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Employing Statistical Control Charts to Enhance the Quality of Bread Loaf Weight: An Applied Study on Bakeries in Zliten City

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استخدام خرائط المراقبة الإحصائية للارتقاء بجودة وزن رغيف الخبز: دراسة تطبيقية على مخابز مدينة زليتن

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Abstract:
The quality and weight of a bread loaf are essential factors in ensuring consumer satisfaction and institutional reliability. This study aimed to evaluate the quality and weight of a bread loaf in Zliten city using statistical monitoring maps to ensure process stability and adherence to specifications. The research methodology relied on the descriptive-analytical approach, where random samples of loaf weights were collected from 40 bakeries across different geographical areas of Zliten during the year 2024 AD. The statistical program MINITAB was employed to construct and analyze statistical control maps for the arithmetic mean (X-chart) and the range (R-chart) to monitor the production process. Initial results indicated the presence of several points outside the control limits in both the mean and range maps, suggesting that the manufacturing process was initially not statistically controlled due to unfamiliar sources of variation. To achieve a state of statistical stability, the points outside the control limits were identified and deleted, and the maps were redrawn until stabilization was reached. After adjustment, the arithmetic average map settled with an upper control limit (UCL) of 115.72 and a lower control limit (LCL) of 96.39. Meanwhile, the range map settled at an upper limit of 40.08 and a lower limit of 0. The study concluded that control maps are accurate tools for monitoring the bread-making process and determining conformity to standards. It recommended that responsible authorities continuously update these maps, train specialized technical staff, and periodically calibrate the machinery used in the manufacturing process to maintain high-quality production.

Keywords: Control map; Quality control; Weight of a loaf of bread; Bakeries; Zliten city.

الملخص:
تعد جودة ووزن رغيف الخبز من العوامل الأساسية لضمان رضا المستهلك وموثوقية المؤسسات. هدفت هذه الدراسة إلى تقييم جودة ووزن رغيف الخبز في مدينة زليتن باستخدام خرائط المراقبة الإحصائية

لضمان استقرار العملية والالتزام بالمواصفات. اعتمدت منهجية البحث على المنهج الوصفي التحليلي، حيث تم جمع عينات عشوائية لأوزان الأرغفة من 40 مخبزاً موزعة على مناطق جغرافية مختلفة في زليتن خلال عام 2024م. تم استخدام البرنامج الإحصائي MINITAB لإنشاء وتحليل خرائط الضبط الإحصائي للمتوسط الحسابي (خارطة -X) والمدى (خارطة R) لمراقبة عملية الإنتاج. أشارت النتائج الأولية إلى وجود عدة نقاط خارج حدود الضبط في كل من خرائط المتوسط والمدى، مما يشير إلى أن عملية التصنيع لم تكن مضبوطة إحصائياً في البداية بسبب مصادر تباين غير مألوفة. ولتحقيق حالة من الاستقرار الإحصائي، تم تحديد وحذف النقاط الخارجة عن حدود الضبط وإعادة رسم الخرائط حتى تم الوصول إلى حالة الاستقرار. وبعد التعديل، استقرت خارطة المتوسط الحسابي بحد ضبط علوي قدره 115.72 وحد ضبط سفلي قدره 96.39. وفي الوقت نفسه، استقرت خارطة المدى عند حد علوي قدره 40.08 وحد سفلي قدره 0. خلصت الدراسة إلى أن خرائط المراقبة هي أدوات دقيقة لمتابعة عملية صنع الخبز وتحديد مدى مطابقتها للمعايير. وأوصت بضرورة قيام الجهات المسؤولة بتحديث هذه الخرائط باستمرار، وتدريب كوادر فنية متخصصة، ومعايرة الآلات المستخدمة في عملية التصنيع بشكل دوري للحفاظ على إنتاج عالي الجودة.

الكلمات المفتاحية :خريطة المراقبة؛ ضبط الجودة؛ وزن رغيف الخبز؛ المخابز؛ مدينة زليتن.

Introduction

Quality control is one of the topics that aims to enhance consumer confidence in the products of industrial and service facilities, and it is the cornerstone of any industry or service. Employing advanced technology for the benefit of the production process and applying the approach to statistical control maps in all production and service institutions in various countries is extremely important. This system is used in services that affect the daily livelihood of the citizen, which can be applied in monitoring bakeries within the city. This is considered one of the important and necessary matters and things that should be given importance and have the greatest attention in this context. The quality of the good loaf in bakeries in the required form is an important matter; thus, the need arose to apply the quality approach in bakeries through the use of statistical control maps in order to improve the bread production level (Al-Baldawi, 2004).

Many studies have dealt with the topic of statistical quality. For instance, the study of Muhammad and Ahmed (2017) dealt with the use of statistical methods in monitoring production quality with a practical application. In that study, work was done to study the problem of the production situation in a factory and the performance level of some sections, determine the extent to which production conforms to specifications, diagnose defects, and apply the Six Sigma method and control maps to evaluate production and the performance of the sections in an electrical transformer production factory. It was found that the factory has production specifications of up to 4 Sigma. It also reached a diagnosis of the level of production efficiency for some sections of the factory in order to work to bridge the gap between the current specifications and the level of customer satisfaction with production.

The study of Muhammad and Azouz (2015) dealt with quality control using horizontal and vertical analysis of statistical control panels, an applied study in one of the cement companies affiliated with the Iraqi Ministry of Industry and Minerals. This study included statistical control methods in controlling the production process and identifying cases of non-conformity and the state of transition in the average process. Through the application of the average panel and the standard deviation of the specific surface characteristic of the cement produced, it was found that the process is statistically uncontrolled; by applying the horizontal and vertical analysis method, it became clear that there are some important indicators that were discovered. Also, the use of the normal distribution curve with quality control panels, especially in the case of vertical analysis, led to good results.

Khalil's study (2014) dealt with the use of quality control maps in analyzing the drinking water of the Essaouira Technical Institute. This study included two aspects: the theoretical aspect, in which the statistical observation maps were reviewed, namely the arithmetic mean map, the range map, the standard deviation map, and the common aggregate standard deviation map. As for the applied aspect, it included an analysis of the data recorded from the readings of the water complex laboratory at the Technical Institute / Essaouira regarding pH, turbidity (NTU), dissolved substances (TDS), and chlorine (Cl_2), by applying the above-mentioned maps.
The study of Ali and Muhammad (2013) dealt with statistical control of the quality of concrete blocks. The study dealt with a detailed explanation of the types of statistical control maps, their importance, the advantages of using them, and the method of working with them, in addition to the types, advantages, and uses of concrete blocks as a theoretical aspect. It explained how to use control maps in making appropriate decisions regarding the production process of manufacturing concrete blocks and how they help to study the changes that occur in the properties of the materials or qualities studied, as they help to make these changes a minimum for monitoring or remove them. Their use leads to them remaining in conformity with the required specifications as a practical aspect of the research.
Muhammad's (2010) study dealt with the role of knowledge management processes in activating statistical control methods on quality, a case study in the General Company for the Manufacture of Pharmaceuticals and Medical Supplies in Nineveh. This study concluded with a number of results that enhance the use of the concept of knowledge management in activating the application of statistical methods to control quality. The most important result was that the organization under study has an orientation towards quality by adopting a policy of error prevention, as well as presenting the obstacles that the organization faces in the application process. The study of Muhammad and Sami (2007) dealt with the use of quality methods and tools in controlling the production process in industrial business organizations. This study concluded that the production process in the General Tire Company is characterized by several stages, starting with the preparation stage and ending with the installation process, meaning that the stages complement each other. Quality control starts from detecting internal objections and continues to the final consumer customer. There are also several tools and means to improve the quality of the product, including statistical methods to detect control or non-control of the production process, such as the arithmetic mean (X) and range (R) maps.
Accordingly, the problem of the study is the difference in the weights of loaves of bread in the city of Zliten in particular and Libya in general, with the absence of a fixed scientific standard for monitoring weights, which leads to instability in the quality of the product. This, in turn, has a negative impact on consumer satisfaction. The importance of the study lies in the extent to which the application of quality statistical control maps can benefit the improvement of production and services to consumers. This study is an attempt to draw the attention of those in charge of bakery affairs to the possibility of benefiting from the techniques of statistical methods used in quality control to control the quality of their bread products, so that the machines used become capable of producing the product according to the specified specifications. In addition, it aims to determine scientific standards to control the weights of loaves of bread and to educate those in charge of bakery affairs to benefit from studying points outside the control limits. This study aims to know the concept, importance, and stages of statistical methods used in quality control, and focus on studying control maps of practical importance in the field of production quality control, including control maps for quantities. In addition, it measures the stability of the weight of a loaf of bread using quality control maps for the arithmetic mean and range, and calibrates the degree of variation and discrepancy in the weight of the loaves of bread produced.
This article reviewed the theoretical framework of quality control in terms of the concept, stages, objectives, standards, and costs of quality, as well as the statistical methods used in the

control process. As for the applied framework, it focused on the statistical analysis of monitoring maps of loaf manufacturing in the city of Zliten in terms of weight.

Theoretical Framework

There are several definitions of quality, including the following:

1) Quality has been defined as the degree of conformity with requirements. The more a product's specifications conform to customer requirements, the higher its quality.

2) The International Standard ISO 9000:2000 defines quality as the degree to which a product's inherited characteristics meet customer requirements.

3) Besterfield defined quality as "the features that meet consumer expectations".

4) Quality, in its general sense, is defined as an organization's output of a good or service at a high level of distinctive quality, enabling it to meet the needs and desires of its customers in a manner consistent with their expectations and to achieve their satisfaction (Besterfield, 2019; Juan & Godfrey, 2010).

Definition of a Control Chart: A control chart is defined as a graphical method that illustrates the upper and lower limits of acceptable quality levels. Samples of production are taken at different intervals, examined, and the quality characteristic is measured, with the value of this characteristic recorded on the graph (Qazzaz & Abdel-Malek, 1997).

Components of a Control Chart: It consists of three horizontal lines drawn on the vertical axis. The middle line represents the required quality level of the production processes and is called the Central Control Limit (CCL). The upper line represents the Upper Control Limit (UCL), and the lower line represents the Lower Control Limit (LCL) (Ismail, 2006).

Objectives of Control Charts: Control charts are primarily used to monitor processes, aiming to minimize variations in their outputs. A control chart is a diagnostic tool that measures process performance and determines the extent of its stability (Aqili, 2001).

Types of Control Charts: Control charts can be classified according to the type of data they contain into two types: quality control charts and quantitative variable control charts. Variable control charts are used when the quality of the product is a characteristic that can be practically measured and expressed numerically; that is, it measures properties that can be measured in units such as weight, length, width, thickness, temperature, time, speed, etc. Its objectives include improving quality, determining process capabilities, and making decisions related to product specifications and production processes. There are a number of charts for variables, and two types have been used in this study: mean control charts (X-Charts) and range control charts (R-Charts) (Montgomery, 2020; Oakland, 2014).

Arithmetic Mean ($\overline{x}$) Chart)

prepare control charts for the arithmetic mean. We know that if X is a random variable then the ,σ and standard deviation μ following a normal distribution with a mean arithmetic mean is also a random variable following a normal distribution, but with a mean both and are unknown, then control σ^2 ، μ If . $\sigma_{\overline{x}} = \frac{\sigma}{\sqrt{n}}$ and standard deviation μ

σ^2 ، μ charts in this case are found by estimating

from samples of production as follows:

1. Take $k \geq 25$ .samples of production with a sample size of n individual samples

2. $\overline{X}_1, \overline{X}_2, \overline{X}_3, \ldots, \overline{X}_k$ Calculating the arithmetic means of these samples .

3. Estimating the mean using the estimator $\overline{\overline{X}} = \frac{1}{k}\sum_{i=1}^{k}\overline{X}_i \rightarrow (1)$.

As for the variance, it is estimated based on the range R or the standard deviation (S) (Evans & Lindsay, 2017; Omari & Al-Ujaili, 2000).

Estimation Using the Range (R σ):
The control limits for the arithmetic mean using the range are defined as follows:

Lower control boundary $LCL = \overline{\overline{X}} - 3\frac{\overline{R}}{d_2\sqrt{n}} \rightarrow (2)$

Middle control boundary $CL = \overline{\overline{X}} \rightarrow (3)$

Upper control boundary $UCL = \overline{\overline{X}} + 3\frac{\overline{R}}{d_2\sqrt{n}} \rightarrow (4)$

The value d_2 is a statistical constant that depends on the sample size n, derived from the relationship:

$$E(\frac{\hat{R}}{d_2}) = \sigma$$

To simplify calculations, the factor A2 is used, which incorporates the constants 3, d2, and n into a single value that varies with n:

$$A_2 = \frac{3}{d_2\sqrt{n}}$$

Consequently, the simplified control limits are expressed as follows:

- **Lower Control Limit (LCL):** $LCL = \overline{\overline{X}} - A_2\overline{R} \rightarrow (5)$
- **Central Control Limit (CCL):** $CL = \overline{\overline{X}} \rightarrow (6)$
- **Upper Control Limit (UCL):** $UCL = \overline{\overline{X}} + A_2\overline{R} \rightarrow (7)$

This method is typically used provided that the sample size n does not exceed 10 items; for larger samples, the standard deviation chart (S-chart) is preferred (Oakland, 2014; Montgomery, 2020).

Range Chart (R-Chart)

The range chart is used to measure the precision and dispersion of process outputs, as it reflects the variations in the range values of subsets. The range (*R*) of a sample of size *n*, consisting of values $X_1, X_2, ..., X_n$, is defined as the difference between the largest and smallest values:

$$R = X_{max} - X_{min}$$

In practice, determining the exact distribution of *R* is complex; however, a direct relationship exists between the sample range and the standard deviation(σ) when drawn from a normal population. The relative range (*W*) is defined as:

$$W = \frac{R}{\sigma}$$

The mean of this relative range is denoted as d_2.

Estimation of Control Limits:

If we have k samples with ranges $R_1, R_2, ..., Rk$, the average range ($\bar{R}$) is calculated as:

$$\bar{R} = \frac{R_1 + R_2 + ... + R_k}{k}$$

Since the process parameters are often unknown, they must be estimated. The standard deviation of the range is related to the process standard deviation by the constant d_3 (σ R = d_3 σ. Using the estimator $\hat{\sigma} = \frac{\bar{R}}{d_2}$, the control limits are established as:

- **Lower Control Limit (LCL):** $LCL = \bar{R}(1 - 3d_3 \frac{1}{d_2}) = R - 3d_3 \frac{\bar{R}}{d_2} \rightarrow (11)$
- **Central Control Limit (CCL):** $CL = \bar{R} \rightarrow (12)$
- **Upper Control Limit (UCL):** $UCL = \bar{R}(1 + 3d_3 \frac{1}{d_2}) = R + 3d_3 \frac{\bar{R}}{d_2} \rightarrow (13)$

To simplify the calculations for quality control practitioners, these formulas are standardized using the constants D_3 and D_4:

$$D_3 = (1 - 3d_3 \frac{1}{d_2})$$

$$D_4 = (1 + 3d_3 \frac{1}{d_2})$$

Consequently, the final R-chart boundaries are:

- **Lower Control Limit (LCL):** $D_3 \bar{R}$
- **Central Control Limit (CCL):** $\bar{R}$
- **Upper Control Limit (UCL):** $D_4\bar{R}$

The values for D_3 and D_4 are extracted from standard statistical control chart tables (Evans & Lindsay, 2017; Omari & Al-Ujaili, 2000).

Practical Aspect

Data for the study were collected through field visits to forty bakeries geographically distributed across the city of Zliten. The weight of bread loaves was measured using a high-precision scale. This study employed a descriptive-analytical methodology to analyze the collected data and evaluate production stability using two types of control charts: the Mean chart (X) and the Range chart (R).

Table (1): Arithmetic Mean and Standard Deviation of Bread Loaf Weights (in grams).

Bakery No.	Mean	SD	Bakery No.	Mean	SD
1	92.5	4.8	21	107.7	2.4
2	141.0	8.1	22	91.5	4.8
3	98.5	8.9	23	104.7	5.4
4	106.8	6.0	24	91.3	13.8
5	108.0	3.2	25	109.7	5.7
6	113.5	4.5	26	96.7	5.4
7	110.7	11.4	27	94.0	5.1
8	104.7	5.8	28	120.5	9.4
9	108.5	6.9	29	96.2	8.8
10	112.8	10.1	30	136.7	8.7
11	93.8	3.1	31	90.3	9.2
12	99.7	5.2	32	104.5	7.3
13	106.5	4.1	33	112.2	15.6
14	113.7	4.0	34	100.7	9.1
15	108.0	7.4	35	108.0	13.6
16	108.5	14.9	36	95.8	11.1
17	96.3	3.7	37	97.0	7.9
18	107.8	7.4	38	120.5	19.6
19	99.3	7.0	39	101.7	14.1
20	114.7	4.4	40	111.0	4.1

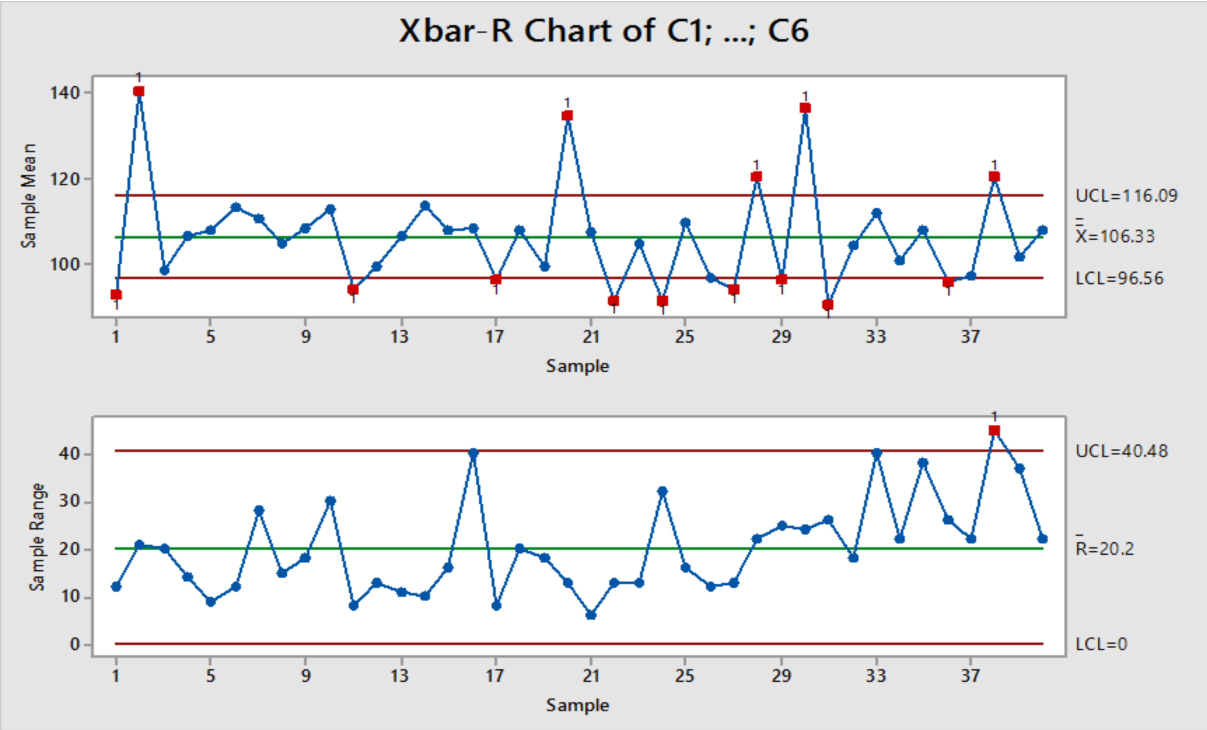

Figure (1) shows the mean and range map from the output of the Minitab program.

The researchers utilized the Minitab statistical software to generate the initial monitoring maps.

- **Arithmetic Mean Chart (X):** The limits were set at LCL = 96.56 and UCL = 116.09, with the grand mean at 106.33. Several points were found outside these boundaries, indicating that the process was not in a state of statistical control.
- **Range Chart (R):** The limits were set at LCL = 0 and UCL = 40.08. Bakery number 38 fell outside the control range, signifying high variability in that specific production batch.

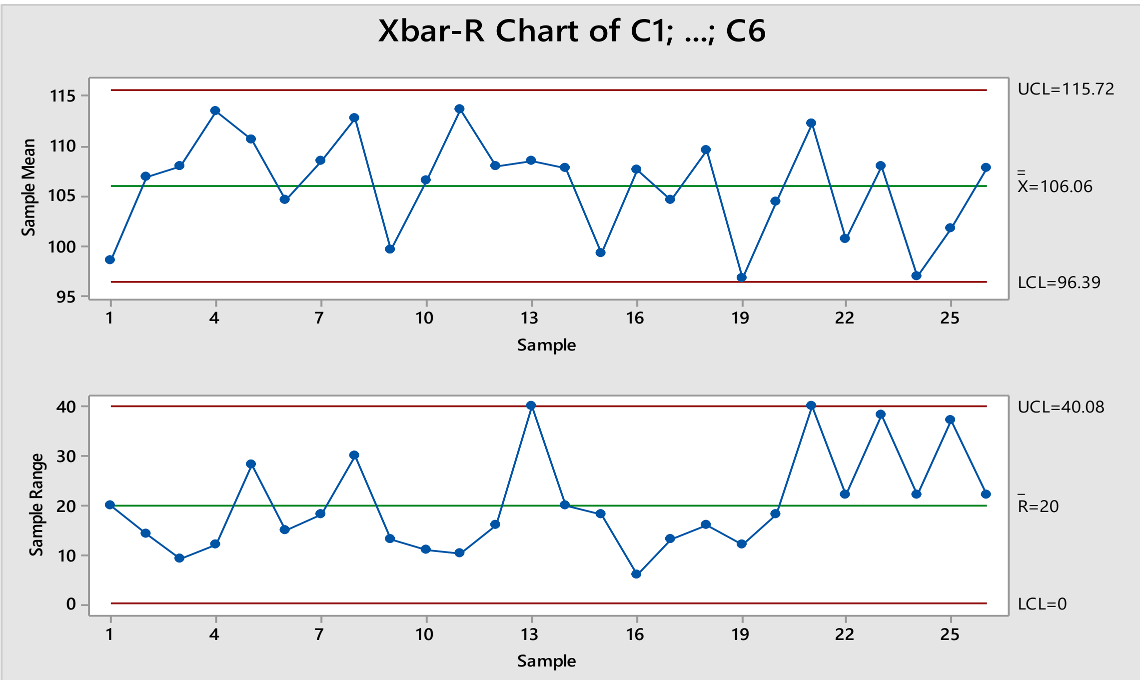

Figure (2) shows the mean and range map from the output of the Minitab program.

Following the identification of instability, the researchers excluded the out-of-control points to re-evaluate process potential.

- **Arithmetic Mean Chart (X):** The revised limits were LCL = 96.39, Center = 106.06, and UCL = 115.72. After refinement, all points were within the control limits, showing no irregular patterns.
- **Range Chart (R):** The refined limits remained stable (LCL = 0, Center = 20, UCL = 40.08), with all points falling within the limits, indicating that the variation is now statistically controlled.

Results and Discussion

1. **Efficiency of Statistical Diagnostic Tools:** The study demonstrates that statistical control charts (X and R charts) function as highly precise diagnostic instruments for overseeing the bread-manufacturing lifecycle. These tools provide a systematic framework for verifying whether production outputs strictly adhere to predetermined weight specifications and quality standards, moving beyond traditional subjective inspection methods.
2. **Optimization of Production Consistency:** The integration of statistical control methods is indispensable for ensuring operational consistency and minimizing economic waste. By reducing the variance in loaf weights, bakeries can mitigate the loss of raw materials (overweight loaves) and prevent consumer dissatisfaction or regulatory penalties (underweight loaves), thereby enhancing overall production efficiency.
3. **Identification of Assignable Causes of Variation:** Initial analytical phases revealed significant process instability. The control charts successfully isolated "assignable causes"—non-random factors such as mechanical malfunctions, inconsistent raw material quality, or human error. The ability of these charts to distinguish between natural process "noise" and actionable "signals" is a critical finding for maintaining quality.
4. **Attainment of Statistical Process Stability:** Through the iterative process of identifying and removing statistical outliers (anomalies) and subsequently recalculating control limits, the manufacturing process successfully transitioned to a state of statistical stability. This refined state allows for predictable future performance, ensuring that the process remains within a defined "in-control" range of 96.39g to 115.72g.
5. **Technical Capacity Building and Precision:** Evaluation of performance levels serves as a catalyst for developing the technical competencies of bakery personnel. By providing objective feedback through data visualization, the study underscores that increasing the precision of manufacturing processes is directly linked to the continuous monitoring and training of the workforce.

Recommendations

1. **In-depth Root Cause Investigation:** It is imperative that regulatory authorities and bakery management conduct thorough investigations into the specific triggers of out-of-control points. Whether the cause is equipment degradation, fluctuations in flour quality, or environmental factors, targeted corrective actions must be implemented to eliminate these systemic errors.

2. **Institutionalizing Continuous Monitoring:** Regulatory bodies should move toward the institutionalization of statistical control charts as a standard for regular quality audits. These maps should not be static; they must be updated continuously to reflect process improvements and changing technological standards within the industry.
3. **Real-Time Process Standardization:** To ensure maximum consumer protection, real-time monitoring maps should be deployed directly at the production site in every bakery. This proactive approach facilitates the immediate detection of deviations, preventing non-conforming, underweight products from reaching the market.
4. **Advanced Technical Training Initiatives:** Educational institutions and vocational centers should collaborate to establish specialized technical programs. These programs should focus on training staff in the application of Statistical Quality Control (SQC) methodologies and the operation of modern, automated manufacturing machinery.
5. **Rigorous Calibration and Maintenance Protocols:** To maintain long-term process stability, strict protocols for the periodic calibration of high-precision weighing scales and production machinery must be enforced. Regular preventive maintenance is essential to ensure that mechanical wear does not introduce new variables into the weight of the final product.

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