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Statistical Quality Control as a Tool for Monitoring and Improving Dimensional Accuracy in Soap Manufacturing

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Abstract

This study examines the application of Statistical Quality Control (SQC) techniques to enhance dimensional consistency, specifically in length and weight in the production of Sunlight Soap at Unilever's Aba Plant. Data were collected from 20 production batches in January 2024 and analyzed using $\bar{X}$ and R control charts, along with process capability indices (C_p and C_{pk}). Analysis revealed that both dimensions were statistically in control, with no significant variation across batches ($p = 0.9875$ for length; $p = 0.939$ for weight). However, while weight measurements exhibited excellent process capability ($C_p = 2.35$, $C_{pk} = 2.31$), length measurements reflected poor capability ($C_p = 0.412$, $C_{pk} = 0.301$), indicating excessive variability. To address this inconsistency, the study recommends equipment recalibration, real-time monitoring, and targeted staff training. The findings contribute a replicable quality control framework aimed at improving product uniformity within fast-moving consumer goods (FMCG) manufacturing environments.

Keywords: Statistical Quality Control; Process Capability; Dimensional Consistency; Control Charts; FMCG Manufacturing

INTRODUCTION

In the fast-moving consumer goods (FMCG) sector, consistent product quality is critical to meet stringent consumer expectations and regulatory standards, ensuring operational efficiency and market competitiveness. Soap production demands dimensional consistency—uniform length, width, and thickness—to enhance visual appeal, streamline packaging, and maintain customer satisfaction. Despite advancements in automation, dimensional deviations persist due to raw material variability, equipment misalignment, or operator error, leading to waste, rework, and potential reputational damage. At the Unilever Aba Plant, dimensional inconsistencies in Sunlight Soap production have emerged as a significant challenge, necessitating a systematic approach to quality control. Statistical Quality Control (SQC) offers a robust framework for monitoring and reducing variability, as demonstrated in manufacturing applications where process stability is critical (Smith and Lee, 2024).

SQC techniques, such as control charts and hypothesis testing, are essential for monitoring production processes by distinguishing common-cause variations (inherent to the system) from special-cause variations (specific issues requiring intervention). Control charts, for instance, enable real-time tracking of process performance, identifying deviations for timely corrective actions. A study by El-Din *et al.* (2020) applied SQC in steel manufacturing, using $\bar{X}$ and R control charts to monitor quality characteristics and improve efficiency, a methodology applicable to soap production. Similarly, integrating SQC with modern Manufacturing Execution Systems (MES) enhances real-time variability detection, supporting precision in automated production lines (Geprom, 2024). These tools are vital for addressing dimensional inconsistencies in FMCG manufacturing, ensuring product uniformity.

Despite SQC's proven effectiveness, its application to geometric dimensions such as length, width, and thickness remains underexplored in soap production. While attributes like weight and chemical composition are commonly studied, dimensional parameters critical for packaging efficiency receive less attention, creating a gap in quality management literature. Current SQC frameworks often lack specificity for individual facilities like Unilever Aba, where automation demands precise, tailored interventions (Kim and Park, 2022). This limitation hinders plant managers' ability to implement effective quality solutions, particularly in complex, automated production environments where dimensional accuracy is paramount.

At Unilever Aba, dimensional inconsistencies in Sunlight Soap production compromise packaging efficiency and increase operational costs. Current reliance on periodic manual inspections fails to detect process anomalies in real time, resulting in delayed interventions and excess scrap. These challenges, driven by factors such as equipment wear and raw material variability, underscore the need for robust SQC techniques to maintain process control and competitiveness. Recent advancements, such as automated quality control systems with real-time dashboards, offer promising solutions for proactive defect identification, achieving high detection rates with minimal false alarms (Wang and Zhang, 2023). Without such measures, the plant risks ongoing inefficiencies and reduced customer satisfaction.

This study addresses both practical and scholarly gaps by evaluating dimensional variability in Sunlight Soap production at Unilever Aba, employing SQC techniques to identify root causes and recommend data-driven improvements. By constructing $\bar{X}$ and R control charts, analyzing process capability, and testing for batch-to-batch differences, the research aims to establish control limits, assess process stability, and ensure compliance with specification limits. These objectives align with modern SQC applications, such as those reducing defects in garment manufacturing through control charts (Tests and Trials, 2022). The study seeks to enhance dimensional accuracy, reduce waste, and improve product quality, offering actionable insights for Unilever Aba and similar FMCG settings.

The significance of this study extends beyond Unilever Aba, providing a replicable framework for dimensional quality control in soap production and comparable manufacturing contexts. Successful SQC applications, such as those integrating statistical methods with automated systems to achieve near-perfect defect detection, highlight the potential for operational improvements (Xu *et al.*, 2022). By focusing on an underexplored aspect of quality management, this research contributes empirical evidence to the SQC literature, supporting industry practices and academic discourse in achieving manufacturing excellence in the competitive FMCG sector.

MATERIALS AND METHODS

This study investigates the application of Statistical Quality Control (SQC) techniques to monitor and improve dimensional consistency in Sunlight Soap production at the Unilever Aba Plant. A descriptive and analytical research design with a quantitative approach was employed to assess process stability and capability for length and weight measurements.

Data were sourced from the Quality Control Department, and analytical tools, including control charts, process capability indices, and one-way ANOVA, were used to achieve the study's objectives. All analyses were conducted using Python in Google Colab, ensuring reproducibility and precision

Data were collected from the Quality Control Department of Unilever Aba Plant, covering Sunlight Soap bars produced in January. The dataset includes measurements of length (cm) and weight (g) from 20 production batches, with each batch comprising five randomly selected soap bars ($n = 5$ per batch, total $n = 100$ per variable). Key variables included:

1. length of soap bars (cm), representing linear dimensions;
2. weight of soap bars (g), indicating mass;
3. batch number $(1\ to\ 20)$, identifying production batches; and
4. observation number (1 to 5), denoting individual measurements within each batch.

Control Charts

Control charts were constructed to monitor process stability, focusing on $\bar{X}$ (mean) and R (range) charts for length and weight measurements. $\bar{X}$ charts tracked shifts in the process mean, while R charts assessed variability within subgroups.

The center line (CL), upper control limit (UCL), and lower control limit (LCL) for $\bar{X}$ charts were calculated as:

$$\mathrm{CL} = \bar{\bar{X}} \tag{1}$$

$$\mathrm{UCL} = \bar{\bar{X}} + A_2 R \tag{2}$$

$$\mathrm{LCL} = \bar{\bar{X}} - A_2 R \tag{3}$$

Where $\bar{\bar{X}}$ is the grand mean, R is the average range, and A_2 is a constant.

For R charts,

$$CL = R \quad (4)$$

$$UCL = D_4R \quad (5)$$

$$UCL = D_3R \quad (6)$$

Where D_3 and D_4 derived from standard tables.

A process is in state of control if all points fall within control limits with no non-random patterns, such as trends or clustering, indicating only common-cause variation.

2.2 Process Capability Analysis

Process Capability Analysis (PCA) evaluated the ability of the stable process to meet specification limits.

The process capability index (C_p) and centered capability index (C_{pk}) were calculated as:

$$C_P = \frac{(USL - LSL)}{6\sigma} \quad (7)$$

$$C_{pk} = Minimum\left(\frac{USL - \bar{X}}{3\sigma}, \frac{\bar{X} - USL}{3\sigma}\right) \quad (8)$$

Where USL and LSL are upper and lower specification limits, μ is the process mean, and σ is the within-subgroup standard deviation. A C_P or $C_{Pk} \geq 1.33$ indicates a capable process with minimal nonconforming output. Histogram can also be used to confirm normality assumptions.

RESULTS

$\bar{X}$ and R Control Charts for Monitoring Sunlight Soap Weight and Height

To evaluate the stability of the Sunlight soap production process, $\bar{X}$ and R control charts were constructed for two critical quality characteristics: weight and height. These charts were implemented in Google Colab. The resulting control charts are presented in Figures 2 through 5, with Figures 2 and 3 illustrating the control charts for weight, and Figures 4 and 5 corresponding to the control charts for height.

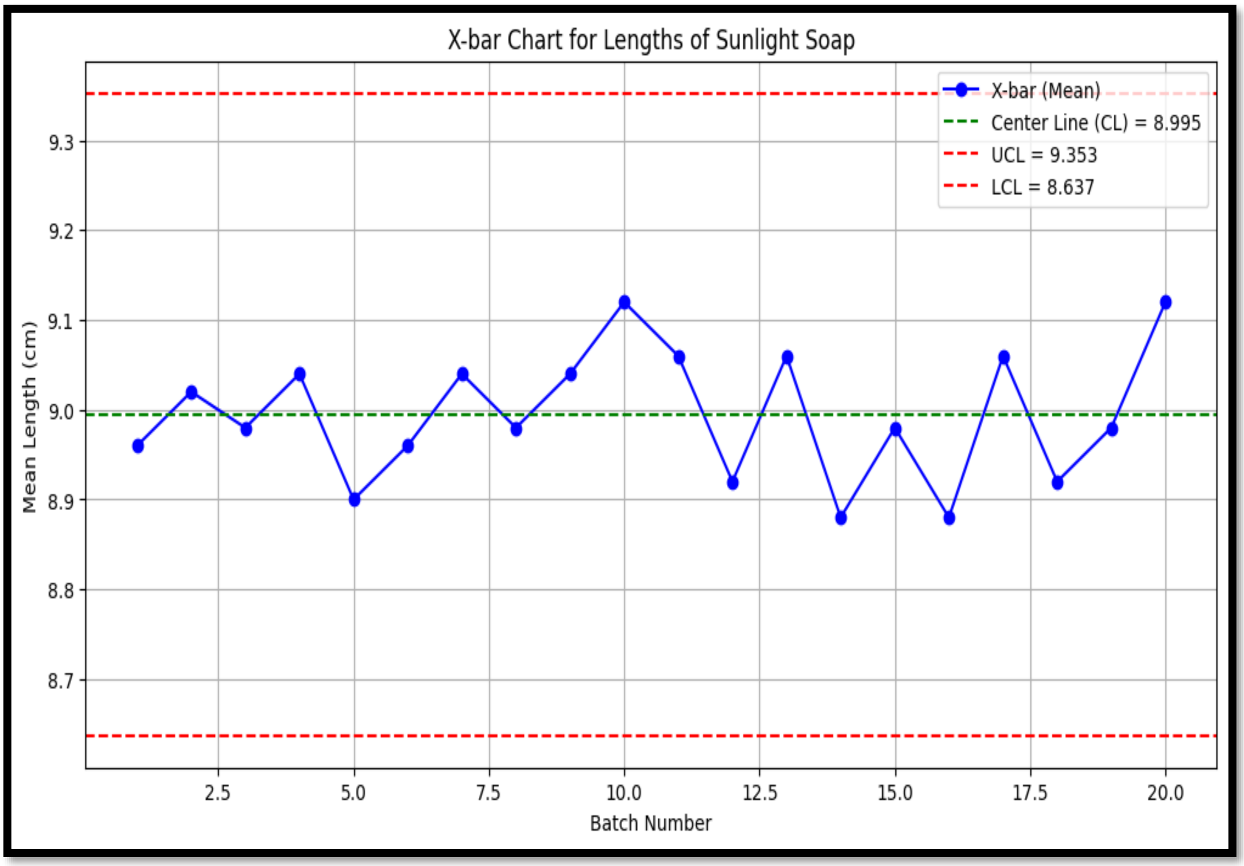

Figure 1: $\overline{\mathrm{X}}$ *Chart for length of Sunlight soap*

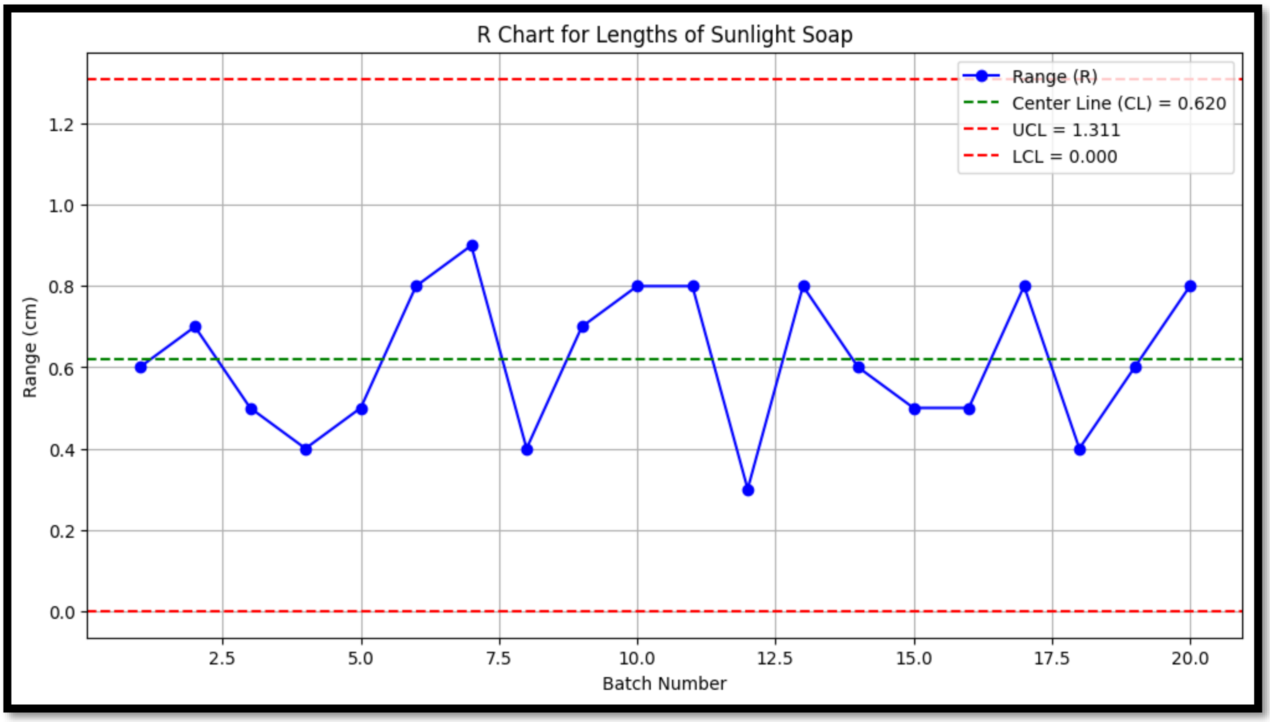

Figure 2: R *Chart for length of Sunlight soap*

Table 1: *Runs Test For:* $\bar{X}$ *and R Chart*

Statistic	Z-Value	P-Value	Conclusion ($\alpha = 0.05$
$\bar{\mathbf{X}}$	1.207	1.000	Random(fail to reject H_0)
R	0.781	0.706	Random(fail to reject H_0)

The $\bar{X}$ and R control charts constructed for monitoring the height of Sunlight Soap exhibit plot points that consistently fall within the established upper and lower control limits. This indicates that there are no signs of instability or variation beyond the expected process behaviour. Furthermore, the application of run tests to both control charts confirms that the plotted data points are randomly distributed within the control limits. There is no evidence of non-random patterns such as trends, cycles, or clustering, which would otherwise suggest special cause variation. Based on these findings, we conclude that the process is statistically in control. This implies that the current production system is operating under stable conditions, and any observed variations are due to common causes inherent in the process rather than assignable or special causes.

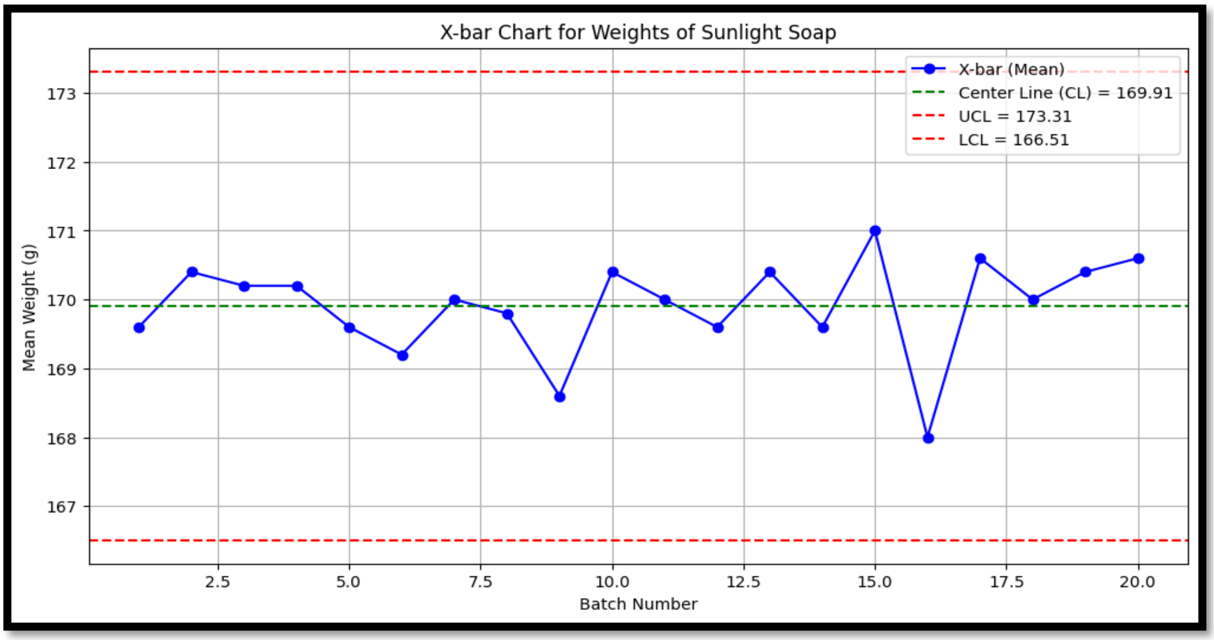

Figure 3: $\bar{X}$ *Chart for Weight of Sunlight soap*

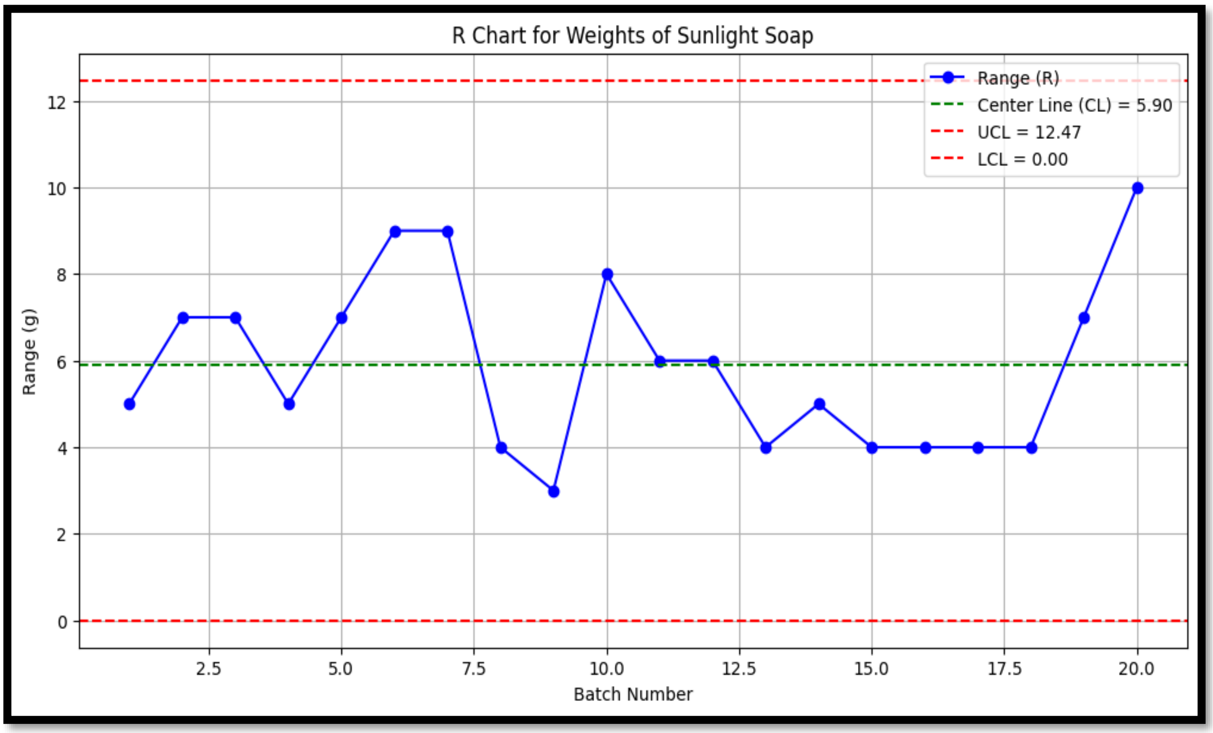

Figure 4: R *Chart for Weight of Sunlight soap*

Table 2: *Runs Test For* $\bar{X}$ *and R Chart*

Statistic	Z-Value	P-Value	Conclusion ($\alpha = 0.05$
$\bar{\mathbf{X}}$	1.207	0.227	Random(fail to reject H_0)
R	0.279	0.781	Random(fail to reject H_0)

The analysis of the Weight of Sunlight Soap through the construction of $\bar{X}$ and R control charts reveals a process that operates within expected statistical boundaries. Specifically, all data points plotted on these control charts consistently remain within the predefined upper and lower control limits, demonstrating that the process does not exhibit any indications of instability or abnormal variation. This adherence to control limits strongly suggests that the production process is behaving predictably and is free from erratic fluctuations that would otherwise signal a deviation from normal operating conditions.

In addition to visual inspection, rigorous statistical run tests were applied to the control charts to assess the randomness of data point distribution. The results of these run tests corroborate that the data points are randomly scattered within the control limits, without displaying any discernible non-random patterns such as upward or downward trends, cyclical variations, or clustering effects. The absence of such patterns further validates the conclusion that no special causes or assignable variations are influencing the process.

Process Capability Analysis for Height and Weight of Sunlight Soap

Following confirmation that both weight and height are in statistical control, as indicated by stable control charts and absence of assignable cause variation, process capability analysis was conducted to assess the ability of the production process to consistently meet specified tolerance limits.

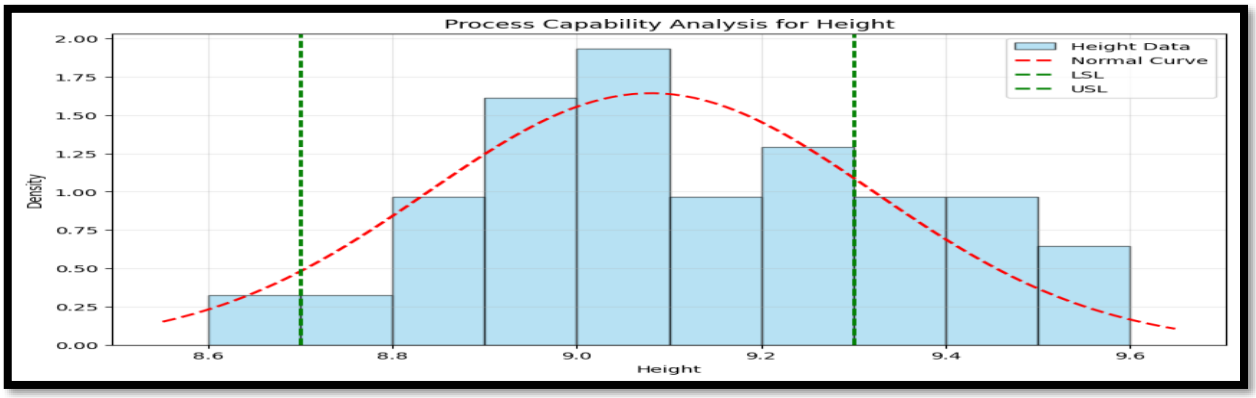

Figure 5: *Process capability Analysis for Height of Sunlight Soap*

Process Mean (μ): 9.081
Process Std Dev (σ): 0.243
C_p: 0.412
C_{pk}: 0.301

The process capability analysis for the height of Sunlight soap bars indicates that the manufacturing process does not consistently meet specified quality requirements. With a process mean of 9.081 cm and a standard deviation of 0.243 cm, the spread of the process is wide relative to the specification range (8.7–9.3 cm). Although the height data approximates a normal distribution centered around the mean, the calculated capability indices, $C_p = 0.412$ and $C_{pk} = 0.301$ reveal inadequate performance. The low C_p indicates excessive process variation, while the even lower C_{pk} reflects both poor centering and high variability.

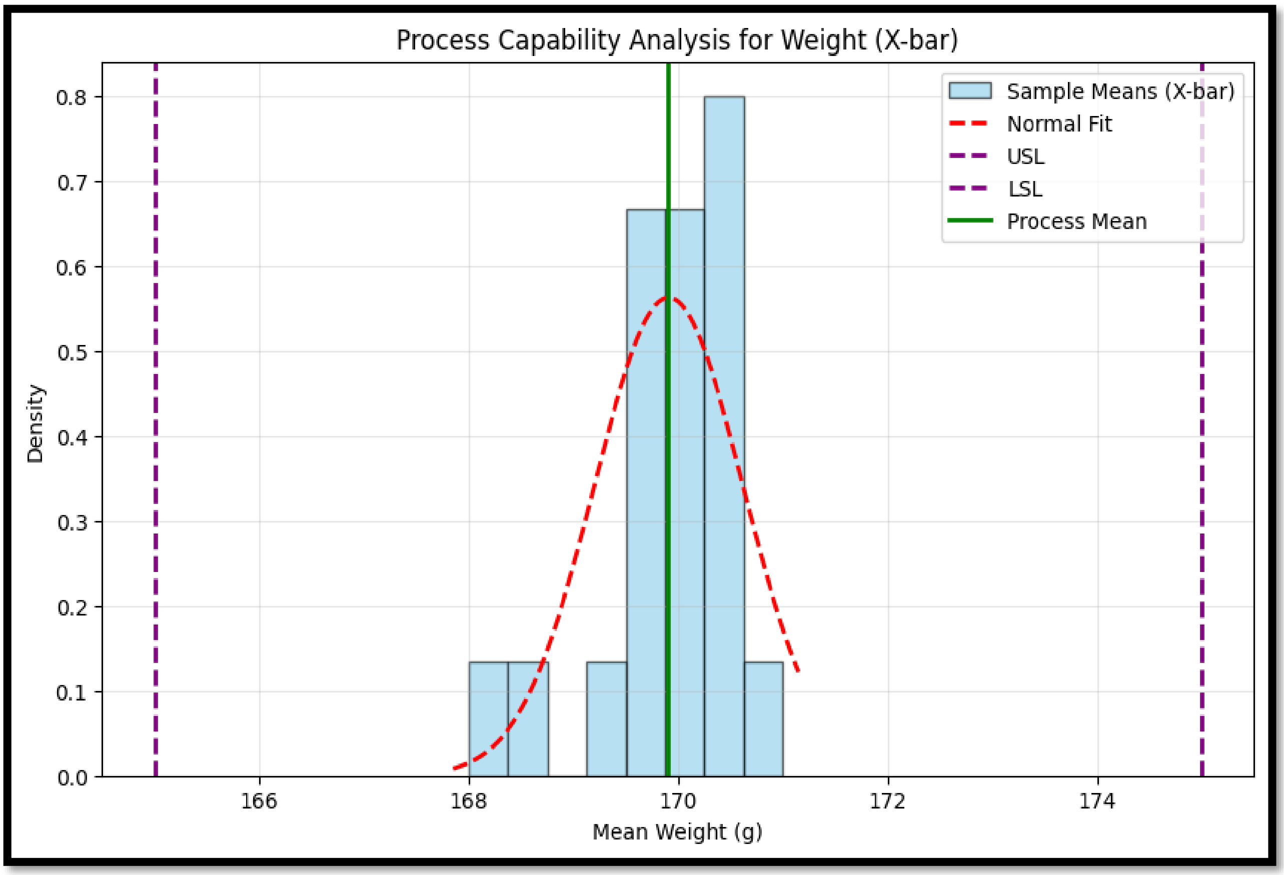

Figure 6: *Process capability Analysis for Weight of Sunlight Soap*

Process Mean (μ): 169.91
Process Std Dev (σ): 0.71
Cp: 2.35
Cpk: 2.31

The process capability analysis for the weight of Sunlight Soap, based on a histogram with an overlaid normal curve, demonstrates a highly capable and well-controlled manufacturing process. The process mean is 169.91 grams with a standard deviation of 0.71 grams. A C_p value of 2.35 indicates that the process variation is substantially narrower than the specification range of 165 to 175 grams, reflecting excellent potential to meet specifications. The C_{pk} value of 2.31 further confirms that the process is not only precise but also well-centered, ensuring minimal risk of producing nonconforming products. Overall, the analysis indicates high precision, accuracy, and consistent quality in production.

DISCUSSION

The detailed evaluation of the Sunlight Soap manufacturing process, conducted at Unilever Brothers PLC, Aba, using $\bar{X}$ and R control charts and process capability indices, provides a comprehensive insight into the consistency and effectiveness of the production process. The results of the $\bar{X}$ and R control charts for both the length and weight of the soap bars demonstrated that the process was under statistical control, with all data points remaining well within the specified upper and lower control limits. This outcome indicates a stable process with no evident signs of instability or special cause variation, which is consistent with established principles of statistical process control (Montgomery, 2019). Further validation of the results through runs tests supported this observation, as the p-values for the runs tests were significantly above the 0.05 threshold (e.g., p = 1.000 for length and p = 0.227 for weight), reinforcing that the variations observed were due to inherent common causes rather than any assignable or external influences.

The process capability analysis revealed distinct results for the height and weight of the soap bars. For the height of the soap bars, the process capability indices (C_p = 0.412, C_{pk} = 0.301) indicated a clear deviation from the industry-standard benchmark of 1.33. These figures suggest that the process variation exceeds the specification range (8.7 cm to 9.3 cm) and is not well-centered. This misalignment poses a significant risk of producing nonconforming units, which calls for targeted improvements, either through reducing the variability in the manufacturing process or re-centering the process mean to better align with the specification limits.

On the other hand, the weight of the soap bars demonstrated exceptional process capability. The C_p value of 2.35 and C_{pk} value of 2.31 indicate a highly capable and well-centered process, far exceeding the typical benchmark of 1.33 for process capability. These results signify that the weight variation is tightly controlled, with the process consistently meeting the specifications. The histogram for weight data corroborated these findings, displaying a normal distribution with minimal dispersion, which visually affirmed the numerical results. The tight distribution of the weight data further suggests adherence to best practices in quality management, reinforcing the reliability and consistency of the manufacturing process (Juran & Godfrey, 1999).

In conclusion, the findings from this study indicate that while the Sunlight Soap production process at Unilever Brothers PLC excels in controlling the weight of the soap bars, there are areas requiring attention, particularly concerning the height of the bars. Addressing these issues will require targeted interventions to reduce variability and ensure that the height parameter meets the same high standards of capability as the weight, ultimately improving overall product quality and reducing the likelihood of nonconforming outputs.

CONCLUSION

In summary, this study provides a robust assessment of the Sunlight Soap manufacturing process, revealing a statistically stable and well-controlled system for both length and weight dimensions. The analysis highlights outstanding process capability in the control of product weight, reflecting effective quality assurance measures and adherence to industry best practices. However, the process performance related to the height of the soap bars falls short of acceptable capability standards, indicating the presence of excessive variability and a lack of centering within the specification limits. These findings underscore the need for targeted process optimization strategies focused on dimensional accuracy and consistency. Enhancing control over the height parameter will be critical for aligning all product attributes with stringent quality requirements and sustaining high levels of customer satisfaction.

Recommendations

Based on the findings, the following recommendations are proposed:

1. Implement real-time monitoring systems to detect length variations promptly.
2. Conduct root cause analysis to address equipment calibration and raw material inconsistencies.
3. Provide training on SQC techniques to enhance staff capability in quality management.
4. Regularly review control limits and specification ranges to align with evolving standards.

Data Availability: Based on request.

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