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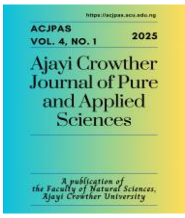
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Article

Application of Statistical Quality Control in Monitoring the Production and Marketing Process of Sachet Water at Ajayi Crowther Water Factory, Oyo, Nigeria

Alfred Ayo Ayenigba [1*] **and Olutunde Michael Ajao**

[1] Statistics Programme, Department of Mathematical Sciences, Faculty of Natural Sciences, Ajayi Crowther University, Oyo, Oyo State, Nigeria; aa.ayenigba@acu.edu.ng (A.A.A), mo.ajao@acu.edu.ng (O.M.A.)

* Correspondence: A.A. Ayenigba (aa.ayenigba@acu.edu.ng)

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Abstract

This study aims to analyse the application of Statistical Quality Control (SQC) in monitoring the production and marketing processes of sachet water at Ajayi Crowther Water Factory, with a focus on integrating educational technology to enhance these processes. Data were collected from the management and personnel, including the total production of bags of sachet water and the number of defective products each day for 29 days, as well as total sales each day for 40 days. A pie chart was used to determine the percentage of defective products, revealing that 1% were defective while 99% were non-defective. P and nP charts were utilized to check whether the defectives were within control limits. The control charts indicated that the process was in control; however, the process capability indices showed that the process is not capable of consistent production within the pre-set limits. An Individual $\bar{X}$ chart was used to determine whether the sales of sachet water were in control, and the control chart confirmed that the sales process was stable. This study concluded that SQC, complemented by educational technology, has the potential to improve the quality of sachet water produced by Ajayi Crowther Water Factory. It is recommended that the factory should consistently use SQC, alongside educational technology, to monitor their production and marketing processes to enhance quality control measures. These findings could inform policymakers and stakeholders in the sachet water production industry and contribute to improving the quality of water produced and marketed in Nigeria.

Keywords: Educational Technology, SQC, $\overline{\mathrm{X}} -$ chart P-Chart, np-Chart and process capability analysis.

1. Introduction

The application of Statistical Quality Control (SQC) is crucial in ensuring the consistent quality of products in manufacturing industries. SQC employs various statistical methods to monitor and control production processes, thereby minimizing defects and ensuring that products meet predefined quality standards [6]. In the context of the sachet water industry, maintaining high quality is particularly important due to the direct impact on public health. Ajayi Crowther Water Factory in Oyo, Nigeria, has implemented SQC to oversee its production and marketing processes, aiming to enhance product quality and customer satisfaction. The integration of educational technology into this framework can further streamline these processes by providing training tools, real-time data analysis, and decision-support systems for the personnel involved. Educational technology can facilitate the understanding and application of SQC principles among employees, leading to more effective quality control measures [9]. This study examines the dual application of SQC and educational technology at Ajayi

Crowther Water Factory, highlighting their combined potential to improve the production and marketing of sachet water in Nigeria.

Recent studies emphasize the critical role of SQC in enhancing manufacturing efficiency and product consistency. For instance, [1] highlighted how SQC tools, particularly control charts and Pareto analysis, contribute significantly to identifying production bottlenecks and minimizing waste in beverage manufacturing. Similarly,[10] underscored the importance of integrating real-time data analytics with SQC to improve decision-making in production environments. These findings are further supported by [8], who demonstrated that combining SQC with digital training tools reduces operational errors and enhances product traceability across the supply chain

The quality of sachet water is a critical issue, especially in developing countries where it is a primary source of drinking water for many people. Ensuring that sachet water meets health and safety standards is essential to prevent waterborne diseases and promote public health. At Ajayi Crowther Water Factory, the implementation of SQC has been a strategic move to enhance the quality of their sachet water. SQC tools such as control charts, process capability indices, and Pareto analysis help in identifying and rectifying variations in the production process, thereby ensuring that the final product is consistent with the desired quality standards [2]. By monitoring key quality indicators, the factory can detect any deviations from the norm and take corrective actions promptly, thus reducing the likelihood of defective products reaching the market. The role of educational technology in this context cannot be overstated. It provides a platform for training and educating factory personnel on the principles and practices of SQC. For instance, interactive e-learning modules can be used to train employees on how to use control charts and interpret process capability indices. Additionally, educational technology can facilitate real-time data analysis and decision-making. Advanced software tools can collect and analyze production data, generating insights that can be used to improve the production process. By integrating these technological tools into the SQC framework, Ajayi Crowther Water Factory can enhance its quality control measures and ensure that its products meet the highest standards of quality.

Educational technology also plays a pivotal role in fostering a culture of continuous improvement within the factory. Continuous improvement is a key principle of SQC, and it requires a commitment to ongoing learning and development. Through the use of educational technology, employees can access a wealth of resources and learning opportunities that keep them up-to-date with the latest advancements in quality control. Online courses, webinars, and virtual workshops can provide employees with the knowledge and skills they need to continuously improve their work processes. This culture of continuous improvement can lead to significant enhancements in product quality and operational efficiency. The integration of SQC and educational technology at Ajayi Crowther Water Factory is a forward-thinking approach that leverages the strengths of both fields. SQC provides the statistical tools and methodologies needed to monitor and control production processes, while educational technology provides the training and real-time data analysis tools needed to apply these methodologies effectively. Together, they create a comprehensive quality control system that can significantly enhance the production and marketing processes of sachet water. One of the key tools in SQC is the control chart, which is used to monitor the variability of a process over time. At Ajayi Crowther Water Factory, control charts are used to track key quality indicators such as the number of defective sachets produced each day. By plotting these indicators on a control chart, the factory can easily see if the process is within control limits or if there are any out-of-control points that need to be addressed. This real-time monitoring allows the factory to take corrective actions promptly, thus reducing the likelihood of defective products reaching the market.

Process capability indices are another important tool in SQC. These indices measure the ability of a process to produce products that meet specifications. At Ajayi Crowther Water Factory, process capability indices are used to assess the effectiveness of the production process in meeting quality standards. If the indices show that the process is not capable of consistently producing products within specifications, the factory can take steps to improve the process. This might involve adjusting the production parameters, upgrading equipment, or providing additional training to employees. Pareto analysis is also used at Ajayi Crowther Water Factory to identify the most common causes of defects.

By focusing on the most significant issues, the factory can prioritize its efforts and resources to address the root causes of defects. This targeted approach can lead to significant improvements in product quality and operational efficiency. For example, if Pareto analysis reveals that a large percentage of defects are due to a specific issue, the factory can focus on resolving that issue, which can have a substantial impact on reducing overall defect rates [5]. Educational technology complements these SQC tools by providing the training and real-time data analysis tools needed to apply them effectively. For example, interactive e-learning modules can be used to train employees on how to use control charts and interpret process capability indices. These modules can include simulations and case studies that provide hands-on experience with using these tools in real-world scenarios. Additionally, advanced software tools can collect and analyze production data, generating insights that can be used to improve the production process. By integrating these technological tools into the SQC framework, Ajayi Crowther Water Factory can enhance its quality control measures and ensure that its products meet the highest standards of quality [4].

The benefits of integrating SQC and educational technology extend beyond the factory floor. They also have a positive impact on the marketing process. By ensuring that the sachet water produced by Ajayi Crowther Water Factory consistently meets quality standards, the factory can build a strong reputation for quality and reliability. This can enhance customer satisfaction and loyalty, leading to increased sales and market share. Additionally, the insights generated from SQC and educational technology can be used to inform marketing strategies. For example, the factory can use data on customer preferences and purchasing patterns to tailor its marketing efforts and better meet the needs of its customers [7].

Furthermore, the integration of SQC and educational technology can contribute to broader industry improvements. The findings of this study can be used to inform policymakers and stakeholders in the sachet water production industry. By demonstrating the effectiveness of SQC and educational technology in improving product quality, the study can encourage other factories to adopt similar approaches. This can lead to overall improvements in the quality of sachet water produced and marketed in Nigeria, thereby promoting public health and safety.

The production of sachet water in Nigeria, particularly at facilities like Ajayi Crowther Water Factory, is a critical component of the public health infrastructure. Given the widespread reliance on sachet water as a primary drinking source, ensuring its quality is paramount. However, maintaining consistent product quality in such a dynamic production environment poses significant challenges. Variations in the production process can lead to inconsistencies in volume and quality, resulting in defective products that fail to meet regulatory standards and consumer expectations. Despite the implementation of quality control measures, Ajayi Crowther Water Factory faces persistent issues with volume dispersion during the filling process. The traditional final product inspection methods are labour-intensive and often inadequate for ensuring consistent quality. Defective products, even if they constitute a small percentage, can have substantial negative impacts on consumer trust and public health. Moreover, the current quality control practices do not fully leverage modern technological advancements that could enhance process monitoring and efficiency. The primary problem is the factory's limited capacity to continuously and effectively monitor and control the quality of sachet water during production. This limitation results in an inability to consistently produce sachet water within the pre-set quality limits. Additionally, there is a lack of integration of educational technology in training personnel on advanced quality control methods, which hinders the effective application of Statistical Quality Control (SQC) tools.

Given these challenges, it is imperative to adopt a more robust and technologically integrated approach to quality control. This study aims to address these issues by applying Statistical Quality Control (SQC) methods enhanced with educational technology tools to monitor and improve the production process. By doing so, the study seeks to reduce the burden of final product inspection, ensure consistent product quality, and provide a framework for continuous improvement in production practices. This problem statement highlights the critical need for a systematic and technologically advanced approach to quality control in the sachet water production industry. The findings and recommendations from this study will not only benefit Ajayi Crowther Water Factory but also serve as a model for other facilities, ultimately contributing to improved public health outcomes in Nigeria.

The objective of this study is to utilize Statistical Process Control (SPC) and Educational Technology (ET) as a Quality Control tool for Ajayi Crowther Water Factory products, with a focus on integrating educational technology to enhance the monitoring of volume dispersion during the filling process. This approach aims to reduce the burden of final product inspection by ensuring quality control throughout the production process. The specific objectives of the study are to:

1. establish the control limits of the machine processing lines.
2. construct various control charts for the process and use them to detect any causes of variation in the production process before they result in defective products.
3. propose potential solutions for the causes of variation identified in objective (2).
4. analyze the process capability of the filling process to ascertain which machines meet the specifications for filling bottles and containers accurately

2. Methodology

This study established the essential parameters, including the mean, range, and construction of control charts, as well as process capability index values, necessary to achieve the stated objectives. The research utilized secondary data obtained from Ajayi Crowther Water Factory.

i. The Mean ($\bar{x}$)

This measures the central tendency of a data. Mathematically;

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} = \frac{x_1+x_2+\cdots+x_n}{n} \tag{1}$$

ii. The Range (R)

Range is the simplest and most straight forward measure of dispersion. It is the difference between the maximum and the minimum values in the set of data. Mathematically:

$$\text{R} = \text{Maximum value} - \text{Minimum value} \tag{2}$$

iii. Standard Deviation (S)

This measures the amount of data dispersion around the mean. Mathematically;

$$S = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n-1}} \tag{3}$$

iv. Standard Error ($s_{\bar{x}}$)

This is the error of the mean of the distribution of the sample means.

$$\mathrm{s}_{\bar{\mathrm{x}}} = \frac{\mathrm{s}}{\sqrt{\mathrm{n}}} \tag{4}$$

We construct control charts for both variable and attributes viz

$\bar{X}$-Chart

A mean control chart, commonly known as an x-bar chart, is used to monitor changes in the mean of a process. To construct an $\bar{X}$-chart, the center line must first be established. This involves taking multiple samples (k), calculating the mean of each sample, and then computing the center line as the average of all these sample means.

i. $$\bar{\bar{\mathrm{X}}} = \frac{\bar{\mathrm{X}}_1+\bar{\mathrm{X}}_2+\bar{\mathrm{X}}_3+\ldots+\bar{\mathrm{X}}_k}{\mathrm{k}} \tag{5}$$

ii. $\mathrm{R} = \frac{\mathrm{R_1+R_2+R_3+ \ldots +R_k}}{\mathrm{k}}$ (6)

iii. $\mathrm{CL} = \overline{\overline{\mathrm{X}}}$ (7)

iv. $\mathrm{UCL} = \overline{\overline{\mathrm{X}}} + \mathrm{A_2R}$ (8)

v. $\mathrm{LCL} = \overline{\overline{\mathrm{X}}} - \mathrm{A_2R}$ (9)

Where

i. $\overline{\overline{X}}$ *is the average of the sample means,*

ii. R *is the average range of the samples and*

iii. A_2*is obtained from standard tables.*

R chart

Range (R) charts are another type of control chart used for monitoring variables. While $\bar{X}$-chart measure shifts in the central tendency of a process, R charts are used to monitor the dispersion or variability of the process. The methodology for developing and utilizing R charts is similar to that for $\bar{X}$-chart s. The center line of an R chart is the average range, and the upper and lower control limits are calculated accordingly.

i. $\mathrm{CL} = \mathrm{R}$ (10)

ii. $\mathrm{UCL} = \mathrm{D_4R}$ (11)

iii. $\mathrm{UCL} = \mathrm{D_3R}$ (12)

Where values for D_3 *and* D_4*are obtained from already established statistical tables*.

Many quality characteristics cannot be easily quantified or measured numerically. In such instances, items are typically classified as either defective or non-defective. When products are produced in large quantities, they are categorized based on their conformity, defectiveness, and overall quality. These types of quality characteristics are known as attributes. Attributes can be further classified into two categories:

1. Number of defective items (P-Chart)
2. Number of defects per item (C-Chart)

The statistical principle that underlines the control chart for fractions defective is based on the binomial distribution. The control limits for the chart are given as follow:

i. $\mathrm{CL} = \bar{P}$ (13)

ii. $\mathrm{UCL} = \bar{P} + 3\sigma_p$ (14)

iii. $\mathrm{LCL} = \bar{P} - 3\sigma_p$ (15)

Where $\bar{P} = \frac{\sum_{i=1}^{n} d_i}{k}$ (16)

$\sigma_p = \sqrt{\frac{p(1-p)}{n}}$ (17)

Process Capability Analysis

A capable process is one in which nearly all measurements fall within the specified limits. This is often depicted pictorially using a normal distribution curve with a sharp peak. Combining histograms with control charts provides valuable insights into the process. It is also standard practice to express process capability using the following indices:

The process capability index, denoted as C_P is a straightforward measure of process capability. It is calculated by dividing the process width by six times sigma, the estimated within-subgroup standard deviation. The process width is defined as the difference between the upper specification limit and the lower specification limit.

$$C_P = \frac{(USL-LSL)}{6\sigma} \tag{18}$$

Interpretation

When$C_P < 1$, the process exceeds the specification limits, indicating incapability to consistently produce products within specification. Even $C_P > 1$, defective parts may still be produced if the process is not centered. Therefore, there is a necessity for a capability index that considers process centering.

Demonstrated Excellence($\mathrm{C_{Pk}}$) is the difference between x double bar and the nearer specification limit divided by 3 times sigma.

$$C_{Pk} = C_P(1-k) \tag{19}$$

$$= Minimum(C_{Pu}, C_{Pl}) \tag{20}$$

Where $C_{Pu} = \frac{USL-\bar{X}}{3\sigma}$ (21)

$$C_{Pl} = \frac{\bar{X}-USL}{3\sigma} \tag{22}$$

Interpretation

If $C_{Pk} \geq 1$, then 99.7% of the products of the process will be within specification limits.

If $C_{Pk} < 1$, then more non-conforming products are being made.

3. Results and Discussion

Total bags of water produced and Defective Bags

Figure 1 depicts the percentage of defective bags to the total bags produced.

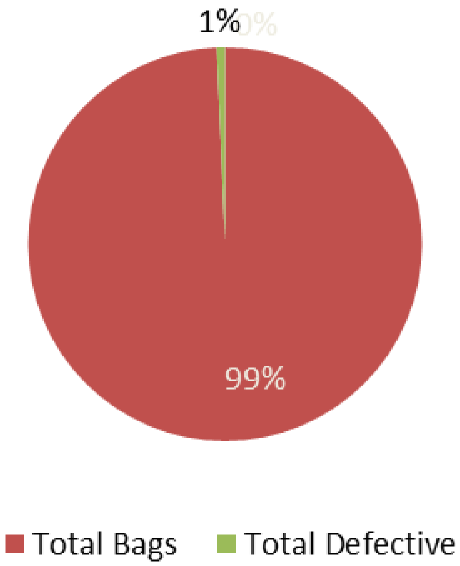


Figure 1: Proportion of defective bags

During the 29-day investigation period, the defect rate was 1.00%, with non-defective products constituting 99.00% of the total production. This defect rate implies that out of every 1,000 packs produced, approximately 10 packs were defective, primarily due to sachet leakage.

Control Charts

The control Charts for attribute P and NP charts using the data from Ajayi Crowther Water factory using equations (14 to 17) on Minitab give the following Figure 2 and Figure 3 respectively.

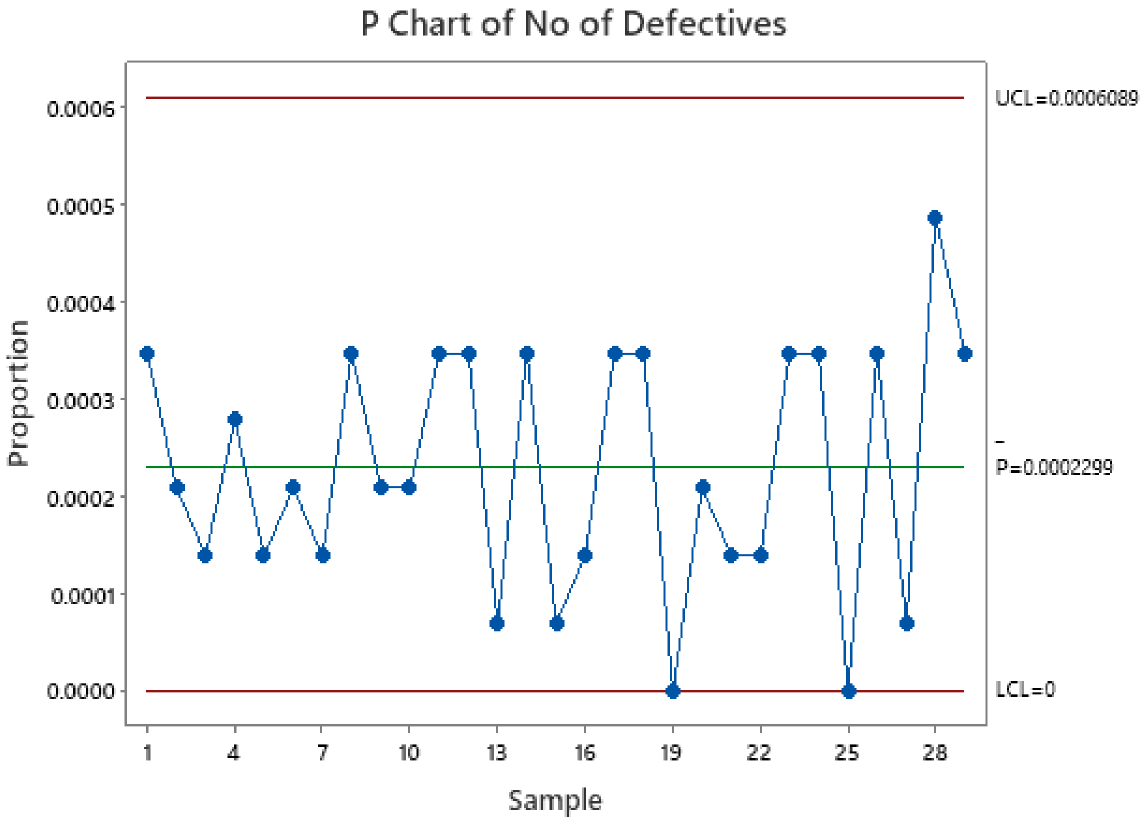


Figure 2: P Chart of Defective Units

The plotted points all fall within the upper and lower control limits, hence it is in state of statistical control.

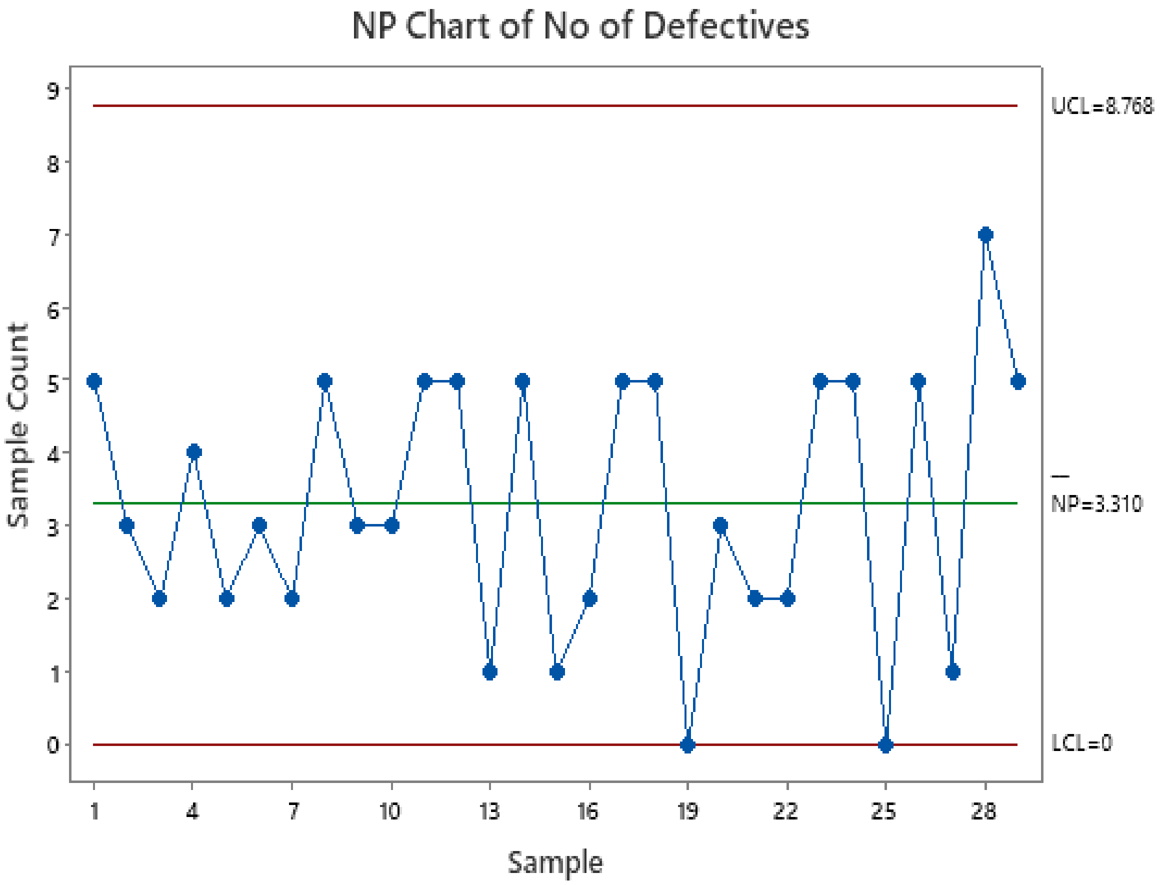


Figure 3: NP Chart of Defective Units

Since all the points are within the control limits, the process is statistical control.

Test for Randomness.

To ascertain the state of control accurately, test of randomness is very vital.

Hypothesis

H_0: *The plotted points are random*

H_1: *The plotted points not are random*

Significance Level: $\alpha = 0.05$

Decision Rule

Reject H_0 if the P-Value is greater than significance level otherwise do not reject H_0

Using Minitab, the run test gives the following summary:

N	K	$\leq k$	$> k$	P- Value
29	3.31034	16	13	0.527

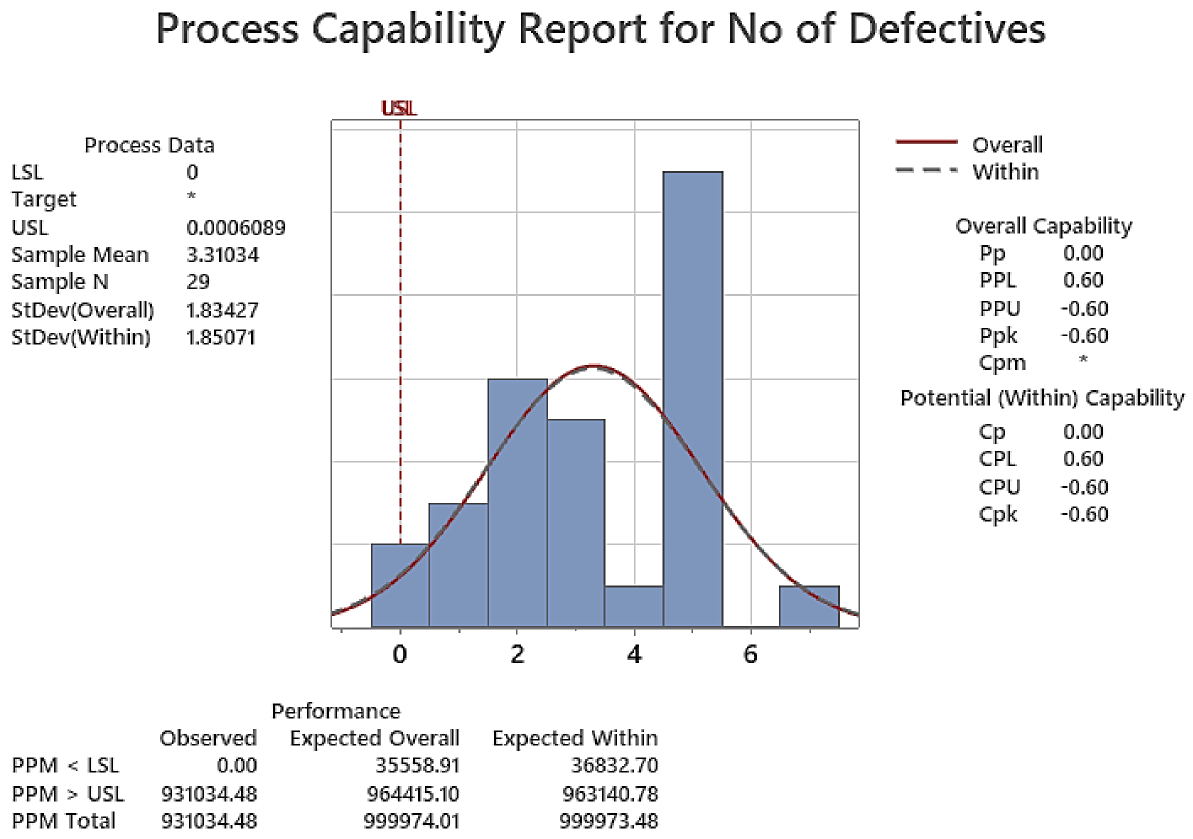
$k = sample\ mean$

Conclusion

Given that the P-Value is 0.527, which is greater than the significance level $\alpha = 0.05$, we do not reject the null hypothesis (H0). Consequently, we conclude that the plotted points are random. Furthermore, since the plotted points fall within both the upper and lower control limits and exhibit randomness, we conclude that the process is in a state of control.

Process capability analysis for Proportion Defective

The summary of capability analysis on the proportion defective using Minitab is given below:



Process Data	
LSL	0
Target	*
USL	0.0006089
Sample Mean	3.31034
Sample N	29
StDev(Overall)	1.83427
StDev(Within)	1.85071

Overall Capability	
Pp	0.00
PPL	0.60
PPU	-0.60
Ppk	-0.60
Cpm	*

Potential (Within) Capability	
Cp	0.00
CPL	0.60
CPU	-0.60
Cpk	-0.60

Performance	Observed	Expected Overall	Expected Within
PPM < LSL	0.00	35558.91	36832.70
PPM > USL	931034.48	964415.10	963140.78
PPM Total	931034.48	999974.01	999973.48

Figure 4: Process Capability Analysis for Defective Units

Figure 4 presents the process capability analysis for the proportion of defective products, revealing low process capability indices. The normal distribution curve is not centered according to the preset specifications, as indicated by a capability index of less than 1. Consequently, the process is not capable of consistently meeting the preset specification limits over the long term.

Individual Control Chart for Number of Sales of Sachet Water

The sales data were collected from a single distribution route. Therefore, an individual control chart for variables was applied using Minitab using the sales data obtained from Ajayi Crowther Water Factory.

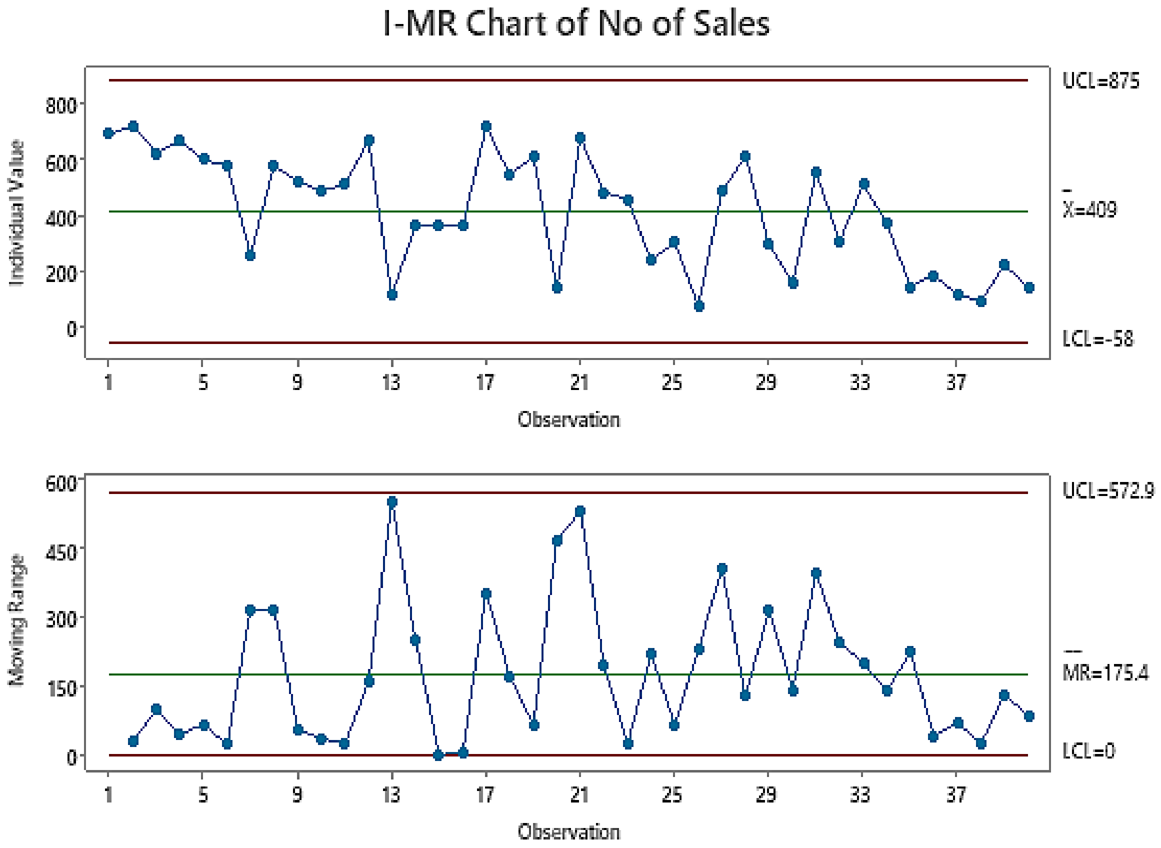


Figure 5: I-MR Control Chart for Sales Data

The control chart shows that the process is in control since all the plotted points all fall within the upper and lower control limits.

Test for Randomness for IMR Charts

To ascertain the state of control accurately, test of randomness is very vital.

Hypothesis

$H_0: The\ plotted\ points\ are\ random$

$H_1: The\ plotted\ points\ not\ are\ random$

Significance Level: $\alpha = 0.05$

Decision Rule

Reject H_0 if the P-Value is greater than significance level otherwise do not reject H_0

Using Minitab, the run test gives the following summary:

N	K	$\leq k$	$> k$	P- Value
40	408.7	19	21	0.026

$k = sample\ mean$

Conclusion

Given that the P-Value is 0.026, which is less than the significance level $\alpha = 0.05$, we do not reject the null hypothesis. Consequently, we conclude that the plotted points are random.

Additionally, since the plotted points fall within both the upper and lower control limits and exhibit randomness, we conclude that the process is in a state of control.

4. Conclusion

During the 29-day investigation period, 99% of the total production output was non-defective, with a defect rate of 1%. The P-chart and NP-chart were constructed to assess the process control status. The charts indicate that all plotted points fall within the control limits, and run tests confirm that the points are random. Thus, we conclude that the process is in a state of statistical control. The process capability indices for the proportion of defective products were calculated using Minitab. The Potential Capability (within) indicators, CP, CPL, CPU, and CPK, are all less than one. This indicates that the process is not capable of consistently producing products within the specified limits. The individual moving average chart for the sales of bags of sachet water shows that all plotted points fall within the upper and lower control limits. Tests of randomness indicate that the points are random, leading to the conclusion that the sales process for bags of sachet water is in statistical control.

5. Recommendation

Management, staff, and workers at the water factory should be thoroughly educated on the importance of quality for organizational performance in a competitive market. This can be achieved through seminars on quality control. Although the P and NP charts indicate that the process is currently in a state of statistical control, the process capability indices suggest that long-term control may not be sustainable. Therefore, it is recommended that the equipment and machinery be regularly monitored and serviced. It is advisable to explore different distribution channels to better reach consumers.

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The author(s) hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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