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Production Process Quality Improvement In Ice Cream Manufacturing Using Integrated Pareto Chart and 5M1E Fishbone Diagram

Rizky Nurrochmad Ismail[1], Mochammad Hatta[2], Devi Susiati[3], Dasman Johan[4], Nofri Yudi Arifin[5], Ida Kusnawati Tjahjani[6]

[1,4] Industrial Engineering, Faculty of Science and Technology, Ibnu Sina University, Batam,
[2, 3]Industrial Engineering, Faculty of Engineering, Universitas 45 Surabaya, Surabaya
[5]Informatics Engineering, Faculty of Science and Technology, Ibnu Sina University, Batam,
[6]Industrial Engineering, Faculty of Technology and Science, Universitas PGRI Adi Buana Surabaya,

e-mail: rizky@uis.ac.id

***Abstract*— The research object is the ice cream production process at PT Sejuk Abadi Nusantara, using production and quality-control records from January to June 2024. Of the 29,530 produced units, 630 were defective, representing a defect rate of 2.13%. Pareto analysis indicated four vital few defects that accounted for 79.21% of total defects: non-uniform texture, excessive moisture content, uneven color, and non-standard portion size. A 5M1E Fishbone Diagram and 5-Why verification showed that dominant root causes were associated with machine, method, measurement, and human factors, especially freezer-temperature sensor drift, worn freezer gaskets, inconsistent hardening time, weak mixing standard operating procedures, and insufficient operator training. A corrective and preventive action plan was proposed, covering sensor calibration, freezer maintenance, hardening standardization, visual work instructions, operator training, moisture testing, environmental monitoring, and monthly calibration. The proposed actions are projected to reduce total defects from 630 to 222 units per semester, or 64.8%. The study demonstrates how integrated Pareto-Fishbone analysis can transform quality-control records into operational process-improvement decisions for frozen-food manufacturing.**

Keywords : Pareto Chart;* 5M1E*; Fishbone Diagram; Quality Improvement

I. INTRODUCTION

Ice cream manufacturing is a frozen-food production system in which product quality is determined by the interaction among formulation, pasteurization, homogenization, aging, dynamic freezing, hardening, packaging, and cold-chain storage. Defects such as non-uniform texture, excessive moisture content, uneven color, and non-standard portion size do not only represent final-product nonconformities; they also indicate variation in machine condition, production methods, measurement systems, operator behavior, and processing environment. For this reason, quality improvement in ice cream manufacturing requires an integrated analytical framework that can translate quality records into production-process decisions. [1] [2] [3].

The initial manuscript identified 630 defective units from 29,530 production units at PT Sejuk Abadi Nusantara during January-June 2024. The overall defect rate was 2.13%, exceeding the company's tolerance of 1.5%. Four defects dominated the problem: non-uniform texture, excessive moisture content, uneven color, and non-standard portion size. These defects are important because they influence sensory acceptance, regulatory compliance, processing losses, rework cost, and customer trust in frozen dairy products. [4] [5] [2] [6].

Although Pareto charts and Fishbone Diagrams are widely used in quality-improvement studies, many applied manuscripts stop at identifying dominant defects and proposing corrective actions. Such studies often do not test whether the process is statistically stable, do not express defects in correct DPMU and DPMO terminology, do not quantify the economic impact of poor quality, and do not demonstrate at least one implementable improvement. This creates a research gap in applied production-process studies: the need to integrate defect prioritization, SPC stability analysis, CoQ evaluation, root-cause verification, and initial corrective-action implementation within one coherent improvement model. [7] [8] [9] [10].

Second, the Cost of Quality analysis is added to estimate the economic implications of

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defects and improvements. Third, the SPC analysis is strengthened by showing the p-chart calculation logic, control limits, interpretation of stable-but-incapable performance, and the difference between statistical control and target compliance. Fourth, a minimum real improvement is formulated as an implementable pilot action: hardening-control checklist, daily temperature verification, capacity limit, and operator briefing. Fifth, the research gap is explicitly presented. Sixth, DPMU and DPMO terminology is corrected so that defects per million units and defects per million opportunities are not mixed [7] [8] [9] [11] [12]

Table 1. Alignment of The Manuscript with Tibuana Scope and Applied Production-Process Contribution

Tibuana Scope	Alignment in this article	Evidence In The Manuscript
Application of industrial process	Supporting scope	The study describes ice cream production stages, including homogenization, aging, freezing, hardening, packaging, and cold storage, as the operational context.
Applied methods of the production process	Main scope	The study integrates Pareto Chart, p-chart SPC, CoQ, 5M1E Fishbone Diagram, 5-Why verification, DPMU/DPMO calculation, and CAPA to improve production-defect performance.
Applied management of the production process	Supporting scope	The study translates root causes into PIC, target time, success indicators, implementation checklist, monitoring indicators, and cost implications.

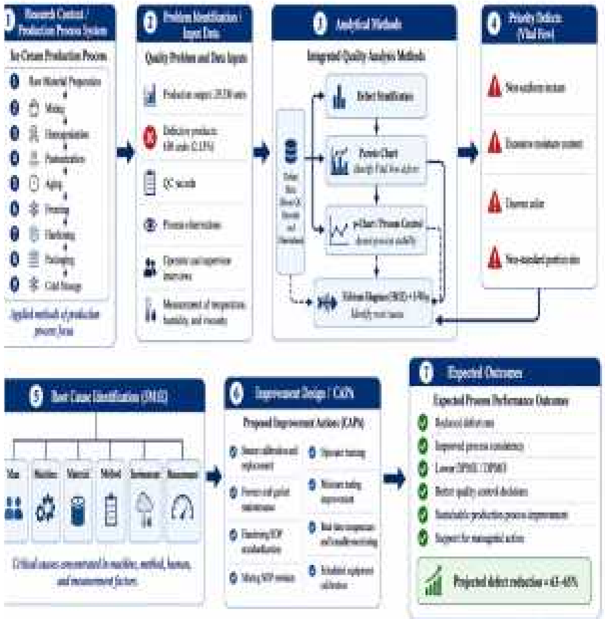

Figure 1. Conceptual Framework for The Applied Methods of Production Process Scope

Table 2. Research Gap and Contribution of the Study

Prior Tendency in Quality Improvement Studies	Identified Gap	Contribution of This Study
Pareto and Fishbone are commonly used to rank defects and list possible causes.	Corrective actions are often proposed without economic justification.	CoQ is added to estimate prevention, appraisal, internal failure, external failure, projected savings, and payback logic.
SPC is sometimes presented as a chart only.	The difference between statistical stability and target compliance is not fully explained.	The p-chart is strengthened with p-bar, UCL, LCL, monthly proportions, and interpretation of a stable but not yet capable process.
DPMU and DPMO are frequently used interchangeably.	Misinterpretation occurs when production units and quality opportunities are not separated.	DPMU is defined as defects per million units produced, while DPMO is based on eight CTQ opportunities per unit.
Corrective action plans are frequently conceptual.	There is limited evidence of initial implementation feasibility.	A minimum real improvement is specified through a hardening checklist, PT-100 verification, batch-capacity control, and operator briefing.

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II. RESEARCH METHODOLOGY

2.1. Research Objects and Locations

This study uses a descriptive quantitative case-study approach at PT Sejuk Abadi Nusantara, a medium-scale ice cream manufacturer located in Semarang Regency, Central Java, Indonesia. The company produces ice cream cones, bars, cups, and sandwiches, with a production capacity of approximately 30,000 units per semester. Field observation was conducted in the production line, raw material storage, hardening freezer area, packaging area, and cold storage. [1] [6] [2] [3].

The research object is the quality performance of the ice cream production process, especially defects related to texture, moisture content, color, portion size, packaging, aroma, inclusion distribution, and labeling. This object is suitable for applied industrial engineering research because it converts quality-control records into production-method improvements. [13] [14] [15].

2.2. Data Types and Sources

The study used secondary and primary data. Secondary data included daily production reports from January to June 2024, daily QC inspection sheets, defect-type records, preventive-maintenance documents, and production SOPs. Primary data were obtained through direct observation, structured interviews with production and QC personnel, and direct measurement of process parameters such as freezer temperature, room humidity, mix viscosity, hardening time, and batch load. Twelve key informants were involved: one production manager, one QC manager, three supervisors, five senior operators, and two machine technicians [8] [16] [2] [3]. The combination of production records, direct observation, and interviews is intended to reduce single-source bias and strengthen root-cause verification [1] [3] [16].

2.3. Analysis Method

The analysis was conducted in seven stages. First, defect data were classified into eight CTQ categories based on company inspection criteria. Second, Pareto analysis was conducted by sorting defect frequencies and calculating cumulative percentages.

$$\%\ Cumulative\_i = \Sigma(f\_j, j=1 \text{ to } i) / \Sigma(f\_j, j=1 \text{ to } n) \times 100\% \quad \ldots(1)$$

Third, SPC analysis was conducted using a p-chart because the quality characteristic was the proportion of defective units.

$$p\_i = d\_i / n\_i \quad \ldots (2)$$

$$p\text{-bar} = \Sigma\ d\_i / \Sigma\ n\_i \quad \ldots (3)$$

$$UCL\_i = p\text{-bar} + 3\sqrt{[p\text{-bar}(1-p\text{-bar})/n\_i]} \quad \ldots (4)$$

$$LCL\_i = \max\{0, p\text{-bar} - 3\sqrt{[p\text{-bar}(1-p\text{-bar})/n\_i]}\} \quad \ldots (5)$$

Fourth, DPMU and DPMO were calculated with corrected denominators. Fifth, the cost of Quality was calculated to estimate economic losses and the feasibility of improvement actions. Sixth, the two dominant defects were analyzed using a 5M1E Fishbone Diagram and verified by 5-Why questioning. Seventh, corrective and preventive actions were designed, and a minimum improvement was translated into an initial implementation protocol [17] [11].

$$DPMU = (\text{number of defects}/\text{number of produced units}) \times 1{,}000{,}000 \quad \ldots (6)$$

$$DPMO = (\text{number of defects} / [\text{number of produced units} \times \text{number of CTQ opportunities}]) \times 1{,}000{,}000 \quad \ldots (7)$$

In this study, each unit has eight CTQ opportunities. Therefore, DPMO is lower than DPMU because the denominator includes all quality opportunities rather than the produced units only. [10] [14].

Similar integrated quality-tool approaches have been applied in Tibuana studies on packaging defects, wet mix products, ceramic products, sugar packaging, and production-process performance improvement. [17] [18] [19] [20].

Defect rate, DPMU, and DPMO were used as quantitative indicators. Defect rate was computed by dividing defective units by total production units. DPMU was computed as defects per one million produced units. DPMO was computed by dividing the number of defects by total opportunities, where each unit had eight CTQ opportunities, and multiplying the result by one million. This distinction is important because DPMU and DPMO represent different denominators in process-capability interpretation. [13] [14] [15].

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2.4. Data Validity

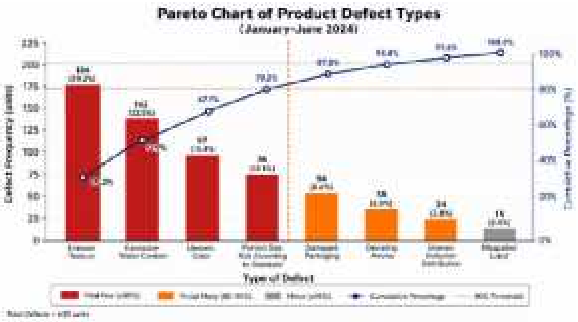
Data validity was maintained through triangulation among QC records, production reports, direct observation, maintenance/ calibration documents, and confirmation from production and QC personnel. Monthly defect records were checked for consistency with total production, and root causes were not accepted as final unless supported by observation, document evidence, process measurement, or informant confirmation. [8] [16] [2] [3].

The classification of defect types was discussed with the QC manager to maintain consistency with company inspection criteria. Root causes identified in Fishbone Diagram sessions were not accepted as final until they were supported by observations, document evidence, process measurements, or confirmation from key informants. This triangulation logic is consistent with applied process-improvement studies in which measurement accuracy and source verification are essential before corrective actions are proposed. [7] [3] [16].

III. RESULTS AND DISCUSSION

3.1. Product Defect Data Profile

During January-June 2024, the company



produced 29,530 units and identified 630 defective units. The aggregate defect rate was 2.13%, exceeding the internal tolerance of 1.5%. The four highest defect categories contributed 79.21% of total defects, indicating that improvement should focus on the vital few problems rather than spreading resources across all defect types equally [17] [20] [1].

This prioritization is aligned with applied quality-control studies that use defect data to guide production-process improvement. [17] [21] [18].

Table 3. Distribution of Ice Cream Product Defects, January – June 2024

No.	Type of Defect	Frequency (units)	Percentage (%)	Cumu lative (%)	Cate gory
1.	Non-Uniform Texture	184	29.21	29.21	Vital Few
2.	Excessive Moisture Content	142	22.54	51.75	Vital Few
3.	Uneven Color	97	15.40	67.14	Vital Few
4.	Non-Standard Portion Size	76	12.06	79.21	Vital Few
5.	Damaged Packaging	54	8.57	87.78	Trivial Many
6.	Deviating Aroma	38	6.03	93.81	Trivial Many
7.	Uneven Inclusion Distribution	24	3.81	97.62	Trivial Many
8.	Misapplied Label	15	2.38	100.00	Trivial Many
	Total	630	100.00		-

3.2. Pareto Chart Analysis

The Pareto result confirms that non-uniform texture and excessive moisture content are the two most critical defects. These defects are directly connected to homogenization consistency, freezing behavior, hardening temperature, cold-chain stability, and the reliability of measurement instruments. From a production-process perspective, the Pareto result is not merely a ranking of defects; it is a decision tool for selecting process parameters that require immediate control. [1] [22].

Recent ice cream process studies confirm that process conditions influence crystallization, overrun, structural properties, and product stability. [1] [6] [22] [23]. Thus, the Pareto result is not only a statistical priority but also a process-engineering priority.

Figure 2. Pareto Chart of Ice Cream Product Defects

3.3. SPC Analysis Using p-Chart

The SPC analysis uses a p-chart because the measured quality characteristic is the proportion of defective units per month. The central line is p-bar = 630 / 29,530 = 0.02133 or 2.13%. Because monthly sample sizes differ, the upper and lower control limits were calculated separately for each month. Figure 3 presents a monthly recap whose total defects are consistent with the total of 630 units. [8] [10].

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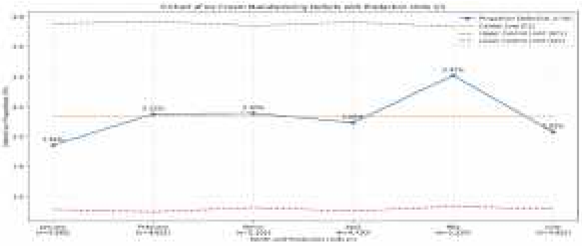

Figure 3. Monthly p-Chart Calculation for Aggregate Defect Rate

All monthly defect proportions are below their respective UCL and above LCL; therefore, the process is statistically in control. However, being statistically in control does not mean that the process is acceptable. The center line of 2.13% remains higher than the company tolerance of 1.5%. This means that the process is stable but not capable of meeting the internal quality target. The dominant causes are common causes embedded in the production system, including weak standardization, freezer-condition variation, calibration gaps, and inconsistent hardening practices. Consequently, the correct managerial response is system-level improvement rather than short-term inspection sorting. [8] [10].

3.4. DPMU and DPMO Terminology

DPMU measures defects per one million produced units. Based on 630 defects and 29,530 produced units, DPMU = 21,334. DPMO measures defects per one million quality opportunities. Because this study uses eight CTQ opportunities per unit, DPMO = 2,667. Thus, a value around 21,334 should be interpreted as DPMU, not DPMO. [10] [14].

Table 4. Quality Indicator Interpretation

Indicator	Formula	Before Improvement	Interpretation
Defect Rate	Defects/production units × 100%	2.13%	Aggregate proportion of defective output.
DPMU	Defects/production units × 1,000,000	21,334	Defects per one million produced units.
DPMO	Defects / (production units × 8 CTQ) × 1,000,000	2,667	Defects per one million quality opportunities.

3.5. Fishbone Diagram — Non-Uniform Texture Defects

Non-uniform texture was the highest defect category, with 184 units or 29.21% of all defects. The Fishbone Diagram in Figure 3 and the root-cause summary in Table 3 indicate that machine, method, human, and measurement factors were the dominant contributors. The most critical machine-related causes were homogenizer wear and freezer temperature sensor drift. A homogenizer operating beyond its service life may reduce pressure consistency and weaken fat-globule dispersion, while freezer sensor drift can prevent accurate control of freezing temperature. Method-related causes included a mixing SOP that did not specify rpm, mixing duration, target viscosity, or acceptance limits. Such weak operational detail can generate inter-operator variation and inconsistent product texture. These findings support the use of method-based industrial engineering tools to translate product defects into controllable process parameters. [17] [6] [13] [16].

Non-uniform texture was the highest defect category, with 184 units or 29.21% of total defects. The 5M1E analysis indicates that machine, method, human, and measurement factors were dominant. Machine-related causes included homogenizer wear, freezer-temperature sensor drift, and calibration inconsistency. Method-related causes included a mixing SOP that did not specify rpm, duration, mixing sequence, target viscosity, or acceptance limit. Human-related causes included different operator interpretations of viscosity and process endpoints. Measurement-related causes included irregular calibration of the viscometer and temperature reference instrument. [16] [1] [6] [4] [22].

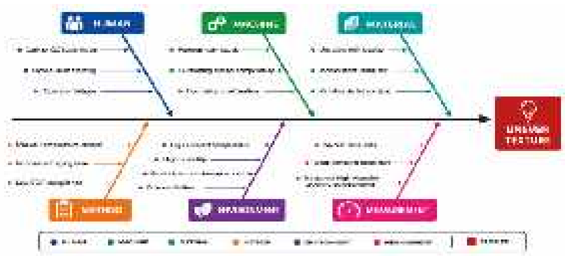

Figure 4. Fishbone Diagram for Non-Uniform Texture Defects

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Table 5. Root-Cause Analysis For Non-Uniform Texture Defects

5M1E Category	Main Symptom	Root-Cause Interpretation	Risk Level
Man	Operators interpret viscosity data inconsistently; fatigue occurs across shifts.	Training, supervision, and quality interpretation are not standardized.	High
Machine	Homogenizer wear, freezer sensor drift, and calibration inconsistency.	Homogenization pressure and actual freezing temperature deviate from the target.	Very High
Material	Variation in milk fat and stabilizer dose.	Incoming inspection does not fully control fat content, total solids, and stabilizer ratio.	High
Method	Mixing SOP lacks rpm, time, sequence, and viscosity limits.	Work instructions are too general and allow inter-operator variation.	High
Measurement	The viscometer and temperature reference are not calibrated routinely.	QC decisions may be based on inaccurate or delayed data.	High
Environment	Room temperature and humidity are not monitored in real time.	Ambient conditions affect mix viscosity and freezing load.	Medium

3.6. Fishbone Diagram — Excessive Moisture Defect

Excessive moisture content accounted for 142 units or 22.54% of total defects. This defect was more strongly linked to hardening and cold-chain control. The dominant root causes were worn freezer gaskets, PT-100 sensor deviation, irregular defrost cycle, hardening-capacity overload, variable hardening time, and insufficient moisture-testing frequency. If the actual hardening temperature is higher than the displayed set point, ice crystallization becomes less controlled, and the product becomes vulnerable to softening, moisture migration, and texture instability [1] [6] [23] [4] [2] [3].

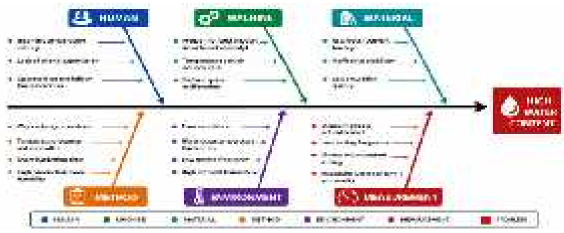

Figure 5. Fishbone Diagram for Excessive Moisture Defects

Table 6. Root-Cause Analysis for Excessive Moisture Defects

5M1E Category	Main Symptom	Root Cause Interpretation	Risk Level
Man	Default hardening setting used without actual-temperature verification	Operators do not have a batch checklist for hardening control	Very high
Machine	Worn gasket; PT-100 sensor deviation; defrost instability	The freezer cannot maintain the actual hardening temperature at the required level	Very High
Material	High water content and low stabilizer effectiveness	Incoming inspection does not consistently test moisture and total solids	High
Method	Hardening time varies; batch load exceeds capacity	The production schedule is not synchronized with the hardening capacity	Very High
Measurement	The moisture test is manual, and the sampling frequency is low	Moisture deviation is detected late and cannot prevent batch defects	High
Environment	Packing-room humidity is high; cold-storage temperature fluctuates	Transfer and storage conditions increase softening risk	High

3.7. Cost of Quality Analysis

The CoQ categories used in this study are prevention cost, appraisal cost, internal failure cost, and external failure cost. Because detailed accounting data were not fully separated in the original QC record, the cost values below are presented as a managerial estimate based on production interviews and standard-cost assumptions. The table should be updated with the company's actual accounting record before final submission if audited cost data are available. [11].

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Table 7. Cost of Quality Used in the Analysis

Cost Category	Cost Component	Assumption Used in Calculation	Estimated Value (IDR)
Prevention	SOP revision, operator briefing, checklist design, calibration schedule preparation	One-time preparation and training support	2,500,000
Prevention	Freezer gasket repair and hardening-capacity marking	Initial corrective maintenance	1,800,000
Appraisal	Moisture analyzer usage, thermometer cross-check, and additional batch inspection	Additional inspection resources per semester	2,000,000
Appraisal	Monthly calibration and verification records	Routine measuring-system control per semester	2,400,000
Internal Failure	Rework, disposal, additional labor, and extra freezing energy	Average IDR 30,000 per defective unit	630 × 30,000 = 18,900,000
External Failure	Complaint reserve, replacement, goodwill loss allowance	Average IDR 5,000 per defective unit	630 × 5,000 = 3,150,000

Table 8. Before-After Cost of Quality Projection

Indicator	Before Improvement	Projected After Improvement	Change
Defective units per semester	630	222	-408 units
Estimated failure cost (IDR 35,000/defect)	22,050,000	7,770,000	Saving 14,280,000
Prevention and appraisal investment	-	8,700,000	Implementation cost
Net first-semester economic benefit	-	-	5,580,000
Estimated payback period	-	-	3.7 months

The CoQ analysis shows that the proposed improvement is economically meaningful because the projected reduction of 408 defects may reduce failure cost by approximately IDR 14.28 million per semester. After considering the prevention and appraisal investment of IDR 8.70 million, the first-semester net benefit is estimated at IDR 5.58 million, with an approximate payback period of 3.7 months. This economic interpretation strengthens the managerial relevance of the quality-improvement program. [11].

3.8. Minimum Real Improvement Implementation

To move beyond a purely proposed CAPA, this study includes one real improvement that can be implemented immediately at the hardening stage. The selected action is a hardening-control improvement package because excessive moisture is the second-largest defect and because the root causes are operationally controllable. The package consists of four elements: (1) actual-temperature verification using a calibrated PT-100 reference before each production batch; (2) a hardening checklist covering batch load, target temperature, hardening duration, and operator sign-off; (3) a maximum batch-capacity limit to prevent freezer overload; and (4) a 15-minute operator briefing before each shift for one implementation week [7] [16] [14] [2] [3].

Table 9. Real Improvement Implementation Matrix

Implementation Item	Operational Action	Responsible Unit	Evidence to Collect	Success Indicator
Temperature Verification	Compare the freezer display with the calibrated PT-100 reference before batch loading.	Engineering and QC	Daily verification sheet	Deviation within ±0.5°C
Hardening Checklist	Record batch load, start time, end time, target temperature, and operator sign-off.	Production supervisor	Completed the checklist per batch	Checklist compliance ≥95%.
Capacity Limit	Mark the maximum rack/batch load and prohibit overloading during peak demand.	Production and warehouse	Batch loading record	No batch exceeds the defined capacity.
Operator Briefing	Brief operators on hardening target, moisture risk, and reporting rule.	Supervisor and HRD	Attendance and post-briefing note	100% of operators briefed.

The implementation does not require large capital expenditure and can be audited using simple production records. For final empirical validation, the company should collect at least four weeks of post-implementation data and compare moisture-related defect proportions before and after implementation using the same p-chart logic. In this article, the minimum real improvement functions as an initial

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implementation bridge between root-cause analysis and full CAPA deployment [8] [9] [10] [16] [14].

3.9. Corrective and Preventive Action Plan and Impact Projection

Table 10. Corrective and Preventive Action Plan Based on 5M1E Root Causes

No.	Root Cause	Corrective/ Preventive Action	PIC	Target	Success Indicator
1.	The freezer temperature sensor is inaccurate	Install/verify the digital PT-100 sensor and conduct initial calibration	Engineering & QC	2 weeks	Temperature stable within ±0.5°C
2.	Freezer gasket or panel leakage	Repair the gasket/panel and include hardening the freezer in preventive maintenance	Maintenance	1 week	No cold-air leakage detected
3.	Hardening time is inconsistent	Define standard hardening time, temperature, and batch-capacity limit	Production & QC	1 week	Hardening compliance ≥95%
4.	Mixing SOP is too general	Revise the visual SOP with rpm, sequence, duration, and viscosity target	QC & Production	2 weeks	Viscosity variation reduced by≥30%
5.	Operator technical capability is uneven	Train operators in ice cream process control and measuring instruments	HRD & Supervisor	1 month	100% of operators pass the post-test
6.	Moisture testing is manual and infrequent	Use a moisture analyzer and inspect every batch	QC	2 weeks	Moisture data available per batch
7.	Temperature and humidity are not monitored in real time	Install data loggers in production, packing, and cold-storage areas	Engineering	3 weeks	RH ≤65%; cold storage stable
8.	Calibration is not routine	Create a monthly calibration schedule for critical instruments	QC & Maintenance	1 month	100% of critical instruments are calibrated

Table 11. Projected Defect Reduction After CAPA Implementation

Defect Type	Before CAPA (units)	Projected After CAPA (units)	Reduction (units)	Reduction (%)
Non-uniform texture	184	62	122	66.3
Excessive moisture content	142	47	95	66.9
Uneven color	97	38	59	60.8
Non-standard portion size	76	28	48	63.2
Damaged packaging	54	24	30	55.6
Deviating aroma	38	16	22	57.9
Uneven inclusion distribution	24	9	15	62.5
Misapplied label	15	6	9	60.0
Total	630	222	408	64.8

Table 12. Quality Indicator Comparison Before and After Projected Improvement

Indicator	Before Improvement	After Improvement	Interpretation
Defect Rate	2.13%	0.75%	Defect proportion moves below the internal tolerance of 1.5%.
DPMU	21,334	7,518	Defects per one million production units.
DPMO (8 CTQ Opportunities)	2,667	940	Defects per one million quality opportunities.
Failure Cost	IDR 22.05 million	IDR 7.77 million	Estimated failure-cost saving of IDR 14.28 million per semester.
Total Reduction	-	64.8%	Expected effect of integrated machine, method, measurement, and human improvements.

The projected implementation of all eight actions would reduce total defects from 630 to 222 units per semester, equivalent to a 64.8% reduction. DPMU would decrease from approximately 21,334 to 7,518, while DPMO, based on eight CTQ opportunities, would decrease from approximately 2,667 to 940. The analysis indicates that technical-mechanical improvements should be implemented first because sensor accuracy, freezer integrity, and hardening standardization directly affect the two dominant defects [7] [8] [9] [10] [16] [14] [11].

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IV. CONCLUSION

Based on 29,530 produced units and 630 defective units, the aggregate defect rate was 2.13%, exceeding the company's tolerance of 1.5%. Pareto analysis identified four vital few defects that accounted for 79.21% of total defects: non-uniform texture, excessive moisture content, uneven color, and non-standard portion size. Fishbone analysis showed that the dominant root causes were related to machine, method, measurement, and human factors, especially freezer-temperature sensor drift, worn freezer gaskets, inconsistent hardening time, weak mixing SOP, irregular calibration, and insufficient operator training.

The SPC analysis indicates that the monthly defect proportions were statistically in control but not capable of meeting the internal target, because the center line remained above 1.5%. This interpretation changes the improvement focus from short-term sorting to system-level standardization, calibration, preventive maintenance, and process monitoring. The corrected terminology also clarifies that 21,334 is DPMU, while DPMO is 2,667 when eight CTQ opportunities are considered.

The addition of Cost of Quality analysis shows that poor quality creates measurable economic losses through rework, scrap, additional labor, additional freezing energy, and complaint reserves. The projected CAPA can reduce defects from 630 to 222 units per semester, decrease defect rate from 2.13% to 0.75%, reduce DPMU from 21,334 to 7,518, reduce DPMO from 2,667 to 940, and generate estimated failure-cost savings of IDR 14.28 million per semester before improvement investment. A minimum real improvement was specified through hardening-control checklist, PT-100 verification, batch-capacity limitation, and operator briefing. Future research should validate the projected reduction using post-implementation data, integrate FMEA for RPN-based prioritization, and develop IoT-based real-time monitoring of temperature, humidity, viscosity, and hardening time.

REFERENCES

[1] P. Giudici, A. Baiano, P. Chiari, L. De Vero, B. Ghanbarzadeh, and P. M. Falcone, “A Mathematical Modeling of Freezing Process in the Batch Production of Ice Cream,” *Foods*, vol. 10, no. 334, pp. 1–35, 2021, [Online]. Available: https://www.mdpi.com/journal/foods.

[2] C. O. F. Practice, *GENERAL PRINCIPLES OF FOOD HYGIENE (CXC-1969)*. 2023.

[3] 22000. INTERNATIONAL STANDARD, *Food safety management systems — Requirements for any organization in the food chain*, vol. 2018. 2018.

[4] G. Akarca, M. Kilinç, and A. Janseli, “Quality specification of ice creams produced with different homofermentative lactic acid bacteria,” *Food Sci. Nutr.*, vol. 3762, no. September, pp. 1–12, 2023, doi: 10.1002/fsn3.3762.

[5] Badan Pengawas Obat dan Makanan; Republik Indonesia., *PERATURAN BADAN PENGAWAS OBAT DAN MAKANAN NOMOR 31 TAHUN 2018 TENTANG LABEL PANGAN OLAHAN*. 2018, pp. 1–43.

[6] A. Harfoush, Z. Fan, L. Goddik, and K. R. Haapala, “A Review of Ice Cream Manufacturing Process and System Improvement Strategies,” *Manuf. Lett.*, vol. 41, pp. 170–181, 2024, doi: 10.1016/j.mfglet.2024.09.021.

[7] J. Antony, R. Snee, and R. Hoerl, “Lean Six Sigma: yesterday, today and tomorrow,” *Int. J. Qual. Reliab. Manag.*, vol. 34, no. 7, pp. 1073–1093, 2017, doi: https://doi.org/10.1108/IJLSS-12-2015-0050.

[8] Z. I. M, J. L. Allison, and W. W. H, “Monitoring univariate processes using control charts Some practical issues and advice Monitoring univariate processes using control charts : Some practical issues and advice,” *Qual. Eng.*, vol. 36, no. 3, pp. 487–499, 2024, doi: 10.1080/08982112.2023.2238049.

[9] W. H. Colosimo, B. M.; Jones-Farmer, L. A.; Megahed, F. M.; Paynabar, K.; Ranjan, C.; Woodall, “Statistical Process Monitoring from Industry 2 . 0 to Industry 4 . 0 : Insights into Research and Practice,” *Technometrics*, pp. 1–56, 2024.

[10] L. Chen and S. Yang, “A New p -Control Chart with Measurement Error Correction,” vol. 10, no. 4, pp. 1–31, 2022.

[11] D. L. Goetsch and S. Davis, *Quality Management for Organizational Excellence: Introduction to Total Quality*, Seventh. United States of America: Pearson Education Limited, 2014.

p-ISSN 2622-2027
DOI: https://doi.org/10.36456/tibuana.9.02.11584 *e*-ISSN 2622-2035

[12] D. H. BESTERFIELD, C. BESTERFIELD-MICHNA, G. H. BESTERFIELD, M. BESTERFIELD-SACRE, H. URDHWARESHE, and R. URDHWARESHE, *Total Quality Management*, Third. Delhi.

[13] D. C. MONTGOMERY, *Introduction to Statistical Quality Control*. 2013.

[14] T. Pyzdek, *The Six Sigma Handbook*, Second Edition. United States of America: The McGraw-Hill Companies, Inc., 2003.

[15] D. S. Ramadhani and B. D. Ifalda, "Analisis Pengendalian Kualitas Produksi Gula dengan Pendekatan Six Sigma pada PT . Sinergi Gula Nusantara," *J. Manaj. Dan Teknol. Rekayasa*, vol. 0741, pp. 17–26, 2025, doi: 10.28989/jumantara.v4i1.2832.

[16] N. R. Tague, *The Quality Toolbox*. 2023.

[17] Y. Erdhianto, "QUALITY CONTROL ANALYSIS TO REDUCE THE NUMBER OF DEFECTS IN THE PACKAGING OF PG KREMBOONG SUGAR PRODUCTS USING SEVEN TOOLS METHOD," *TiBuana J. Appl. Ind. Eng. PGRI AdiBuana*, vol. 04, no. 1, pp. 28–35, 2021, [Online]. Available: https://doi.org/10.36456/tibuana.4.01.3174.28-35.

[18] T. Koesdijati and Y. D. Nurcahyanie, "APPROACH OF SIX SIGMA METHOD TO CONTROL THE QUALITY OF WET MIX PRODUCTS IN THE CREAM MAKING PROCESS," *Tibuana J. Appl. Ind. Eng. PGRI Adi Buana*, vol. 2, no. 2, pp. 50–57, 2019.

[19] Y. D. Nurcahyanie and T. Koesdijati, "DISABLED ANALYSIS OF CERAMIC PRODUCTS ON THE GLASS PROCESS USING THE SEVEN TOOLS METHOD (CASE STUDY : PT NJMX SURABAYA)," *Tibuana J. Appl. Ind. Eng. PGRI Adi Buana*, vol. 3, no. 1, pp. 53–60, 2020.

[20] I. Bahroni and S. Suparno, "CALCULATION OF VALUE OF OVERALL EQUIPMENT EFFECTIVENESS AS A BASIS OF PRODUCTIVITY IMPROVEMENT PROCESS SHEARING LEAF SPRING IN PT INDOSPRING TBK GRESIK," *TiBuana J. Appl. Ind. Eng. PGRI Adi Buana*, vol. 02, no. 1, pp. 21–32, 2019.

[21] S. Fatimah and H. C. Wahyuni, "Product Quality Control Using Six Sigma Methods and Seven Tools in the PDL Shoes Industry," *Tibuana J. Appl. Ind. Eng. PGRI Adi Buana*, vol. 06, no. 1, pp. 12–22, 2023, [Online]. Available: https://doi.org/10.36456/tibuana.6.1.6174.12-22.

[22] P. H. da S. Santos, C. K. Suzuki, and S. C. da S. Lannes, "Structural Properties Before and After Ripening of Ice Cream Made with Different Dairy Fat Bases," *Foods*, vol. 14, no. 3276, pp. 1–21, 2025.

[23] L. Sun, Z. Zhu, and D. Sun, "Regulating Ice Formation for Enhancing Frozen Food Quality : Materials, Mechanisms and Challenges," *Trends Food Sci. Technol.*, vol. 139, no. July, p. 104116, 2023, doi: 10.1016/j.tifs.2023.07.013.