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Enhancing Quality Control in Bottled Water Production:

A Comparative Case Study of Weight Consistency Across Local Bottling Plants

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Abstract

This study investigates the weight consistency of half-liter bottled water produced by three local bottling plants (CNO, Shaimaa, and Dijla) using statistical quality control methods. Analysis of twelve samples from each plant revealed significant variability in bottle weights. Shaimaa exhibited the highest mean weight((504.58 grams) and the most consistent production process. ANOVA and post-hoc tests confirmed significant differences in mean weights among the plants ($p < 0.0001$), with Shaimaa producing significantly higher weights compared to CNO and Dijla. Process capability analysis (Cpk) indicated that none of the plants consistently met weight specifications, highlighting the need for process improvements. These findings underscore the importance of rigorous quality control practices and continuous process improvement to ensure product consistency and meet customer expectations.

Keywords: Quality Control, Bottled Water Production, Manufacturing Processes, Statistical Quality Control, Food and Beverage Industry, Total Quality Management

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تعزيز مراقبة الجودة لمصانع تعبئة مياه الشرب المحلية: دراسة حالة لمقارنة اتساق الأوزان للمياه المعبأة

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ملخص

تبحث هذه الدراسة في انتظام وزن عبوات المياه ذات النصف لتر المعبئة من قبل ثلاثة مصانع محلية (CNO ، شيماء، ودجلة) باستخدام أساليب الرقابة الإحصائية على الجودة، حيث تم تحليل بيانات العينات من خلال الوزن العشوائي لاثنتي عشر عينة من كل مصنع، والتي أظهرت تفاوت كبيرة في أوزان العبوات، حيث كان لمصنع شيماء أعلى متوسط وزن (504.58 جرام) و أعلى درجة اتساق في عملية الإنتاج، بينما أكدت اختبارات ANOVA و الاختبارات اللاحقة وجود فروق ذات دلالة إحصائية في الأوزان المتوسطة بين المصانع($p < 0.0001$) ، حيث أنتجت شيماء أوزانًا أعلى بشكل ملحوظ مقارنة بـ CNO ودجلة، وأشارت تحليلات كفاءة العملية (Cpk) إلى أن أيًا من المصانع الثلاث لم يحقق مواصفات الوزن بانتظام، مما يبرز الحاجة إلى تحسين في العمليات الإنتاجية، وبهذا تؤكد هذه الدراسة على أهمية ممارسات الرقابة الصارمة على الجودة والتحسين المستمر للعمليات لضمان اتساق المنتج وتلبية توقعات العملاء.

الكلمات المفتاحية: ضبط مراقبة الجودة، تعبئة مياه الشرب، عمليات التصنيع، الضبط الاحصائي للجودة، التصنيع الغذائي، إدارة الجودة الشاملة.

Introduction

Ensuring the consistency of product weight in bottled water production is critical for maintaining customer trust and complying with regulatory standards. A significant proportion of customer complaints in the bottled water industry stems from inconsistencies in product weight, which not only affects customer satisfaction but also has substantial economic implications. For instance, non-

compliance with weight regulations can lead to fines, product recalls, and a tarnished brand reputation. A study by the International Bottled Water Association (IBWA) found that nearly 15% of consumer complaints were related to weight discrepancies, underscoring the importance of rigorous quality control in this industry.
Quality control in the bottled water industry is essential to ensure that products meet specified standards and regulations. Weight consistency is a critical aspect of quality control, directly impacting customer satisfaction and trust. Inconsistent product weights can lead to customer complaints and potential regulatory issues, making it imperative for bottling plants to understand and control weight variations within and between their production lines.
The weight of a 0.5-liter bottle of water should ideally be 500 grams, based on the density of pure water, which is approximately 1 gram per milliliter [1]. This study focuses on analyzing the weight consistency of half-liter bottled water across three local bottling plants. By examining the weights of twelve samples from each plant, we aim to identify significant variations both within each plant and between the plants. Understanding these variations will help in improving manufacturing processes and ensuring consistent product quality.

Objectives of the Study: This study aims to investigate the weight consistency of half-liter bottled water produced by three local bottling plants (CNO, Shaimaa, and Dijla) using advanced statistical quality control methods. Specifically, the objectives are to:

1. **Determine the Average Weight and Variability**: Calculate the mean weight and variability using standard deviation and range for each plant's production.
2. **Assess Process Stability and Capability**: Utilize control charts (I-MR charts) to evaluate process stability and process capability indices (Cpk) to determine how well each plant meets the weight specifications.
3. **Identify Significant Differences**: Employ one-way ANOVA to identify significant differences in mean weights among the

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three plants and perform post-hoc tests to pinpoint specific discrepancies.

Previous research has highlighted the challenges and methodologies associated with maintaining product weight consistency in the beverage industry. Smith et al. (2020) emphasized the role of statistical quality control methods in identifying and mitigating process variations [2]. Similarly, Johnson (2019) demonstrated the effectiveness of control charts in monitoring production processes in the food and beverage sector [3]. These studies provide a foundational understanding of the tools and techniques applied in this research. By integrating these findings, this study builds on existing knowledge and applies it to the context of local bottled water production, thereby contributing valuable insights into the effectiveness of quality control practices in this industry.

In this study, we build on these foundations by applying statistical analysis to assess the weight consistency in bottled water production. Our goal is to provide insights and recommendations that can help bottling plants improve their quality control practices, ensuring that their products meet the required standards and satisfy customer expectations.

Literature Review

Quality control in the manufacturing sector, particularly in the food and beverage industry, has been extensively studied due to its crucial role in ensuring product consistency and customer satisfaction. Various methodologies have been applied to monitor and control production processes to maintain high standards of product quality.

Montgomery (2012) emphasizes the significance of statistical quality control (SQC) methods in monitoring and controlling production processes [1]. SQC involves the use of statistical methods to observe and manage a process, ensuring that it operates at its maximum potential to produce conforming products consistently. These methods include control charts, process capability analysis, and design of experiments, which help in identifying and reducing variability in the production process.

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Besterfield et al. (2011) discuss the importance of Total Quality Management (TQM) as an integrated approach to achieving long-term success through customer satisfaction [4]. TQM focuses on continuous improvement in all organizational processes, involving all employees in the pursuit of quality enhancement. In the context of bottled water production, TQM practices can help in identifying and addressing variations in product weight, thereby ensuring uniformity and reliability.

In the field of bottled water production, weight consistency is particularly important. Studies have shown that even minor deviations in product weight can lead to significant customer dissatisfaction and regulatory challenges. For instance, a study by Foster (2014) on quality control in beverage manufacturing highlighted that maintaining consistent product weight is critical for both customer trust and compliance with labeling regulations [5].

Moreover, research by Smith and Brown (2015) on the application of Six Sigma methodologies in the food and beverage industry demonstrated that reducing variability in production processes leads to higher quality products and greater efficiency [6]. Six Sigma's DMAIC (Define, Measure, Analyze, Improve, Control) framework helps in systematically identifying root causes of variations and implementing solutions to control them.

Recent advancements in technology have also contributed to improved quality control in manufacturing. For example, automated inspection systems and real-time data analytics allow for more precise monitoring and control of production processes, leading to better consistency in product weights (Johnson & Miller, 2017) [7].

The integration of these quality control methodologies is essential for the bottled water industry to ensure product consistency and customer satisfaction. By applying statistical methods, TQM practices [8], and advanced technologies, manufacturers can better manage and reduce variations in product weight.

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Methodology

Measurement Instrument

The weights of the bottles were measured using a calibrated digital scale model SF-400 shown in Figure 1, which has an accuracy of ±0.1 grams. This scale ensures precise measurements for the analysis.

Figure 1.digital scale model SF-400

Procedure

Each bottle was weighed individually, and the net weight was recorded to ensure accurate data collection. According to the principles of fluid dynamics, the weight (W) of a liquid can be determined using the equation:

$$W = V \times \rho \qquad (1)$$

where:

- W is the weight of the liquid,
- V is the volume of the liquid, and
- ρ is the density of the liquid.

Given that the density of pure water (ρ) is approximately 1 gram per milliliter (*g/mL*), and the volume (V) of each bottle is 0.5 liters (or 500 milliliters), the expected weight of the water in each bottle is:

$$W = 500\ mL \times 1\ g/mL = 500\ grams$$

This means that each 0.5-liter bottle should ideally weigh 500 grams.

Data Collection

The data for this study were collected from three local bottling plants, referred to as Plant CNO, Plant Shaimaa, and Plant Dijla. For each plant, twelve samples of half-liter bottled water were randomly selected. The weight of each bottle was measured and recorded in grams. The weights were recorded as both total weight (including the bottle) and net weight (excluding the bottle). Figure 2 illustrates one sample bottle from each plant.

Figure 2.One sample bottle from each plant

Sampling Process

1. **Plant CNO**: Twelve samples were collected and weighed. The recorded weights are as follows Table 1:

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Table 1. The recorded weights and Net wights of plant CNO

No of Sample	Wights	Net Wights
1	508	495
2	504	491
3	508	495
4	508	495
5	508	495
6	508	495
7	508	495
8	508	495
9	509	496
10	505	492
11	509	496
12	509	496
Average	507.66667	494.66667

2. **Plant Shaimaa**: Twelve samples were collected and weighed. The recorded weights are as follows Table 2:

Table 2. The recorded weights and Net wights of plant Shaimaa

No of Sample	Wights	Net Wights
1	514	501
2	519	506
3	518	505
4	516	503
5	517	504
6	520	507
7	517	504
8	517	504
9	519	506
10	516	503
11	519	506
12	519	506
Average	517.58333	504.58333

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3. **Plant Dijla**: Twelve samples were collected and weighed. The recorded weights are as follows Table 3:

Table 3. The recorded weights and Net Wight of plant Dijla

No of Sample	Wight	Net Wight
1	505	492
2	504	491
3	504	491
4	509	496
5	506	493
6	506	493
7	503	490
8	502	489
9	503	490
10	505	492
11	503	490
12	505	492
Average	504.58333	491.58333

Statistical Analysis

Descriptive Statistics:

Descriptive statistics were calculated to summarize the weight data for each factory. The following metrics were computed:

1. **Mean ($\bar{X}$):** The average weight of the bottles for each factory.

$$\bar{X} = \frac{\sum_{i=1}^{n} Xi}{n} \qquad (2)$$

Where: *Xi*- represents the weight of *i*-the bottle and *n*- is the total number of samples.

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2. **Standard Deviation (S):** A measure of the amount of variation or dispersion in the weights.

$$S = \sqrt{\frac{\sum_{i=1}^{n}(Xi - \bar{X})^2}{n-1}} \quad (3)$$

3. **Range (R):** The difference between the maximum and minimum weights.

$$R = X_{max} - X_{min} \quad (4)$$

Where: X_{max} is the maximum weight and X_{min} is the minimum weight.

Control Charts: I-MR (Individuals-Moving Range) charts were used to monitor the stability of the bottle weights for each factory. The I-MR chart consists of two parts:

1. **Individuals (I) Chart:** Plots the individual sample weights over time.

$$CL = \bar{X} = \frac{\sum_{i=1}^{n} Xi}{n} \quad (5)$$

$$UCL=\bar{X}+ 3σ \quad (6)$$

$$LCL=\bar{X}- 3σ \quad (7)$$

Where: σ is the estimated standard deviation of the process.

2. **Moving Range (MR):** The absolute difference t consecutive sample weights.

$$MR_i = \lfloor X_i - X_{i-1} \rfloor \quad (8)$$

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The I-MR charts were used to monitor the weight consistency and detect any shifts or trends in the process.

Process Capability Analysis: Two Scenarios

Scenario 1: Specification Limits Based on 3 Sigma.

In this scenario, the lower specification limit (LSL) and upper specification limit (USL) are set based on a 3-sigma range around the target weight of 500 grams. This assumes that the process is capable and centered around the target weight.

- Lower Specification Limit (LSL): 497 grams
- Upper Specification Limit (USL): 503 grams

$$\mathrm{Cp} = \frac{\mathrm{USL} - \mathrm{LSL}}{6\sigma} \tag{9}$$

$$CPk = \min\left(\frac{USL - \bar{X}}{3\sigma}, \quad \frac{\bar{X} - LSL}{3\sigma}\right) \tag{10}$$

Where:

USL -is the upper specification limit.

LSL -is the lower specification limit.

σ - is the estimated standard deviation of the process.

Scenario 2: Specification Limit Based on Minimum Customer Expectation

In this scenario, the lower specification limit (LSL) is set to 500 grams, based on the assumption that customers expect each bottle to contain at least 500 grams of water. There is no upper specification limit as long as the weight is not specified to be within a particular range.

- Lower Specification Limit (LSL): 500 grams
- Upper Specification Limit (USL): Not specified (or can be set to the highest observed weight for the analysis)
-

$$CP_L = \frac{\bar{X} - LSL}{3\sigma} \quad (11)$$

The Cp value indicates the potential capability of the process. A higher Cp value suggests a more capable process. A Cp value of 1.33 or higher is typically considered acceptable for most industries. The Cpk value provides a measure of how well the process is performing relative to the specification limits. A higher Cpk value indicates that the process mean is well-centered within the specification limits. A Cpk value of 1.33 or higher is typically considered acceptable.

ANOVA Method: Analysis of Variance for Bottled Water Weight Consistency

Analysis of variance (ANOVA) is a key statistical method used to interpret experimental data objectively. In this study, ANOVA was employed to evaluate the significance of weight differences among the three local bottled water factories. This method helps to understand the impact and significance level of each factory on the weight variability of half-liter bottles.

ANOVA Procedure:

1. **Data Organization:**
- The data is structured into columns with one column for the weights and another indicating the factory.
2. **Statistical Analysis:**
- ANOVA tests the null hypothesis that there are no significant differences between the mean weights of bottles from different factories.
- The ANOVA model used is:
-

$$Yij = \mu + \tau i + \epsilon ij \quad (12)$$

Where: ***Y_{ij}***- is the **j**-th observation in the **i**-th group, **μ**-is the overall mean, **τi**-is the effect of the **i**-th group, and **ϵij**-is the random error term.

The total sum of squares (SS) is partitioned into components attributable to the different sources of variation:

$$SS_F = T - \sum_{j=1}^{q} F_j \tag{13}$$

$$SS_F = \sum_{i=1}^{m} \sum_{j=1}^{q} F_{ij} - SS_F \tag{14}$$

$$SS = \sum\nolimits_{i=1}^{m} [(\frac{S}{N})_i]^2 - \frac{1}{m} - [\sum_{i=1}^{m} (\frac{S}{N})_i]^2 \tag{15}$$

Discussion and Results

Descriptive Statistics Analysis

The descriptive statistics reveal notable differences in the average weights of bottled water produced by the three factories: CNO, Dijla, and Shaimaa. Shaimaaas shown in table (4) demonstrates the highest mean weight at 504.58 mg, followed by CNO at 494.67 mg, and Dijla at 491.58 mg. Variability in bottle weights, as indicated by standard deviations, is highest for Dijla (1.88 mg), whereas CNO (1.56 mg) and Shaimaa (1.73 mg) exhibit comparatively lower variability.

Table 4. Descriptive Statistics Analysis

Variable	Factory	N	Mean	SE Mean	St. Dev.	Variance	Coef. Var.	Min.	Max.	Median	Range
Weight	CNO	12	494.67	0.449	1.56	2.42	0.31	491	496	495	5
	Dijla	12	491.58	0.543	1.88	3.54	0.38	489	496	491	7
	Shaimaa	12	504.58	0.499	1.73	2.99	0.34	501	507	504	6

The range of weights further underscores variability, with Dijla showing the widest range (7.00 mg) and Shaimaa the narrowest (6.00 mg), suggesting differing levels of consistency in production processes across these factories.
Histogram of weights for CNO, Shaimaa and Dijla are shown in figure 3.

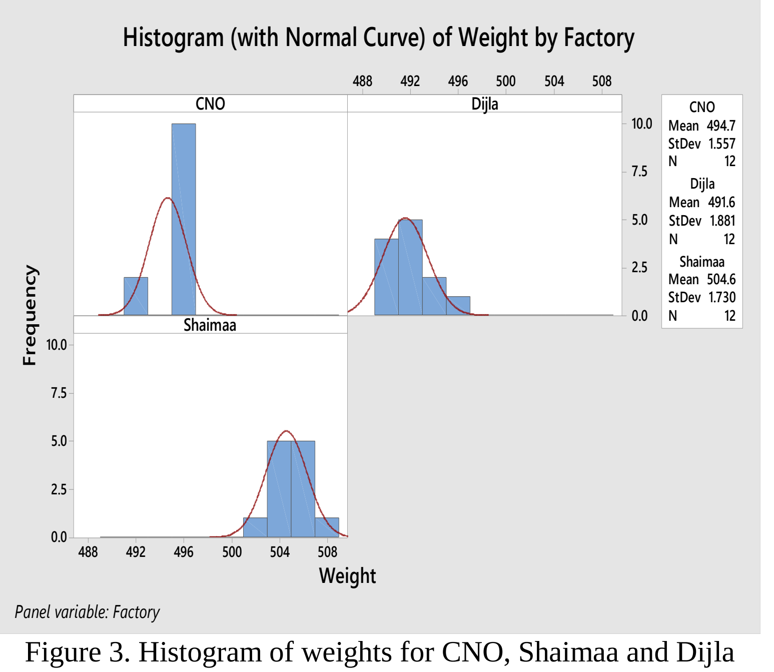

Figure 3. Histogram of weights for CNO, Shaimaa and Dijla

Control Charts and Process Stability

The I-MR Chart highlights instances where bottle weights exceed 3 standard deviation limits, particularly in specific sample ranges, indicating potential process instability and the presence of outliers (Figure 4).

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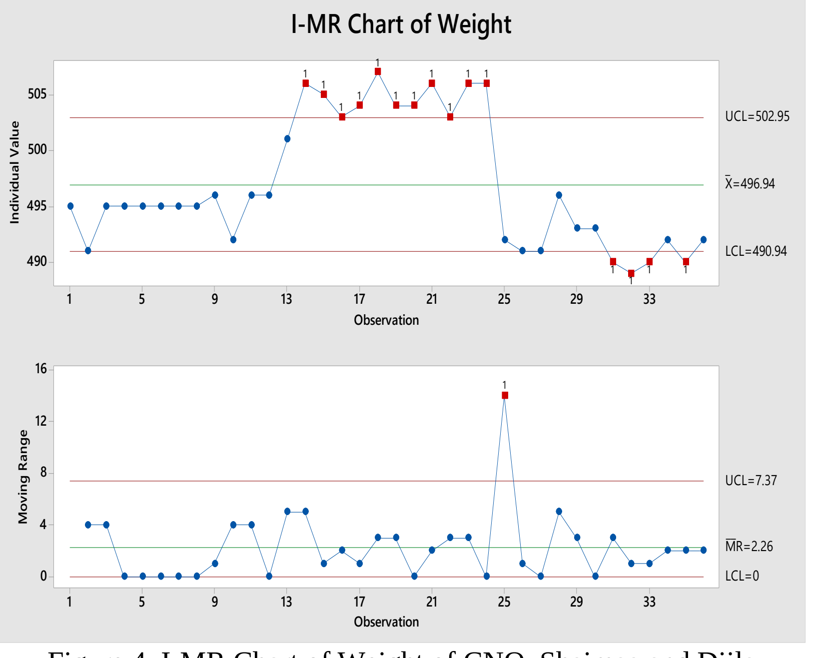

Figure 4. I-MR Chart of Weight of CNO, Shaimaa and Dijla

This underscores the need for enhanced process control measures to mitigate such variability and ensure consistent product quality.

Process Capability Analysis

Under two defined scenarios for weight specifications, the process capability analysis indicates significant challenges across all factories in meeting consistent weight requirements:

1. **Scenario 1**: Specification Limits Based on 3 Sigma

CNO, Shaimaa, and Dijla all exhibit Cpk values below 1.0, indicating insufficient capability to consistently meet weight specifications within the specified tolerance limits (Figure 5-a,b,c,d). This suggests a need for process improvements to enhance consistency and reliability in meeting production targets.

Figure 5 (a, b, c and d) shows the process Capability for Weight CNO-Shaimaa- Dijla with Specification Limits Based on 3 Sigma

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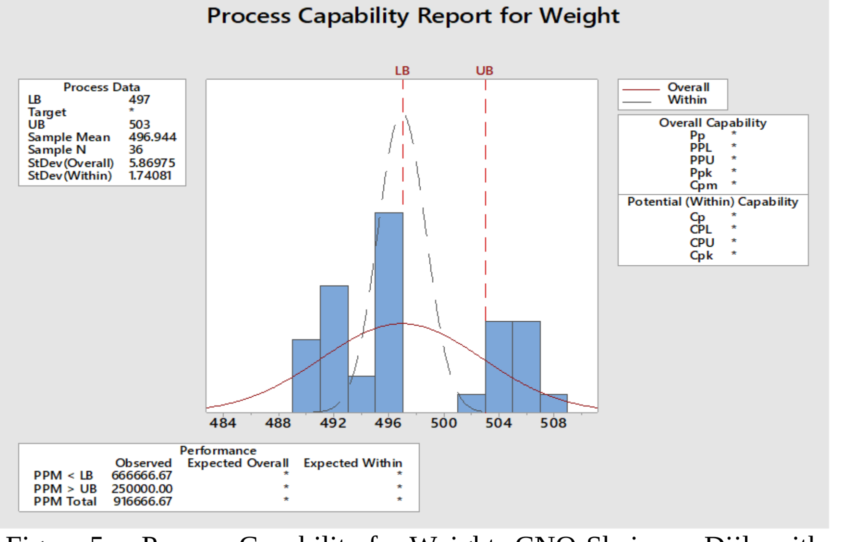

Figure 5-a. Process Capability for Weights CNO-Shaimaa- Dijla with Specification Limits Based on 3 Sigma

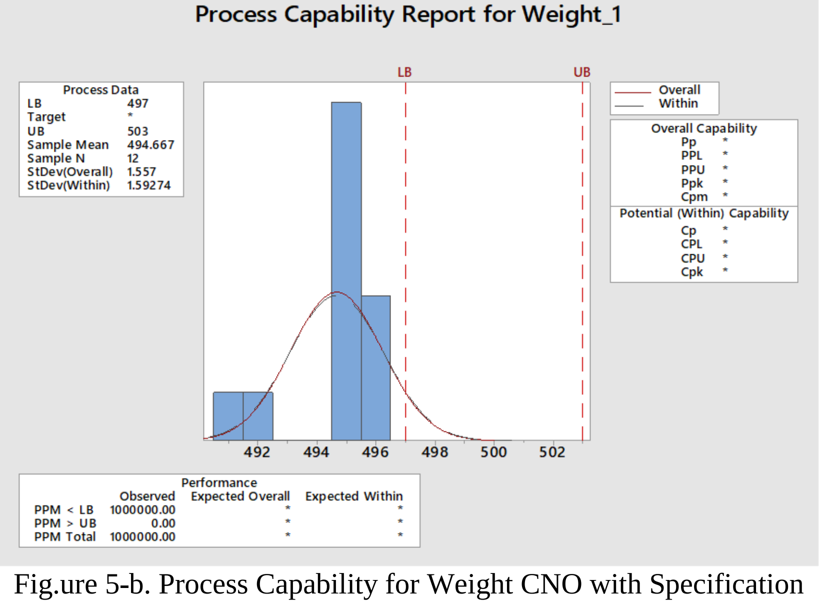

Fig.ure 5-b. Process Capability for Weight CNO with Specification Limits Based on 3 Sigma

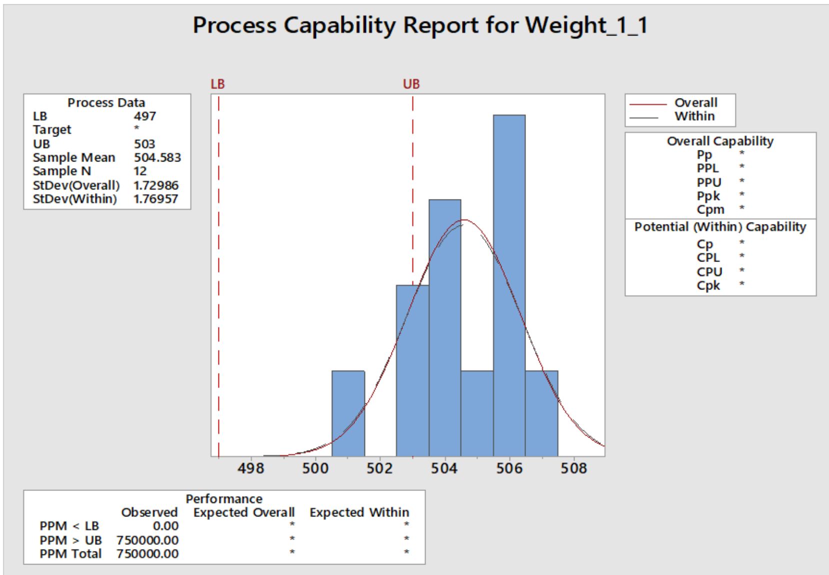

Figure 5-c. Process Capability for WeightShaimaawith Specification Limits Based on 3 Sigma

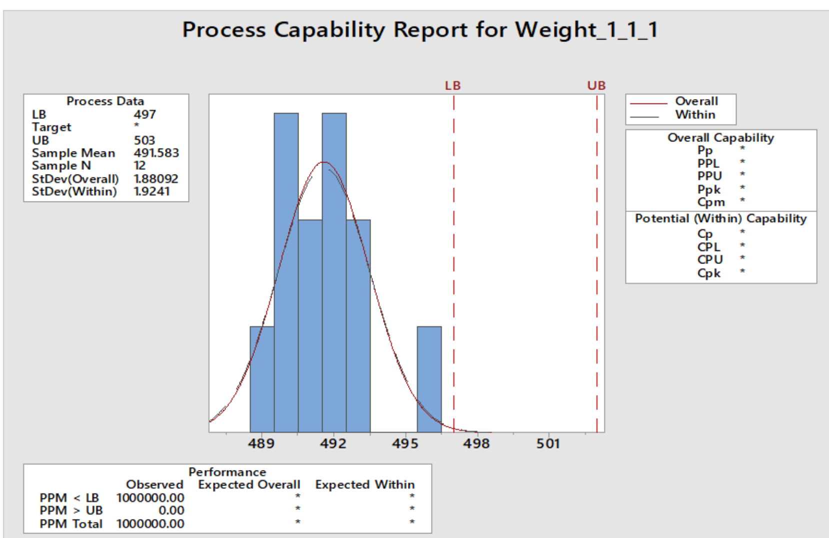

Figure 5-d. Process Capability for WeightDijlawith Specification Limits Based on 3 Sigma

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2. **Scenario 2:** Specification Limit Based on Minimum Customer Expectation (LSL: 500 grams)

While Shaimaa shows a Cpk value slightly above 1.0, indicating a higher likelihood of meeting the minimum weight expectation of 500 grams, CNO and Dijla both demonstrate Cpk values below 1.0 (Figure 6-a, b,c). This implies that these factories struggle to consistently produce bottles meeting the minimum customer expectation, highlighting areas for targeted process enhancements.

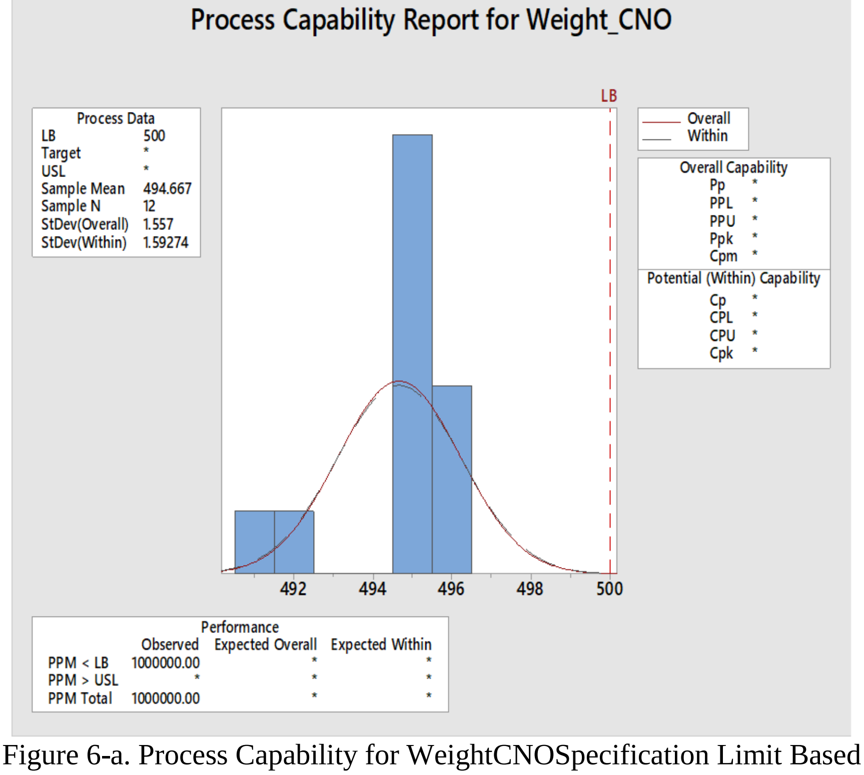

Figure 6-a. Process Capability for WeightCNOSpecification Limit Based on Minimum Customer Expectation

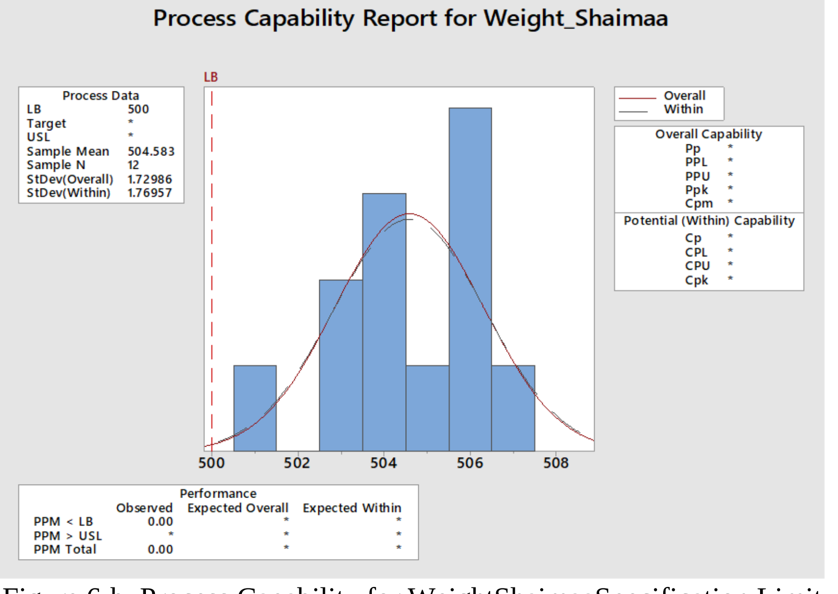

Figure 6-b. Process Capability for WeightShaimaaSpecification Limit Based on Minimum Customer Expectation

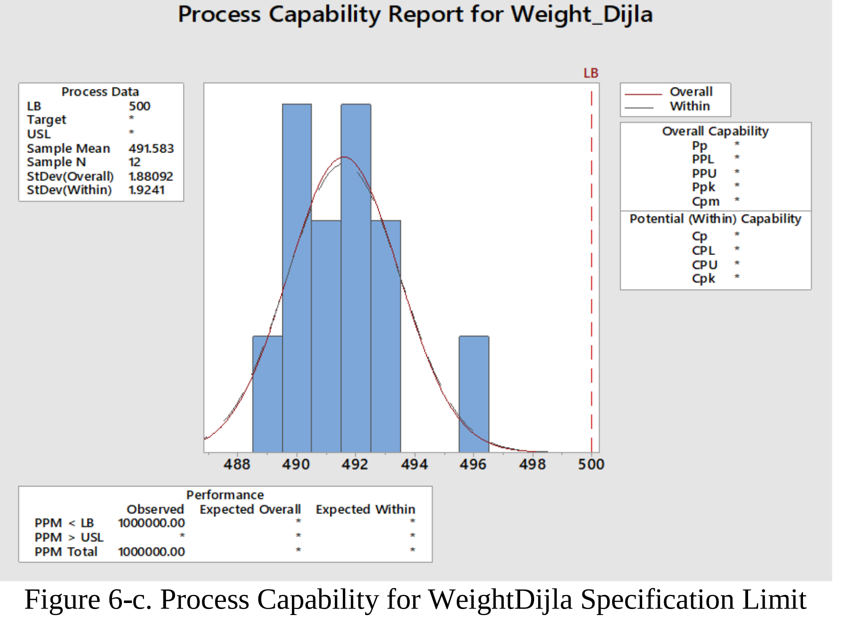

Figure 6-c. Process Capability for WeightDijla Specification Limit Based on Minimum Customer Expectation

Analysis of Variance (ANOVA) and Post-Hoc Testing

Statistical analysis via ANOVA confirms significant differences (p< 0.0001) in the mean weights of bottled water among CNO, Dijla, and Shaimaa as shown table 5.

Table 5. Analysis of Variance (ANOVA) for CNO, Dijla, and Shaimaa

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factory	2	1107.39	553.694	185.50	0.000
Error	33	98.50	2.985		
Total	35	1205.89			

Tukey's Honestly Significant Difference (HSD) post-hoc test further reveals as shown in the table 6.

Table 6. Grouping Information Using the Tukey Method and 95% Confidence

Factory	N	Mean	Group		
Shaimaa	12	504.583	A		
CNO	12	494.667		B	
Dijla	12	491.583			C

That Shaimaa consistently produces bottles with significantly higher average weights compared to CNO and Dijla, whereas there is no significant difference between CNO and Dijla in terms of mean bottle weight as illustrated in figure 7.

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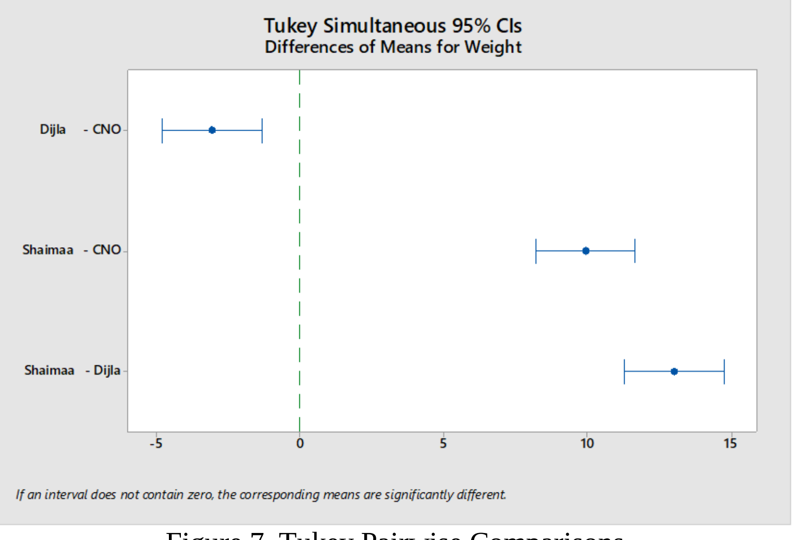

Figure 7. Tukey Pairwise Comparisons

One-Sample T-Tests

One-sample t-tests conducted for each factory validate these findings by providing confidence intervals for mean bottle weights. The results reinforce the conclusion that Shaimaa consistently achieves higher average weights compared to its counterparts, while CNO and Dijla lag behind in meeting weight expectations.

CNO Weights Analysis:

The one-sample t-test for the weights of Plant CNO as shown in table 7 that the mean weight is 494.667 grams with a standard deviation of 1.557 grams. The standard error of the mean is 0.449 grams, and the 95% confidence interval for the mean is (493.677; 495.656). This data indicates that Plant CNO's mean weight is significantly below the ideal weight of 500 grams, suggesting that the plant's bottles consistently weigh less than expected.

Table 7. One-Sample T-Test for Weights of CNO

N	Mean	StDev	SE Mean	95% CI for μ
12	494.667	1.557	0.449	(493.677; 495.656)

Shaimaa Weights Analysis:
The one-sample t-test for the weights of Plant Shaimaa as in table 8 shows a mean weight of 504.583 grams with a standard deviation of 1.730 grams. The standard error of the mean is 0.499 grams, and the 95% confidence interval for the mean is (503.484; 505.682). This indicates that Plant Shaimaa consistently produces bottles that are significantly heavier than the ideal weight of 500 grams.

Table 8. One-Sample T-Test for Weights of CNO

N	Mean	StDev	SE Mean	95% CI for μ
12	504.583	1.730	0.499	(503.484; 505.682)

Dijla Weights Analysis:
The one-sample t-test for the weights of Plant Dijla as shown table 9 indicates a mean weight of 491.583 grams with a standard deviation of 1.881 grams. The standard error of the mean is 0.543 grams, and the 95% confidence interval for the mean is (490.388; 492.778). This shows that Plant Dijla's bottles are consistently underweight compared to the ideal 500 grams.

Table 9. One-Sample T-Test for Weights of Dijla

N	Mean	StDev	SE Mean	95% CI for μ
12	491.583	1.881	0.543	(490.388; 492.778)

In conclusion, the one-sample t-tests highlight significant discrepancies in the average weights of bottled water produced by the three plants. Plant Shaimaa exceeds the ideal weight, while Plants CNO and Dijla produce bottles that consistently weigh less than expected, indicating areas where quality control measures need to be improved.

Conclusion

Based on the comparative analysis of the weight consistency in half-liter bottled water from CNO, Shaimaa, and Dijla plants, the following conclusions and recommendations can be drawn:

- **Significant Variability in Weights:** Notable variability exists across the three plants. Shaimaa demonstrated the highest mean weight (504.58 grams) and the most consistent production process, while Dijla showed the greatest variability, indicating a need for improved quality control.
- **Process Stability and Control:** Control charts revealed instances of instability in all plants, suggesting the presence of outliers and potential process shifts. Enhanced process control measures are required to mitigate these variations.
- **Process Capability:** None of the plants consistently met weight specifications, with Cpk values below 1.0 in most cases. Shaimaa showed a slightly better capability in meeting the minimum weight expectation of 500 grams, while CNO and Dijla struggled.
- **Statistical Analysis:** ANOVA confirmed significant differences in mean weights among the plants, with Shaimaa producing significantly higher average weights. One-sample t-tests validated these findings.

Recommendations for Improvement:

- **Implement Advanced Quality Control Methods:** Use Six Sigma methodologies and Total Quality Management (TQM) to reduce process variations.
- **Adopt Real-Time Monitoring:** Employ automated inspection systems and real-time data analytics to monitor and address deviations.
- **Regular Calibration and Maintenance:** Regularly calibrate and maintain weighing equipment to ensure accuracy.
- **Training and Development:** Provide continuous training on quality control measures and the importance of weight consistency.

- **Continuous Process Improvement:** Foster a culture of continuous improvement by regularly reviewing and refining processes based on data-driven insights.

By addressing these areas, the bottling plants can enhance their production processes, ensuring consistent product quality and customer satisfaction.

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