# Quality Assurance and Quality Control in a Bottle Manufacturing Company Using Statistical Quality Control

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*Author's contribution*

*The sole author designed, analyzed, interpreted and prepared the manuscript.*

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## ABSTRACT

The present paper aimed to investigate the analysis of quality losses in the manufacturing process of 50 cl R/Spirit bottles using Statistical Quality Control method. The analysis covered the factors that affect the quality of the glass bottles and how the production process can be optimized to minimize defects. The data obtained from our investigation hub for 13 days was successfully analyzed using quality control charts and Taguchi quality loss function. The Taguchi quality loss function was successfully employed to calculate quality loss. The loss incurred due to defects was N25, 636.84. Results obtained from $X$ chart and $P$ chart showed that the manufacturing process was out of control as some points fell outside the control limits. The possible causes of variations were identified and eliminated. This led to a reduction in the number of defective bottles produced per batch of production. The common causes of defects and deviations from target values were due to imperfection in the production process, traceable to the operators, machine and inappropriate proportion of raw materials.

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## 1. INTRODUCTION

Nowadays, glass packaging manufacturers tend to create light weight containers without sacrificing strength or performance characteristics. They continue to search for new ways to strengthen glass, through new surface treatments and better designs, without altering the improvements in material reduction and also reducing the total loss (manufacturing cost plus quality loss) [1]. To achieve this target, many studies have been done to improve the quality/cost ratio by optimizing the manufacturing process via regulation machine product with the latest one [2], reducing the raw material and energy consumption by recycling the waste product of glass [3] and optimization of the glass batch composition [4]. Aiming to achieve concurrence, the glass manufacturer uses many new tools and strategies to develop both the product and process designs.

One of the definitions of quality besides "fitness for use" or "satisfying customer's requirements" is simply "conformance to requirements" [5]. As a result of the inherent variability in manufacturing processes, it is almost impossible to produce products that will always match their ideal targets perfectly. That is why every product dimension and characteristic of interest has to have tolerance limits around its target value. With these tolerance limits, the product dimension or characteristic is considered to be satisfactory if its value falls within the specified limits. On the other hand, if the value falls outside the tolerance limits, the dimension or characteristic would be considered unsatisfactory and it must be reworked or scrapped. Moreover, it is worth mentioning that the natural variability in any quality characteristic of a product, i.e. its variance, is a signature of the process itself while the mean of the quality characteristic depends upon the process setting [5].

Therefore, a study on optimization of the manufacturing process with concrete design to achieve adequate nominal target value is of considerable importance. In a concrete design, the number of experiments increases with the number of variables. Thus the main objective of this work was to identify processes that lead to quality losses in the manufacturing of 50 cl R/Spirit bottle.

Control charts and the Taguchi loss function were employed to optimize the manufacturing process. These improvements were aimed to improve the desired characteristics and simultaneously reducing the number of defects by studying the key variables controlling the process and optimizing the procedures or design to yield, which is applicable over a wide range of engineering fields that include processes that manufacture raw materials, sub-systems, products for professional and consumer markets.

The aim of this study was to optimize manufacturing processes by:

i.  Minimizing the defects in the production process of the industry.
ii. Improvement of the quality to meet customers' specification.

The investigation hub is Beta Glass Company Limited, Nigeria.

## 2. EXPERIMENTAL DESIGN

The basic models used in this research are the statistical quality control (SQC) and Taguchi loss function.

## 2.1 Control Charts

A control chart can be defined as a product quality characteristic with limits reflecting the ability to produce, as shown by past experience on the product characteristics. Variations in the manufacturing process are unavoidable. Control charts detect variations in a process and warn if there is any shift from the specified tolerance limits.

Advantages of control charts are:

a.  It indicates whether the process is in or out of control at a particular point of time.
b.  It ensures a level of quality and hence also builds up the reputation of the organization due to customer's satisfaction.
c.  It detects unusual variations taking place in a period.
d.  It helps in reducing rejections, as it warns in time so that process can be rectified in time.
e.  It helps in setting the tolerance limits.

### 2.1.1 Process out of control

After computing the control limits, the next step is to determine whether the process is in statistical control or not. If it is not, then there exists an external cause that drives the process out of control. This cause must be traced and removed so that the process may return to operate under stable statistical conditions. When the process is not in control, the points fall outside the control limits on either $\bar{X}$ and $R$ charts. It means assignable causes (human controlled causes) are present in the process.

### 2.1.2 Process in control

If the process is found to be statistically in control, a comparison between the required specifications and the process capability may be carried out to determine whether the two are compatible or not.

## 2.2 Types of Control Charts

With respect to the two types of inspection methods:

1. When the method of inspection is by variables, the most popular control chart is $\bar{X}$ and R charts
2. When the method of inspection is by attributes, the most common or popular charts are fraction or percent defective charts, (*P*-chart).

Preparation of these two types of control charts are similar and involve the following steps:

i. Select the appropriate quality characteristics to be studied.
ii. Record the data taken on a required number of samples.
iii. Determine the limit from these same sample data.
iv. Check if the control limits are economically satisfactory for the job.
v. Plot the control limits on the suitable graph and record the result for samples at a periodic interval
vi. Take corrective action if the characteristics of the production sample exceed the control limit.

The upper and lower control limits of the charts are computed as follows:

For $\bar{X}$ chart;

$$\text{Upper Control limit } UCL_{\bar{X}} = \bar{\bar{X}} + A_2 \bar{R} \tag{1}$$

$$\text{Lower Control limit } LCL_{\bar{X}} = \bar{\bar{X}} - A_2 \bar{R} \tag{2}$$

For $R$ chart:

$$\text{Upper Control limit } UCL_R = D_4 \bar{R} \tag{3}$$

$$\text{Lower Control limit } LCL_R = D_3 \bar{R} \tag{4}$$

$\bar{\bar{X}}$ = Mean of the mean of $X$ chart and $\bar{R}$ is the Mean of the Range.

For *P* chart:

$$\sigma_p = \sqrt{\frac{\bar{P}(1-\bar{P})}{n}} \tag{5}$$

$\sigma_p = Standard\ deviation\ for\ fraction\ defective$

$$Upper\ Control\ Limit, UCL_P = \bar{P} + 3\,\sigma_p \tag{6}$$

$$Lower\ Control\ Limit, UCL_P = \bar{P} + 3\,\sigma_p \tag{7}$$

Where $n = sample\ size$

$\bar{P} = fraction\ defective$

The factors $A_2, D_3$ and $D_4$ depend on the number of units per sample. The values of these factors are obtained from the Statistical Quality Control Chart in Table 1.

## 2.3 Taguchi Quality Loss Function

Maghsoodloo [6] suggested that one of the most significant contributions of Taguchi's work in the quality engineering field is his quadratic loss function. That is because it provided a new definition of quality and a new vision for what needs to be sought after for improving the quality of a product or a process. Moreover, it provided a tool for measuring the monetary cost of not adhering to the principles of being on target and minimizing variability. The most widely used form of Taguchi's loss function is the quadratic form that is arrived by employing the Taylor series expansion and ignoring higher order terms. According to Byrne et al. [7], the quality loss function for a Nominal - The - Best (N-type) quality characteristic is given as:

$$L(y) = \frac{A_0}{\Delta_0^2}\,(y - ^2 \tag{7}$$

$$K = \frac{A_0}{\Delta_0^2} \qquad (8)$$

$$L(y) = K(y - ^2 \qquad (9)$$

where $L(y) = Loss\ function$

$K = Constant\ of\ proportionality$
$A_0 = Consumer\ loss\ or\ cost\ to\ repair\ a\ product$
$\Delta_0^2 = Point\ of\ intolerance$
$y = Quality\ features\ of\ the\ selected\ product$

**Table 1. Control chart constants**

| n | A₂ | A₃ | d₂ | D₃ | D₄ | B₃ | B₄ |
|---|------|------|------|------|------|------|------|
| 2 | 1.880 | 2.659 | 1.128 | 0.000 | 3.267 | 0.000 | 3.267 |
| 3 | 1.023 | 1.954 | 1.693 | 0.000 | 2.574 | 0.000 | 2.568 |
| 4 | 0.729 | 1.628 | 2.059 | 0.000 | 2.282 | 0.000 | 2.266 |
| 5 | 0.577 | 1.427 | 2.326 | 0.000 | 2.114 | 0.000 | 2.089 |
| 6 | 0.483 | 1.287 | 2.534 | 0.000 | 2.004 | 0.030 | 1.970 |
| 7 | 0.419 | 1.182 | 2.704 | 0.076 | 1.924 | 0.118 | 1.882 |
| 8 | 0.373 | 1.099 | 2.847 | 0.136 | 1.864 | 0.185 | 1.815 |
| 9 | 0.337 | 1.032 | 2.970 | 0.184 | 1.816 | 0.239 | 1.761 |
| 10 | 0.308 | 0.975 | 3.078 | 0.223 | 1.777 | 0.284 | 1.716 |
| 11 | 0.285 | 0.927 | 3.173 | 0.256 | 1.744 | 0.321 | 1.679 |
| 12 | 0.266 | 0.886 | 3.258 | 0.283 | 1.717 | 0.354 | 1.646 |
| 13 | 0.249 | 0.850 | 3.336 | 0.307 | 1.693 | 0.382 | 1.618 |
| 14 | 0.235 | 0.817 | 3.407 | 0.328 | 1.672 | 0.406 | 1.594 |
| 15 | 0.223 | 0.789 | 3.472 | 0.347 | 1.653 | 0.428 | 1.572 |
| 16 | 0.212 | 0.763 | 3.532 | 0.363 | 1.637 | 0.448 | 1.552 |
| 17 | 0.203 | 0.739 | 3.588 | 0.378 | 1.622 | 0.466 | 1.534 |
| 18 | 0.194 | 0.718 | 3.640 | 0.391 | 1.608 | 0.482 | 1.518 |
| 19 | 0.187 | 0.698 | 3.689 | 0.403 | 1.597 | 0.497 | 1.503 |
| 20 | 0.180 | 0.680 | 3.735 | 0.415 | 1.585 | 0.510 | 1.490 |
| 21 | 0.173 | 0.663 | 3.778 | 0.425 | 1.575 | 0.523 | 1.477 |
| 22 | 0.167 | 0.647 | 3.819 | 0.434 | 1.566 | 0.534 | 1.466 |
| 23 | 0.162 | 0.633 | 3.858 | 0.443 | 1.557 | 0.545 | 1.455 |
| 24 | 0.157 | 0.619 | 3.895 | 0.451 | 1.548 | 0.555 | 1.445 |
| 25 | 0.153 | 0.606 | 3.931 | 0.459 | 1.541 | 0.565 | 1.435 |

$m = Nominal\ value\ of\ the\ product$

$(y - m) = Tolerance$ or Mean-Squared Deviation (MSD)

$$MSD = \frac{1}{n}\left((y_1 - m)^2 + (y_2 - m)^2 + (y_n - m)^2\right) \qquad (10)$$

The evaluation of the quality of products using the Taguchi quality loss function approach for three types of tolerances are listed below:

a. The – Nominal - The Best (N type)
b. The - Smaller -The Better (S type)
c. The - Larger -The Better (L type)

These tolerances are applied to different quality characteristics depending on the available data. For example, when the study involves product parts, element, and composition, the nominal - the best is the recommended option for tolerance. Where characteristics such as, the strength of materials and fuel efficiency are studied, the recommended option is to use the - larger - the better tolerance. The - smaller - the better tolerance is used when tolerance involves a non-negative characteristic.

## 2.4 Analysis of Data from Beta Glass Nigeria Plc on Bottle Product

During the production of bottles in the company as mentioned earlier, the rate of production is determined by the demand of the customers and efficiency of machines. Also, sizes of the bottles are considered. The data collection began from the quarry where sand was dredged and was taken to the treatment plant where it was treated and impurities removed from it to get the

**Table 2. Data obtained for 50cl R/spirit bottle production for 13 days**

| Day | X₁ morning | X₂ afternoon | X₃ evening | ∑X | X | R |
|-----|------------|--------------|------------|-----|------|----|
| 1 | 84 | 86 | 83 | 253 | 84.3 | 3 |
| 2 | 84 | 85 | 85 | 254 | 84.7 | 1 |
| 3 | 85 | 87 | 88 | 260 | 86.7 | 3 |
| 4 | 85 | 86 | 89 | 260 | 86.7 | 4 |
| 5 | 82 | 86 | 86 | 254 | 84.7 | 4 |
| 6 | 86 | 89 | 87 | 262 | 87.3 | 3 |
| 7 | 85 | 87 | 87 | 259 | 86.3 | 2 |
| 8 | 83 | 84 | 89 | 256 | 83.3 | 6 |
| 9 | 83 | 88 | 87 | 258 | 86 | 5 |
| 10 | 89 | 89 | 86 | 264 | 88 | 3 |
| 11 | 84 | 78 | 81 | 243 | 81 | 6 |
| 12 | 91 | 89 | 89 | 269 | 89.7 | 2 |
| 13 | 80 | 82 | 83 | 165 | 55 | 1 |
| | | | | | $\bar{X}$ = 1085.7 | R = 43 |

**Table 3. Deviation from target value, $m$**

| $y_n - m$ | 90 | - 91 | 120 | -180 | -80 | 10 | -278 |
|-----------|-----|------|-----|------|-----|-----|------|
|           | 398 | 129  | -83 | 179  | 443 | 220 | 310  |
|           | 211 |      |     |      |     |     |      |

desirable grain size. The silica sand was dried before it could be used for batching. In the batching machine, a mixture of silica sand of 783 kg, limestone 224 kg, feldspar 31 kg, soda ash 228 kg and sulphate 7 kg were properly mixed in the silos before sending it to the furnace through a conveyor belt together with the cullet (treated broken bottles) which will be heated homogeneously at a temperature of 1560°C. The temperature is checked at intervals with a thermocouple. Each and every stage of the production has a check proof (i.e. filtration) to remove impurities. A record of 50cl R/Spirit Bottle Production for 13 days is shown in Table 2.

## 3. RESULTS AND DISCUSSION

### 3.1 Evaluation of Bottle Product (The-nominal-the-best)

In this study, The-Nominal-The Best tolerance was applicable because the characteristic under study was the number of defective bottles produced per batch of production. The cost of a defective bottle of 50cl R/Spirit is N25. The deviation from the target value is ±1500.

Using equations (9) and (10), the quality loss function, $L$, is obtained.

$n = sample\ size = 15$
$m = 0$
$MSD = \frac{1}{15}((90)^2 + (-91)^2 + (120)^2 + (-180)^2 + (-80)^2 + (10)^2] + (-278)^2 + (398)^2 + (129)^2 + (-83)^2 + (-179)^2 + (443)^{2+} (220)^2 + (310)^2 + (211)^2)$
$MSD = (y - m)^2 = 49873.6577$

Substituting into equation (9);

$L(y) = K(y - m)^2$

$K = 25/1500^2$
$K = 0.00001111$

Therefore, the quality loss function, $L$,

$L = 0.00001111 \times 49873.6577$
$L = N24,634$

The Taguchi method of quality loss function showed that the loss incurred due to defects for a period of 13 days was N25,636.84.

Using the data provided in Table 2 to obtain values for the $\bar{X}$ chart and $R$ chart.

$\bar{X} = 1085.7\ and\ R = 43$
$Sample\ size, n = 13$

Mean of the Mean, $(\bar{\bar{X}}) = \frac{\sum \bar{X}}{n} = \frac{1085.7}{13} = 83.5$
$Range, \bar{R} = \frac{43}{13} = 3.3$

For $\bar{X}$ chart:

To obtain the upper and lower control limits, we use equation (1) and (2)

The value of $A_2$, $D_3$, and $D_4$ are obtained from Table 1.

*Upper Control Limit, UCL* = 83.5 + 1.023 x 3.3
$UCL = 86.9$

Lower Control Limit, $UCL$ = 83.5 − 1.023 x 3.3
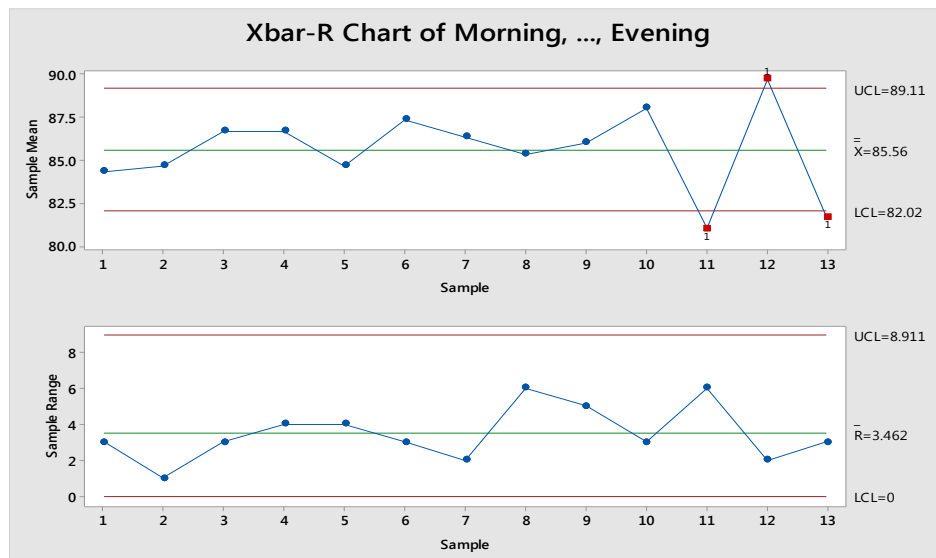$LCL = 83.5 − 3.3759$
$LCL = 80.1241$

**Table 4. Data for morning shift**

| Sample no. | Defective number | Sample size |
|------------|------------------|-------------|
| 1  | 1 | 100 |
| 2  | 1 | 100 |
| 3  | 2 | 100 |
| 4  | 1 | 100 |
| 5  | 1 | 100 |
| 6  | 2 | 100 |
| 7  | 2 | 100 |
| 8  | 3 | 100 |
| 9  | 0 | 100 |
| 10 | 1 | 100 |
| 11 | 3 | 100 |
| 12 | 2 | 100 |
| 13 | 3 | 100 |

For *R* chart:

Using equation (5) and (6), we obtain the following control limits.

$UCL = 2.574$ x 3.3
$UCL = 8.4942$
$UCL \approx 8.5$
$LCL = 0$ x 3.3
$LCL = 0$

**Fig. 1. Minitab plot of X chart and R chart**

The red horizontal lines in Fig. 1(a) and Fig. 1(b) represents the control limits; the green colour represents the sample mean and sample range respectively. Fig. 1(a) represents the $X$ chart plot while Fig. 1(b) represents the $R$ chart. The red points indicate the variables that are outside the control limits while the blue points show the variables that are within the control limits. A process is said to be out of control if there are points which fall outside the control limits. From the $X$ chart in Fig. 1(a), it is evident that the process is out of control since three points fall outside the control limits. These points must be identified and removed, so that the process can return to stable statistical conditions to eliminate defects. The reason must be investigated and eliminated to return to operate under stable statistical conditions. The reasons for the process being out of control may be:

a. Faulty tools
b. Sudden significant change in properties of new materials in a new consignment
c. Breakdown of the lubrication system
d. Faults in the timing of speed mechanisms etc.

In Fig. 1(b), there are no red points in the $R$ chart which means that all the points are within the control limits. This means the process is in control and is compatible with specifications.

$$\bar{P} = \frac{24}{13 \times 100} = 0.018$$

$$Percent\ defect = 100P = 100 \times 0.018 = 1.8\%$$

**Table 5. Number of defectives**

| Day | Actual production | No. of defective (D) | $P_2 = D/n$ |
|---|---|---|---|
| 1 | 25,597 | 1590 | 0.062 |
| 2 | 25,485 | 1409 | 0.055 |
| 3 | 36,632 | 1620 | 0.044 |
| 4 | 26,098 | 1320 | 0.051 |
| 5 | 25,574 | 1481 | 0.055 |
| 6 | 36,746 | 1510 | 0.041 |
| 7 | 25873 | 1222 | 0.047 |
| 8 | 23646 | 1102 | 0.047 |
| 9 | 35772 | 1629 | 0.046 |
| 10 | 25986 | 1417 | 0.055 |
| 11 | 24955 | 1321 | 0.053 |
| 12 | 32962 | 1943 | 0.059 |
| 13 | 24214 | 1720 | 0.071 |
| | | **Σd = 19214** | **ΣP = 0.656** |
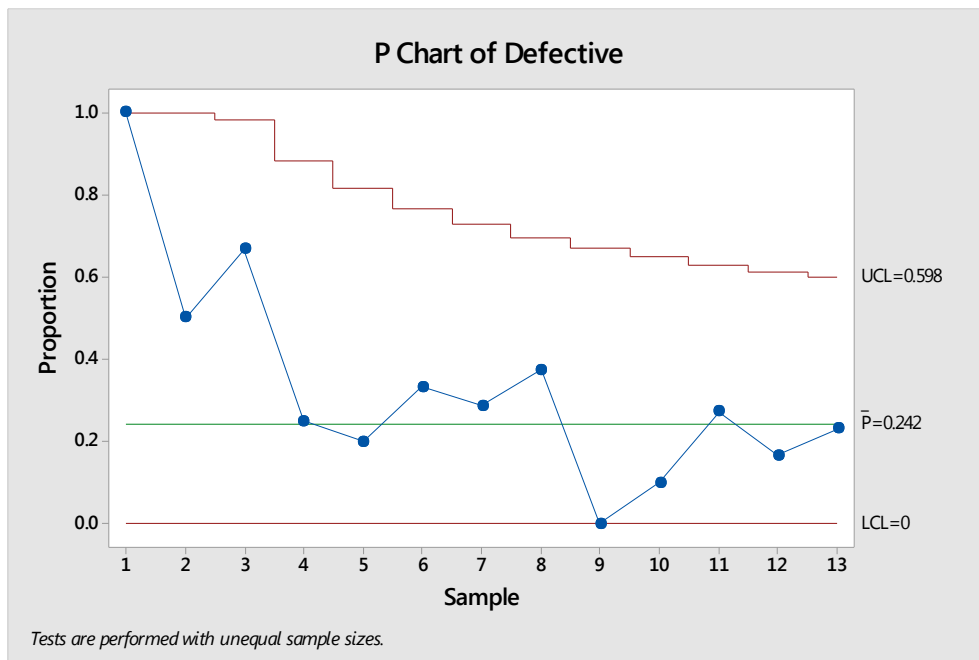
**Fig. 2. Minitab plot of *P* chart for morning shift**
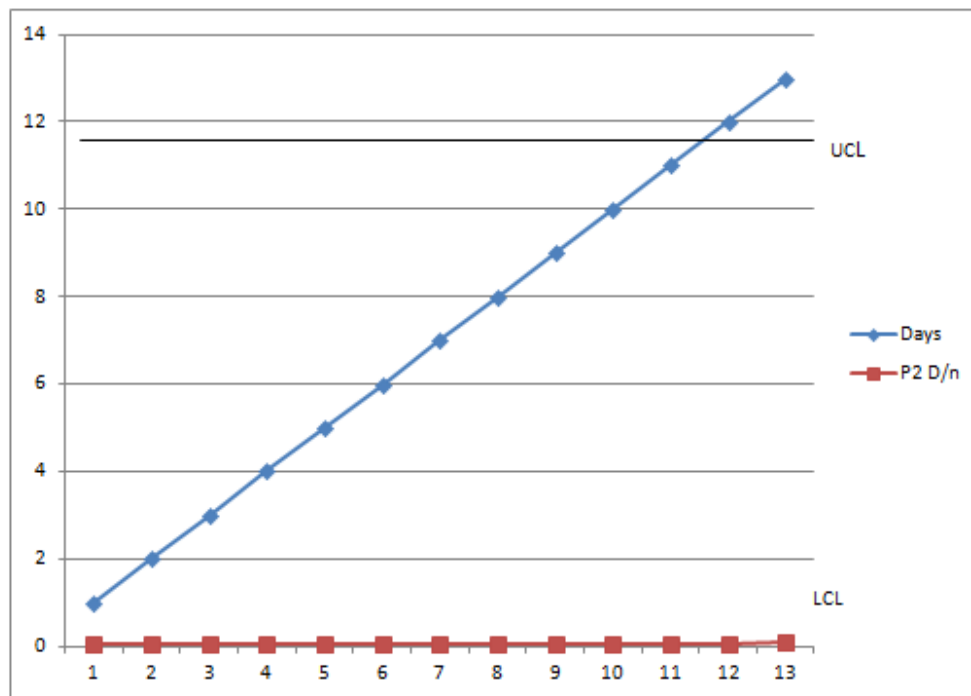


**Fig. 3. *P* chart for the number of defective**

Using equation (5), (6) and (7) to calculate control limits;

$$\sigma_p = 0.012$$
$$UCL = 0.025 + 3(0.012) = 0.05$$
$$LCL = 0.025 - 3(0.012) = 0$$

The red line in the graph represents the control limits; the green line represents the fraction defective. The blue points are the points which fall within the control limits while the red points indicate the points outside the control limits. There are no points outside the control limits as can be seen in Fig. 2. That means that the

process is not out of control. The manufacturing process is according to the specification.

$$\bar{P} = \frac{0.656}{13} = 0.053$$

$$UCL = 0.053 + 3\sqrt{\frac{0.053\,(1-0.053)}{19214}}$$

$$UCL = 0.058$$

$$LCL = 0.053 - 3\sqrt{\frac{0.053\,(1-0.053)}{19214}} = 0.048$$

All the points on the $P$ chart are within the control limits as observed in Fig. 3. Hence, it can be said that the process is statistically controlled. A comparison between the required specifications and the process capability was carried out to determine whether the two were compatible. The obtained result showed compatibility.

## 4. CONCLUSION

In this research study, problems of quality losses in a bottle manufacturing company domiciled in Nigeria was successfully addressed by applying Statistical Quality Control method. Results obtained from the control charts in the data analysis showed that the number of defective products was high and needs to be controlled to a minimum limit. The production process operates on a tolerance type known as The - Nominal - The - Best. It is a situation where the defects level is maintained between bilateral limit to achieve a less defective production process and saving of time. The values obtained from p-chart showed that the variations are far apart from the theoretical gross production calculated N25,636.84 for 13 days and that the fraction defective is out of control. This shows that the variation is far from the nominal value of defective production. The Taguchi method of quality loss function also showed that the loss incurred due to defects for 13 days was N25,636.84. Therefore, a strong signal to noise ratio should be developed to prevent defects and optimize the cost.

## COMPETING INTERESTS

Author has declared that no competing interests exist. The products used for this research are commonly and predominantly used products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by the personal efforts of the authors.

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