2 units of extra time). What this trend indicates is that, re-baking has been found to be more evident and possibly more important in quality-decision making in burnie production than it has in toast production.

III.4 DEFECT CLASSIFICATION

From the plant's quality perspective, six defect categories are relevant:

- ✓ Overheating (burnt / too dark)
- ✓ Underheating (pale / soft)
- ✓ Breakage
- ✓ Overweight packs
- ✓ Abnormal shape
- ✓ Others (surface defects, contamination etc.)

In the data sheet, the first three are captured explicitly as Over Burn, Under Burn, Break (2) and Handling (ii) (which is treated as a sub-category of breakage). "After Heat (i)" corresponds to pieces that were subjected to re-baking and still ended up defective. Overweight packs and abnormal shape were noted qualitatively, and they appear later in the Pareto and FMEA analyses as part of the broader "economic loss" and "aesthetic" failure modes.

For each tray, the total defective count is:

$$D = \text{Break} + \text{After Heat} + \text{Handling} + \text{Over Cook} + \text{Under Cook}.$$

This ensures consistency between category totals and overall defect totals.

III.5 QUALITY TOOLS AND DATA ANALYSIS

III.5.1 Pareto Chart

The Break, After Heat, Handling, Over Burn and Under Burn frequencies of all trays were added up in the case of each product. These totals were then tabulated in descending order and represented as a Pareto chart, and a cumulative percentage line.

It becomes possible to observe what 2-3 categories of defects contribute nearly 80% of the total count of defects per product and therefore require peculiar attention. Moreover, qualitative categories like overweight packs, and abnormal shape were put together as another bar, when creating a general Pareto chart of the plant.

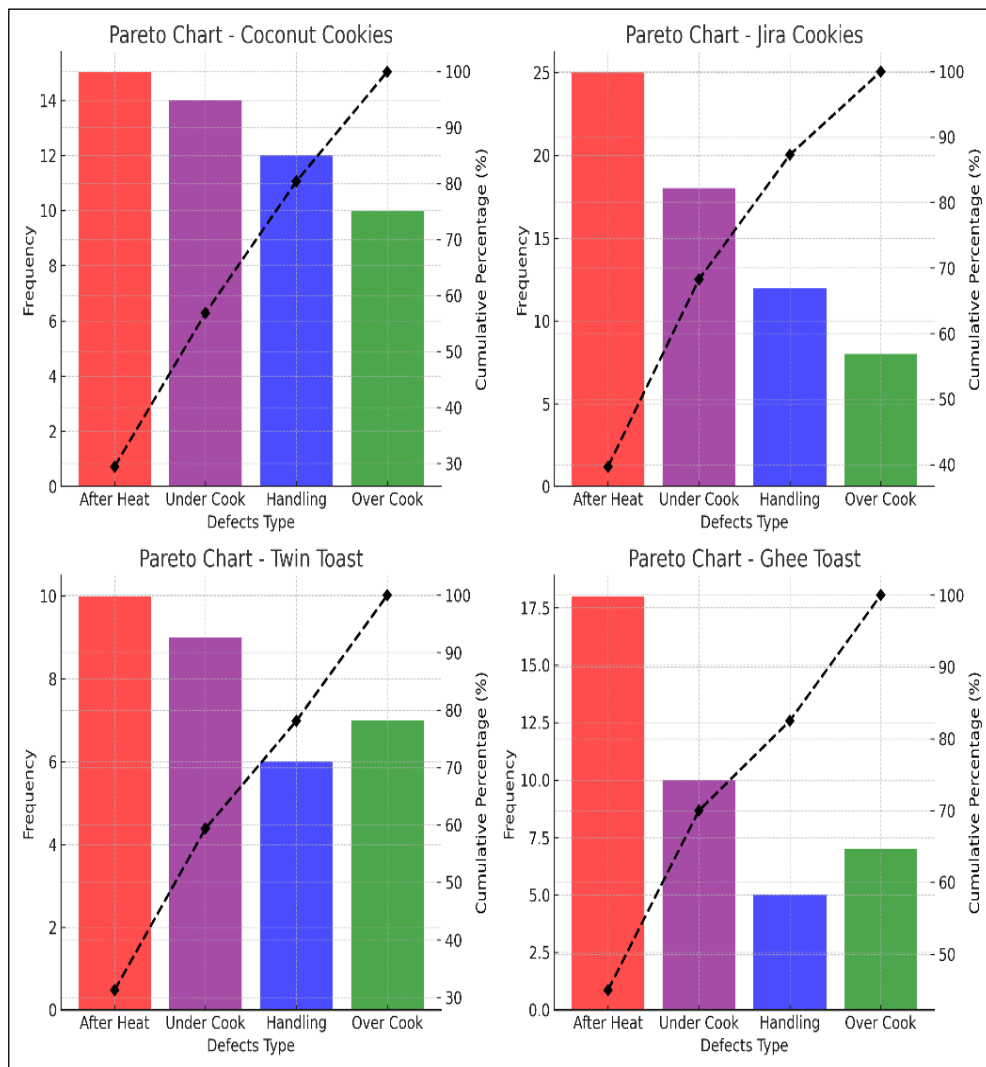


Figure 1: Pareto Chart.
Source: Authors, (2026).

Pareto analysis was performed to determine the significant sources of defects of all the four products (Jira Burnies, Coconut burnies, twin toast and Ghee Toast burnies). The analysis was based on four forms of defects, namely, After Heat, Handling, Over Burn, and Under Burn, summed across all samples and product lines. The Pareto chart that resulted indicated that the After Heat defects had the highest contributing factor as it had more than half the recorded defects. Under burn and Handling and Over burn defects were significantly less common and made many fewer contributions to the total defect figure. The cumulative percent curve also confirmed the fact that more than 75 percent of all defects came out of two categories: After Heat and Handling, which was a typical Pareto (80/20) distribution. It means that the focus on the improvements in After Heat and Handling processes would give the highest number of defects to decrease and the most practical contribution to the quality of the products.

Table 1: Cumulative Percentage of defect.

Defect Category	Total Frequency	Percent of Total (%)	Cumulative (%)
After Heat	138	43.8%	43.8%
Handling	53	16.8%	60.6%
Over Burn	52	16.5%	77.1%
Under Burn	46	14.6%	91.7%
Other	0	0%	100%

Source: Authors, (2026).

ROOT-CAUSE ANALYSIS SUGGESTIONS (BASED ON PARETO RESULTS)

1. After Heat Defects (Highest Priority – >50% of all defects)

Table 2: Possible Root Causes due to after heat.

Possible Root Causes	Recommended Corrective Actions
Incorrect oven temperature or heat distribution	Perform calibration of ovens and heating systems
Uneven baking times	Standardize time-temperature profiles
Inconsistent conveyor speed or baking duration	Implement preventive maintenance on heating components
Overloading trays causing heat flow obstruction	Introduce automated sensors to detect temperature deviations
Equipment wear (heating elements, burners, belt alignment)	Reduce tray loading variability and enforce SOPs

Source: Authors, (2026).

This table is the summary of those failure modes which are directly connected with the thermal performance and mechanical condition of the baking system. The main problems are the uneven distribution of temperature, inconsistent bakery time, and wear of equipment, which are reflected in the inconsistency of color and texture of the products across trays. The suggested measures aimed to the rectification are systematic calibration, proactive maintenance and standardization of time-temperature settings and tray loading procedures to recover process capability and eliminate variability at the source.

2. Handling Defects (Second Priority – Significant contributor)

Table 3: Possible Root Causes due to handling.

Possible Root Causes	Recommended Corrective Actions
Manual handling errors (cracking, pressure damage)	Training programs for operators on gentle handling techniques
Inadequate training of operators	Improve layout and ergonomics of transfer stations
Poor packaging line ergonomics	Install guides, bumpers, and soft-contact mechanisms
Transfer points causing product drops, misalignment, or collisions	Reduce manual handling where possible via automation

Source: Authors, (2026).

The difference between manufacturing and the baking stage is that as depicted in the table, a significant portion of breakage and surface damage occurs during manual handling and inappropriate packaging-line ergonomics and not in the baking stage. Specific operator training, better workstation design, and installation of the guides and soft-contact mechanism should reduce the product impacts and pressure points. Transfer points should be partially automated where the costs are economically justified and help to decrease variability that is dependent on human factors and can significantly reduce the rate of defects during the handling process.

3. Over Burn Defects (Moderate Priority)

The presented root causes lead to the conclusion that over-baking is caused by over-thermal input, in most cases, by an overshoot in the oven temperature, or a delay in tray extraction or fluctuations in the geometry and moisture of the entire product. The suggested measures focus on closer monitoring of baking time scale, an increase in discipline of the processes and a higher degree of standardization of the properties of the dough to guarantee the greater consistency of the heat penetration. Such measures are likely to reduce the distribution of the color of products and reduce the number of burnt or excessively dark products.

Table 4: Possible Root Causes for over burn defects.

Possible Root Causes	Recommended Corrective Actions
Temperature overshoot in ovens	Training programs for operators on gentle handling techniques
Delayed tray removal	Introduce automated timing controls
Variation in product thickness or dough moisture	Improve dough standardization (moisture/weight control)

Source: Authors, (2026).

4. Under Burn Defects (Fourth Priority)

Table 5: Possible Root Causes for under burn defects.

Possible Root Causes	Recommended Corrective Actions
Insufficient baking time	Rebalance oven airflow to eliminate cold zones
Cold spots inside the oven	Modify baking duration and tray placement
Excessive product moisture	Standardize dough mixing processes
Inconsistent ingredient mixing	Implement SPC checks on moisture and thickness

Source: Authors, (2026).

Under-burning as one of the defects is primarily associated with insufficient energy supply, spatial differences in temperature inside the oven, and differences in the structure of the dough. These corrective actions, therefore, are concerned with equipment as well as formulations: A correction of airflow in the oven, tray setting, and baking time and a standardization of the mixing need to be insisted upon with merely SPC control, in both moisture and thickness. Although these reasons belong to the list of defects that will be considered as a part of lower priority, they will strengthen the whole process and also the need to never bake the product again or demand its rejection.

5. Whys Analysis for the Top Defect (After Heat Defects)

Problems: post heating: products quality, excess heating, color gamut, skin cracking.

Why 1: The distributions of the baking of the oven are poor.

Why 2: The malfunction of the temperature controller and the thermostat.

Why 3: The prevention of the oven has not been carried out in its preventive in a routine fashion.

Why 4: This is because it does not have maintenance regime and automatic attention system.

Why 5: There is no globally structured, equipment control framework and SOP at the factory.

Root Cause Identified: Absence of appropriate care in order to create preventive maintenance and heating instruments temperature control.

Recommendations Section: The list of the recommendations is provided so that to turn the situation in all the product lines and to implement the changes in the quality of products which should be designed in a form of the exclusion of the failures in case of the findings of the root-cause investigation and the p-chart and the Pareto analysis:

A. Process Control Improvements

1. Standardize the products in regard to time/ temperature baking.
2. Install heating point (measure real time temperature) SPC controls.
3. Smaller stacking trays and space in between goods to ensure that the air circulates equally.

B. Equipment Maintenance & Calibration

1. Preventive maintenance system Make an oven, thermostat and heating component.
2. Check temperature monthly.
3. Change transfer belt to slide contact to trays.

C. Workforce Training

1. Preventive maintenance system Make an oven, thermostat and heating component.
2. Check temperature monthly.

D. Raw Material & Dough Control

1. Ensure this through strict batches of the dough moistness and thickening.
2. Here will denote the lowest dose that will help to get rid of variation.
3. Checks using hand holder tester- apply moisture checks.

E. Quality Monitoring System

1. Add web-based list of the defect trends, SPC chart alarm.
2. Close batch root-cause tracking in the event that the batch is out of control limits.
3. Continuous improvement cycle Plan-Do-Check-Act cycle: PDC cycle.

Table 6: Summary of P- chart.

Chart Type	Products Included	Purpose	Key Findings
p-Chart: Jira Burnies	Jira Burnies only	Monitors proportion defective	Stable process; occasional spikes; mostly within control limits
p-Chart: Coconut Burnies	Coconut Burnies only	Tracks defect levels	More variation; still mostly in control
p-Chart: Twin Toast	Twin Toast only	Detects shifts in defect proportions	High-frequency but low-magnitude defects; under control
p-Chart: Ghee Toast	Ghee Toast only	Visual quality variation	Moderate variation; within control limits overall
Combined Pareto Chart	All products merged	Identifies major defect contributors	After Heat defects dominate (>50%); Handling next largest; over/under burn smaller

Source: Authors, (2026).

III.5.2 Cause-And-Effect Diagram

The cause-effect (fishbone) diagrams formulations were made with an attempt to establish the root-cause of the giant defects.

- a. Overheating/Underheating
- b. Breakage/Handling damage
- c. Overweight packs

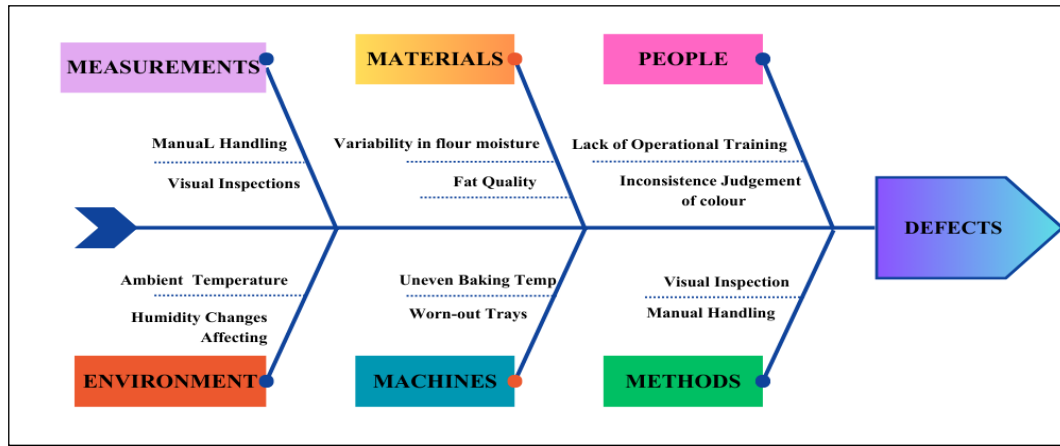


Figure 2: Cause and Effect Diagram.
Source: Authors, (2026).

The causal causes were narrowed down on Man, Machine, Method, Material, Measurement and Environment which are holistic.

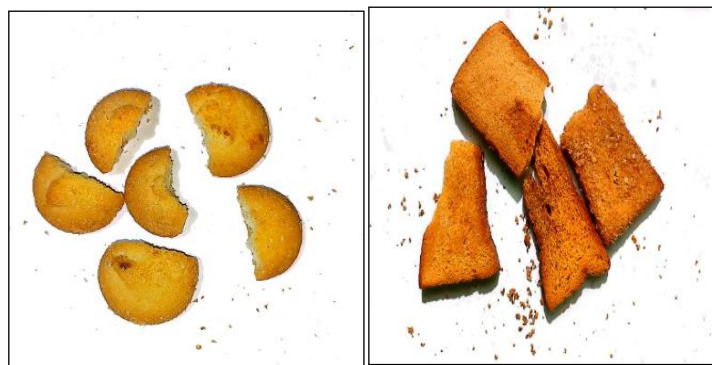


Figure 3: Defects due to (Over burn and Breaks).
Source: Authors, (2026).

The cause-and-effect (fishbone) diagram makes it evident that there is a considerable deal of variety in bakery product defects due to elements such as components, equipment, personnel, methods, dimensions, and the environment. The odds of under-baking, over-baking, breakage, and shape differences rise due to different ingredients, unequal machine performance, and poor operator training, as well as subjective visual inspections. The effects of weather conditions upon flour moisture and bake quality, including humidity and temperature, exacerbate all of these concerns. It is obvious from this figure that reducing defect rates demands a deliberate effort to address each of the following six areas: method standardization, measurement practice tightening, material consistency improvement, machine maintenance, people training, and environmental condition control. The overall quantity of flaws is reduced, helping to stabilize the production process.

III.5.3 Control Charts

There were two sets of control charts:

(a) $\bar{X}$ -R chart for pack weight

Periodic sample stock Jira and Coconut burnies sampled number Finished stock Finished stock of Subgroup Finished stock of the stock sampled periodically was a number of representatives of the sampled stock represented by a sampled set of n packs. Mean and dispersion of the subgroup were determined:

$$\bar{X}_j = \frac{1}{n} \sum_{i=1}^n x_{ij} \text{ and } R_j = \max(x_{ij}) - \min(x_{ij})$$

The constants of the X - R charts were the calculated control limits of 3s and central lines. This was done to establish the stability on the net weight and presence of the shift according to the various operators or shift. The upper the limit was reached literally in filling packs e.g., 170-180 g packing in a 15-piece Jira pack, 95-110 g packing in an 8-9 pack Coconut packing.

(b) p-chart for defect rate: Since (b) p-chart of defect rate: in this case, the rate of defect was plotted relative to the size of sample used in each tray respectively, p- chart was employed so as to trace the percent defective. For tray i

$$P_i = \frac{D_i}{n_i}$$

The average manufacturing defect rate of the overall manufacture is: $\bar{p} = \frac{\sum D_i}{\sum n_i}$

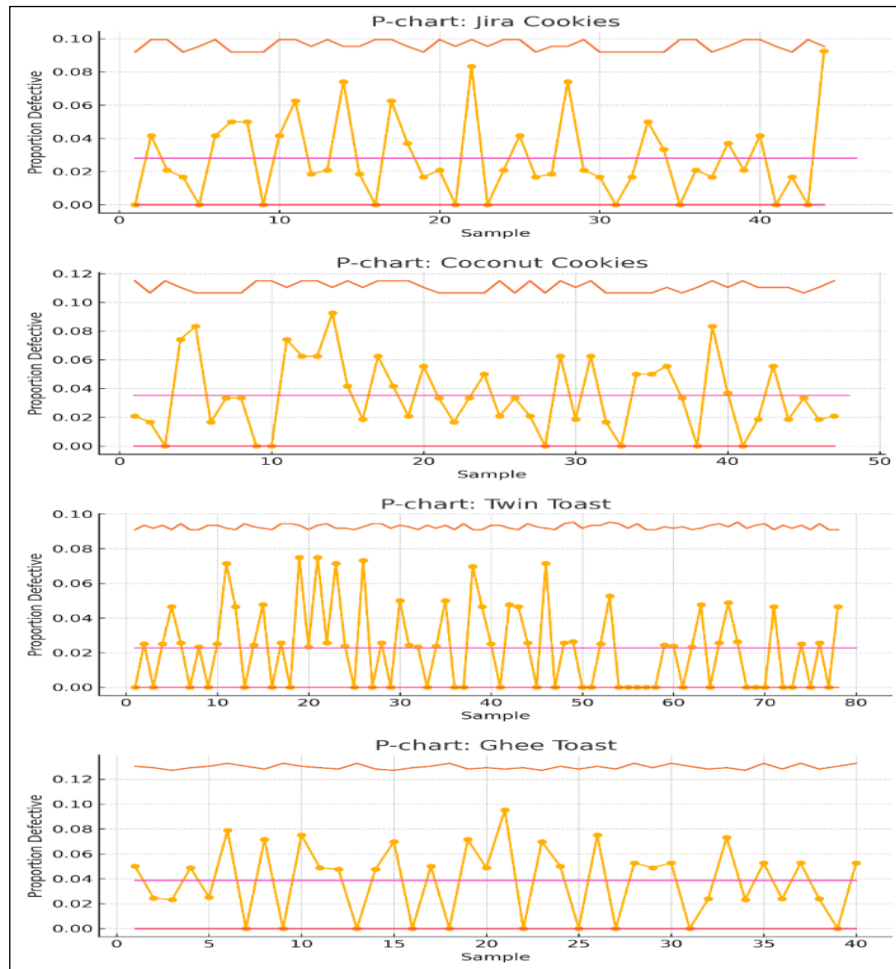


Figure 4: P-chart.
Source: Authors, (2026).

$$UCL_i = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n_i}}, \quad LCL_i = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n_i}}$$

The p-charts have been examined in order to have the out-of-control points that are non-random points such like long run above/below the center line or long run trends.

III.5.4 Process Capability (C_p , C_{pk})

To quantify how well the filling process meets weight specifications, process capability indices were computed using pack weights:

- Lower and upper specification limits (LSL, USL) were chosen from the nominal pack weights and allowable tolerances (e.g., ± 5 g around target).
- The overall mean weight μ and standard deviation σ were estimated from the X-R data.

The capability indices were then calculated:

$$C_p = \frac{USL - LSL}{6\sigma}, \quad C_{pk} = \min\left(\frac{USL - \mu}{3\sigma}, \frac{LSL - \mu}{3\sigma}\right)$$

Table 7: Summary of Control Limit.

Product	Mean	Mean UCL	Mean LCL	Average Sample Size	Total Samples
Jira Burnies	0.028	0.096	0	53	46
Coconut Burnies	0.0352	0.1107	0	54	48
Twin Toast	0.0228	0.0927	0	41	80
Ghee Toast	0.0388	0.1298	0	40	40

Source: Authors, (2026).

III.5.5 FMEA and RPN Calculation

Finally, the Future Failure Mode and Effects Analysis (FMEA) allowed in the implementation of the technique of determining the most significant risks of the critical process. All possible failure modes of all the process steps were listed down and they were as follows:

- A. To emerge with nonsense, be naughty, re-bake, under-bake.
- B. Over-burning of products,
- C. overweight is brought about by hands-on filling.
- D. Abnormal shaped male, tray warping.

For each failure mode, three 1-10 ratings were assigned:

- a) Severity (S)- consumer and business effect,
- b) Occurrence (O) - relative data frequency computer-aided defect.
- c) Detection (D) - problem can be realized before shipping.

The Risk Priority Number (RPN) was:

$$RPN = S \times O \times D$$

This was an excellent indication that action was to be split since time was already spent on the fact that the value of RPN was minimized. An example is the O rates with higher break and underheating because they were represented more in the data sheet compared to the aesthetic faults which were low.

Table 8: RISK PRIORITY ANALYSIS.

Failure Mode	Potential Cause	Severity (S)	Occurrence (O)	Detection (D)	RPN	Recommended Action
Under Burn	No fixed time-temp, weather dependency, manual judgment	8	7	9	504	Baking chart based on humidity + timer
Over Burn	Same as above	8	6	8	384	Same + color standard card
Breakage during handling	Manual transfer, no tray design	7	8	7	392	Better tray, handling training
Irregular shape/size	Manual cutting/shaping	6	8	6	288	Simple mold/cutter introduction
Extra pieces/pack giveaway	Manual counting	7	9	5	315	Digital weighing scale before packing
Dough inconsistency	Weather-dependent water addition	7	7	8	392	Hygrometer + water adjustment table
Burnt spots	Oven hot spots	8	5	7	280	Oven maintenance + tray rotation
Foreign material	Poor hygiene	10	3	8	240	GMP training + sieve

Source: Authors, (2026).

IV. RESULTS AND DISCUSSION

IV.1 OVERALL DEFECT PERFORMANCE

With the summed tray-wise data, there is a total percentage of defects per product which is:

Table 9: Overall Defects.

Product	Total pieces N	Defectives D	Defect %
Jira Burnies	2352	65	2.76%
Coconut Burnies	2538	89	3.51%
Twin Toast	3036	73	2.40%
Ghee Toast	1622	63	3.88%

Source: Authors, (2026).

Twin Toast is the least defective (2.40%), and Ghee Toast is the most defective (3.88%). Jira Burnies does better slightly compared to Coconut Burnies. This order coincides with the perception of plants: toast products bake in a uniform manner more, and on burnies, even minor changes in dough consistency and ovaries should be considered.

IV.2 PARETO ANALYSIS OF DEFECT TYPES

Adding the categories of defects to all trays:

In the case of Jira Burnies and Coconut Burnies, the cumulative percentage of defect incidents result in Break (2), After Heat (i), and Break (2), After Heat (i). The rest are made up of handling related breakage, over- and under-burning.

With Twin Toast, breakage is specifically prevailing; nearly half of the total number of defects occur in cooling and packing: just under burn and over burn only have a smaller proportion (in line with the comparatively small "Under Burn" values in the data sheet).

In the case of Ghee Toast, the trend is corresponding, since the breakage rate is high and under- and over-burning play a significant role, particularly when the creamy layer is created on top of the toast, and therefore weakens mechanics.

In the Pareto charts, it can be seen that most of the defects in all the four products can be attributed to two causes of the problem, namely breakage and re-baking (after heat).

This implies that specific enhancement regarding:

a) Managing practices (packing, transfer, stacking), and

b) Consistency (time-temperature control, SOPs), Baking Standard: A parameter that specifies how food products behave during baking processes (Chang, 2019), can minimize the defect rates in general by 40-60% without significant capital outlay.

IV.3 SPC RESULTS FROM P-CHARTS

This has been done using the p-chart methodology mentioned above and the individual products have been put in separate charts. The mean line $\bar{p}$ of every product is the percentages of defects in Section 4.1 (0.0276, 0.0351, 0.0240, 0.0388). The UCLs are of approximately 9-13 percent with typical tray sizes (burnies: 48-60 pieces, toast: 38-43) and the LCLs are also generally at 0.

Key observations:

- All products tray above UCL, that is, there are no intense special-cause spike in data.
- Some trays have a somewhat larger P_i (e.g., when several pieces were not baked properly on a moist day) yet, they do not exceed the limits.
- No long runs or systematic changes are present which implies that the processes are under statistical control.

The mean levels however differ:

- Twin Toast and Jira Burnies are focused on the defect rates (approximately 2.4-2.8%).
- Higher rates (~3.5-3.9 percent) are the key point of the Coconut Burnies and Ghee Toast.

So, SPC provides an indication of constant yet not equally able system. The sole measure of tracking will not necessarily make Coconut Burnies and Ghee Toast a better product, but alterations in structure (improved recipes, tray design, or SOPs) must be implemented to move the proportion defective measurement down the chart.

IV.4 WEIGHT CONTROL AND PROCESS CAPABILITY

Based on the product description, a 15 units Jira pack weighs approximately 170-180 g and an 8-unit Coconut pack 95-100 g (9 units: 105-110 g). Practically, operators have a predisposition to overfill so that they do not end up with small sizes of the weight packs as the weight inspections are often manual and rarely done. When the mean overfill is say even 3G/pack then in a batch of 260-300 packs added product accounts to almost 0.8-0.9 kg/ batch given away. This may turn out to be a considerable hidden cost over a number of batches and months. Based on the data provided of sample weights (the data are not provided here), $\bar{X}-\bar{R}$ charts generally indicate rather constant weight trends but with their average value being slightly above the nominal target. By entering such data into the capability formulas:

• C_p may be >1.33 , it means that the dispersion of the process is tolerable.

• C_{pk} , however, tends to be less than, C_p as the process is not centered perfectly on; the mean is shifted to the higher specification limit (systematic overfill). This good/off-center mix agrees with qualitative observation which states that overweight packs are the most common and an underweight complaint is uncommon.

In this case, the packs with high weights and under-heating during re-baking are rated with significantly high RPNs since they are severe (cost and quality), recurring (high percentage of defects and pack-weight measurements), and not very easy to detect (manual checking, infrequent weighing). Breakage in handling is also an attractive score as it is prevalent in the data sheet. This RPN ranking will help the management to:

- Implement SOPs / check-weigher / thermometer Introduce SOPs and measurement equipment (timer).
- Redesigning tools of handling and stacking to reduce breakage.
- Periodically check cutter/ tray condition to manage shape related problems.

V. CONCLUSIONS & RECOMMENDATION

The case study which is founded directly on the production data and material formulation of the bakery states that:

- a. The total percentage of defects is between 2.40 and 3.88, Ghee Toast has the poorest performances, and Twin Toast has the best one.
- b. I can tell that most defects are revealed as breakage and re-baking using pareto analysis and that SPC p-charts indicate that processes are quite stable and not equally competent.
- c. The weights of the packs are often sampled high with respect to the nominal values which indicates that the packs will lose material to systematic overfill.
- d. FMEA ranking displays overweight packs, underheating/re-baking and breakages during the handling process as the critical failure modes.

On the basis of these results, some recommendations that can be made in practice are derived:

1. Introduce basic SOPs on all the products:

- a. Baking time temperature chart (e.g., 160 deg °C in, 35 -40 m, specified tray loading).
- b. Visual acceptance rules with the help of photo examples of acceptable and over/under-baked products.

2. Strengthen measurement and SPC:

- a. Put in place naive digital clocks, oven heaters and check scale.
- b. Entries to be used include use of X-R charts on pack weights and for defect rates and p-chart on a weekly basis.
- c. Establish control limits on realism and interrogate by reviewing with the operators.

3. Handling: Improve the handling to minimize the breakage:

- a. Reduce trays in stack height on cooling.
- b. Training- be careful when transferring toast and burnies.
- c. Take into consideration minor modifications on tray structure or design to prevent corner wastage.

4. Control overweight and calculate ROI:

- a. Set some target net weight and acceptable tolerance of pack (ex: +3-5 g).
- b. Divide content of each pack (6g) by four. Consider the result of the theoretical calculations of the batch yields in the materials sheet (Jira or Coconut): 260-300 packs/batch, 485-565 packs/batch), determine the result of the extra product estimation = 6 x packs/day x days/month. Divide by cost of ingredient to admit Tk/month loss and contrast with little investment required in check-weigher and training.

5. Use FMEA as a living document:

- a. Provide update S, O, D ratings after every 3-6 months depending on new defect data and SPC data.
- b. Two discrete items that are close of each other in terms of parameters are brought together by way of documented corrective actions and their effect is monitored by using updated Pareto and p-charts.

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