MANAGEMENT OF THE PRODUCTION PROCESS OF A WATER BOTTLING PLANT TO IMPROVE QUALITY: A CASE STUDY

IHUNWO K. C.
Faculty of Engineering,
University of Port Harcourt,
Rivers State, Nigeria.
(Email: *ihunwokc@yahoo.com*, Phone: *+2348038100086)*

KINIGOMA B. S.
Faculty of Engineering,
University of Port Harcourt,
Rivers State, Nigeria.

ABSTRACT
Most times, the relationship between a production process and profit in an organization is mistakenly ignored without knowing that; a faulty process must always produce faulty products irrespective of the resources invested. This paper examined the management of the production process of a water bottling plant to improve quality: using a water bottling company as a case study. The objectives of the research were primarily to apply statistical process control (SPC) to manage the production process to improve quality and streamline the production process to reduce waste. Data generated by the process before and during this research were collected using data collection tools that were specifically developed by this research. Data analysis was done both qualitatively and quantitatively using control charts and visual basic dot net computer software carefully developed for the process. The results of the qualitative analysis revealed that pH, conductivity and total dissolved solids (TDS) in water increased during rainy season and decreased during dry season due to high level of contamination, water run-offs and stagnation in rainy season than dry season. Also the results from the quantitative analysis showed that the water treatment plant produced 11,814 defectives resulting to a monetary loss of ₦200,838. However, with the introduction and application of SPC, the company experienced a remarkable reduction in waste generation, showing a percentage defect/cost reduction of about 89.6%. Proper data management, documentation, employee involvement, and top management commitment were recommended to improve quality.

Keywords: Statistical Process Control (SPC), Production Process, Quality, Control Charts

1.0 Introduction

1.1 Background

Concerns about pollution and presence of pathogenic bacteria in drinking water have prompted many people to turn to packaged water as a substitute for ordinary tap water (www.articlesbase.com). What first started as a trend is now a profit making industry worldwide. Now, there is a paradigm shift from the term ‘drinking water’ to the term ‘potable water’. For water to be safe for drinking without causing any health issues, it must meet and/or exceed the health requirements of the health regulatory body of any nation or that of the World Health Organisation (WHO). In other words, for water to be potable, it must be of high quality.

Quality, or lack of quality, affects the entire organization from supplier to customer and from product design to maintenance. Perhaps more importantly, building an organization that can achieve quality also affects the entire organization and it is a demanding task. The challenge for business today is to produce quality products or services efficiently. A company that meets this challenge can use quality as a competitive weapon.

1.2 Statement of the Problem

The production process is something that has been overlooked in most organisations because most times the process is automated. Organisations err in believing that since their production process is fully automated with little or no human interference then the errors or problems associated with such systems must have been brought to its barest. The production process, in as much as is fully automated, must be properly managed because: a faulty process must always produce faulty products or services irrespective of the resources invested and thus, bringing a considerable amount of loss to the organisation.

In view of the above, the research relates to the application of SPC to manage the production process of the case study water bottling company in order to improve quality and reduce the waste associated with the production process.

1.3 Definition of terms

Management: Management has no single definition; it is defined differently by different people depending on the area of application, status, background, literacy and so on. The research defined management as the coordination of all the resources of an organisation through the process of planning, organizing, directing and controlling in order to attain organizational objectives at a reasonable time and with minimum waste.

Process: A process is the transformation of a set of inputs (which may include materials, actions, methods and operations), to desired output results (which take the form of products, information or services).

Potable water: Potable water is any packaged water that has been processed, sealed and released into the market under sealed food grade material or other appropriate containers for human consumption (FDA, 2002). This research stands to define potable water as any packaged water that is safe and fit for drinking; haven met and/or exceeded the health requirements of any health regulatory body in that nation or that of the World Health Organisation (WHO).

Quality: Quality has no single definition; it is defined differently by different people depending on the area of application, status, background, literacy and so on. The research defined quality as the totality of the features, characteristics, attributes, and so on that make a product or service able to satisfy the stated or implied needs of the customer and at the same time bringing more profit to the organization.

1.4 Statistical Process Control (SPC)

Ryan (1989) defined Statistical process control (SPC) as a decision-making technique that uses statistics to monitor the consistency of a production process and the resulting product. One of the techniques that are used to monitor manufacturing processes and provide feedback is Statistical Process Control (SPC). The feedback is used to maintain and improve the capability of the process and to ensure product conformance. SPC is used to control the process by signaling when adjustments may be necessary. Some techniques associated with SPC include frequency histograms and control charts.

1.5 Control charts

A control chart is the tool used to monitor the variation in a process and ensure that the process is in a state of control. This allows the operator to monitor the trends occurring in the process. The control chart reflects the specification limits, namely, the Upper Tolerance Limit (UTL) and the Lower Tolerance Limit (LTL). In addition, it has upper and lower control limits that lie within the specification limits.

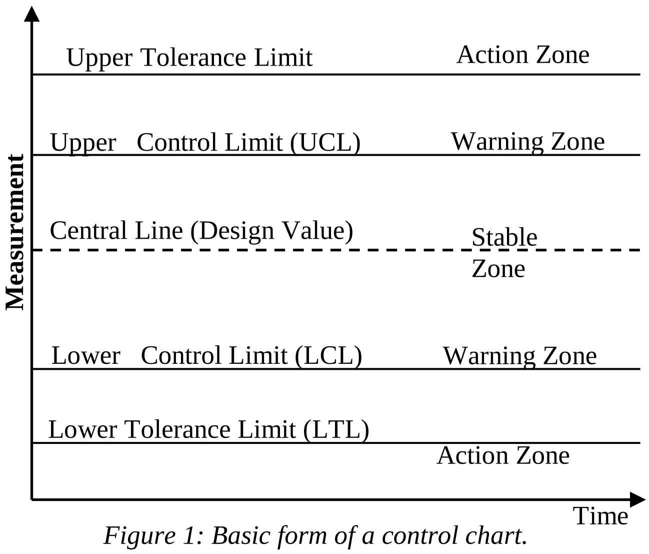

Figure 1: Basic form of a control chart.

1.6 Objectives of the Study

The primary objectives of this study are to:

1. Apply Statistical Process Control to manage the production process in order to improve quality in the case study company, and
2. Streamline the production process to reduce waste.

2.0 Research Method

Qualitative analysis: Statistical process control techniques were used for qualitative analysis of the routinely monitored physio-chemical constituents of water in the water treatment plant. The parameters monitored include:

i. pH,
ii. Conductivity, and
iii. Total Dissolved Solids (TDS)

Quantitative analysis: Statistical process control techniques were also used for quantitative and economic analysis of waste generated from the water treatment plant.

Computer Program: Visual Basic dot net computer program was developed to carry out both the qualitative and quantitative analyses, and display control charts that would aid decision-making.

2.1 Control charts used for Qualitative analysis

The control chart will be like a traffic signal, the operation of which is based on evidence from process samples taken at random intervals.

- A green light is given when the process should be allowed to run without adjustment, only random or common causes of variation being present.
- The equivalent of an amber light appears when trouble is possible.

- The red light shows that there is practically no doubt that assignable or special causes of variation have been introduced; the process has wandered.

This research used the following control charts to analyse the pH of water in the water treatment plant:

i. Mean Chart.
ii. Range Chart.
iii. Cumulative Sum (Cusum) Chart.

Note: However, only the mean control chat would be presented in this paper.

2.1.1 Mean Chart

Determining the Trial Central Line and Control Limits

The central line for the Mean ($\bar{x}$) chart is obtained using the equations:

$$\bar{\bar{x}} = \frac{\sum_{i=1}^{n} \bar{x}_i}{n} \qquad (1)$$

and

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

Where:

$\bar{\bar{x}}$ = Process mean.
$\bar{x}_i$ = Average of the ***i***th measurement.
n = Total number of days data was taken in a month
$\bar{R}$ = Average of the measurement ranges.
R_i = Range of the ***i***th measurement.

The control limits here are represented by:

$$CL\,\bar{x} = \bar{\bar{x}} \pm 3\frac{\sigma}{\sqrt{n}} \qquad (3)$$

Where:

CL $\bar{x}$ = Control limit for mean chart.
$\bar{\bar{x}}$ = Process mean.
σ = Population standard deviation.
n = Sample size.

Note:

- At the start of production, when the process is under control, take mean values ($\bar{x}$) and standard deviation (S) of the first 20 – 25 samples.
- The mean of the sample mean ($\bar{x}$) and the mean of the standard deviations are used as the estimates of the process mean ($\bar{\bar{x}}$) and population standard deviation (σ) respectively.

In practice, we make use of tables called A_2 tables (attached to the main work as Appendix C) which directly give the value of $3\frac{\sigma}{\sqrt{n}}$ as a ratio of the mean range ($\bar{R}$) for different sample sizes. Thus, obtain the mean range from the 20-25 samples and multiply this by the A_2 values corresponding to the sample size, this results in the estimation of the value $3\frac{\sigma}{\sqrt{n}}$.

This simplifies the setting up process. Thus,

$$\text{LCL } \bar{x} = \bar{\bar{x}} - (A_2)_N \bar{R} \quad (4)$$

$$\text{UCL } \bar{x} = \bar{\bar{x}} + (A_2)_N \bar{R} \quad (5)$$

Where:

UCL $\bar{x}$ = Upper control limit of the mean chart.

LCL $\bar{x}$ = Lower control limit of the mean chart.

$\bar{\bar{x}}$ = Process mean.

$(A_2)_N$ = A_2 values corresponding to the sample size.

$\bar{R}$ = Mean range.

Then, the construction of the mean control chart for the pH will be of the form:

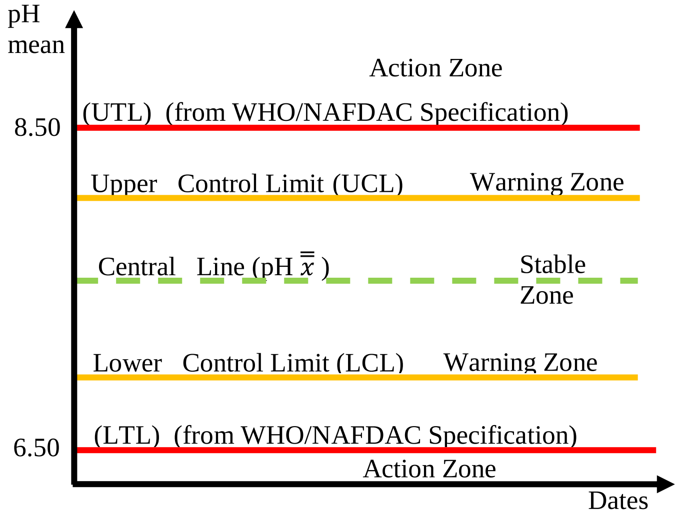

Figure 2: Mean control chart for pH.

2.2 Quantitative analysis of waste generated from the water treatment plant

This research used the Percentage Nonconforming Chart (*P*- Chart) for quantitative and economic analysis of waste generated from the water treatment plant. The quality indicator here is the proportion (that is, the percentage) of defects in a sample. The procedure for setting up control limits is as follows:

i. Select a random sample (usually large, say 200) when the process is in control and inspect 100% to determine the proportion or percentage of rejects (P).

ii. Calculate the standard error:

$$SE = \sqrt{\frac{p\,(1-p)}{n}} \qquad (6)$$

iii. Set up the control limits, the control limit is given by:

$$CL_P = p \pm 3\sqrt{\frac{p\,(1-p)}{n}} \qquad (7)$$

Re-writing Equation 7 using Percentage defective we have:

$$CL_p = \bar{P} \pm 3\sqrt{\frac{\bar{P}\,(100-\bar{P})}{\bar{n}}} \qquad (8)$$

Where:

CL_P = Control limit of P.
$\bar{P}$ = Average Percentage defective.
$\bar{n}$ = Average Number defective.

So, the upper control limit is:

$$UCL_p = \bar{P} + 3\sqrt{\frac{\bar{P}\,(100-\bar{P})}{\bar{n}}} \qquad (9)$$

And the lower control limit is:

$$LCL_p = \bar{P} - 3\sqrt{\frac{\bar{P}\,(100-\bar{P})}{\bar{n}}} \qquad (10)$$

Note:

In practice, when the lower control limit is positive, it may in some cases be changed to zero (0). If the *P*- chart is to be viewed by operating personnel, it would be difficult to explain why a proportion defective (non-conforming) that is below the lower control limit is out of control. In other words, performance of exceptionally good quality would be classified as out of control and since one of the objectives of this research work is to reduce defects and wastage, a defect/waste reduction to zero is foreseeable. To avoid the need to explain this situation to the operating personnel, the lower control limit is changed from a positive value to a zero (0). Thus, the lower control limit is $LCL_p = 0$.

3.0 Results and Discussion

3.1 Qualitative analysis:

pH Analysis:

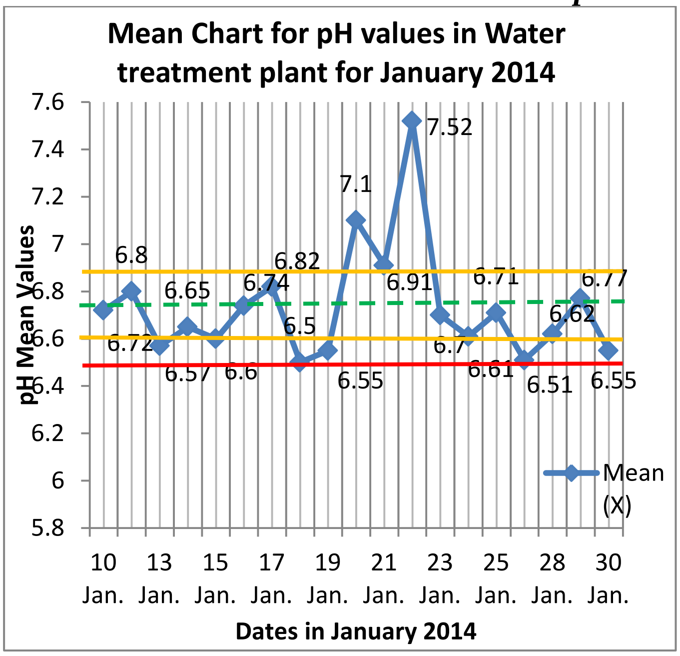

Figure 3: Mean Chart for pH values in Water treatment plant for January 2014.

Figure 3 shows the mean chart for the pH record of the water treatment plant in January 2014. The chart however, revealed the presence of assignable causes of variation at various stages showing that the process was statistically out of control.

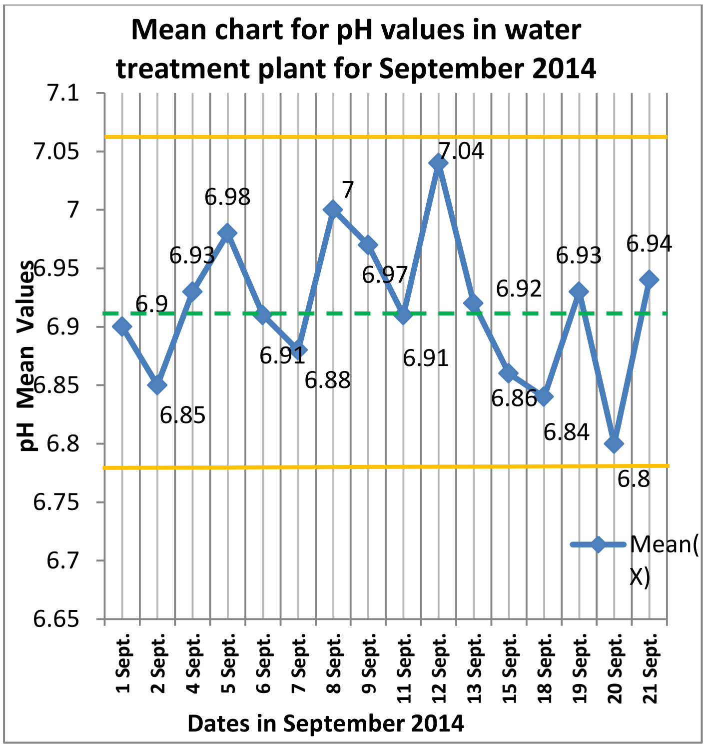

Figure 4: Mean chart for pH values in water treatment plant for September 2014.

Figure 4 shows the mean charts for the pH record of the water treatment plant in September 2014. From the above chart, it can be seen that the mean chart indicate that the water treatment process is in statistical control. This could be attributed to the turnaround maintenance of the process coupled with the introduction of statistical process control to the company as a result of this research work.

Result for Total Dissolved Solids (TDS) analysis:

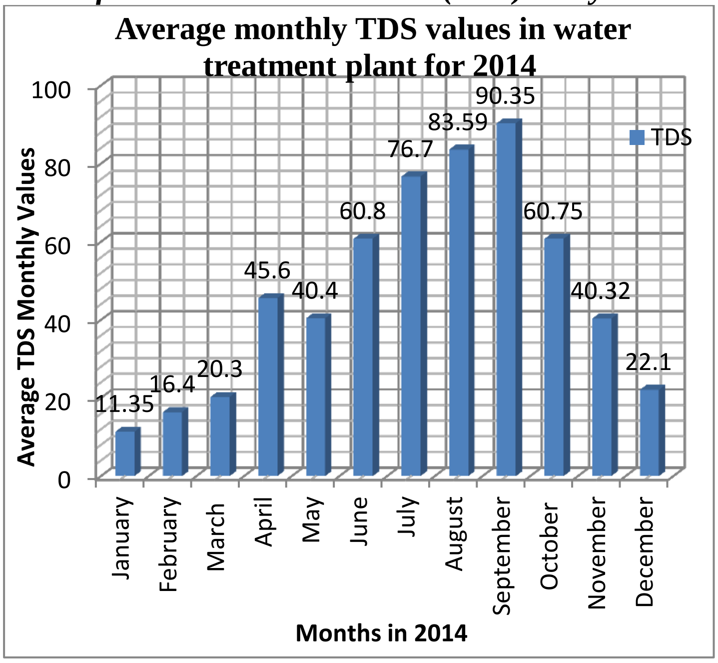

Figure 5: Average monthly TDS values in water treatment plant for 2014.

Figure 5 shows the average monthly Total Dissolved Solids (TDS) values in the water treatment plant for 2014. The graph shows that the TDS in the water treatment plant is high during the rainy season and low in dry season.

Result for Conductivity analysis:

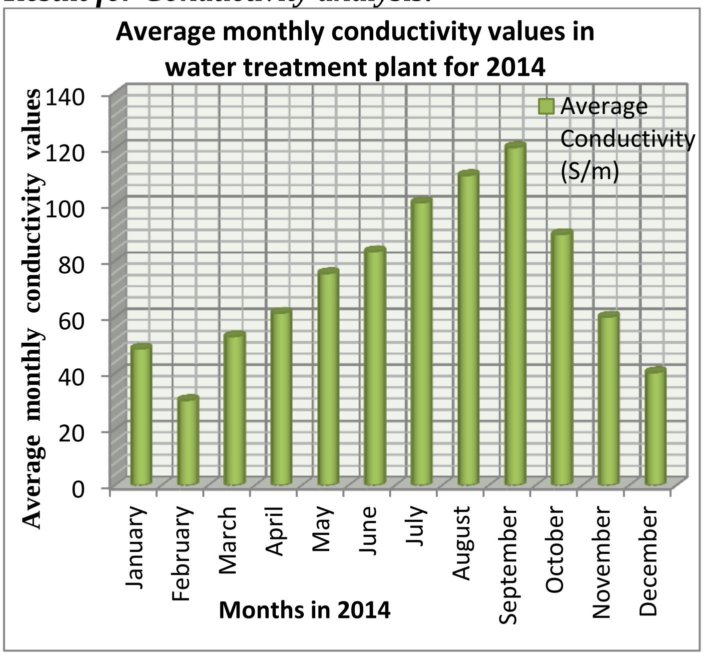

Figure 6: Average monthly conductivity values in water treatment plant for 2014.

Figure 6 shows the average monthly conductivity values in the water treatment plant for 2014. The graph shows that the conductivity of water in the water treatment plant is high during the rainy season and low in dry season.

3.2 Quantitative analysis:

August 2014:

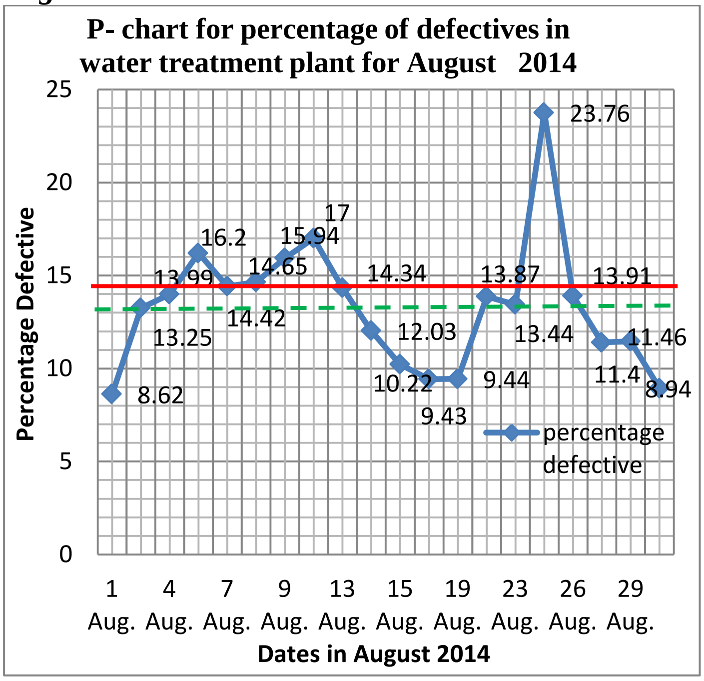

Figure 7: P- chart for percentage of defectives in water treatment plant for August 2014.

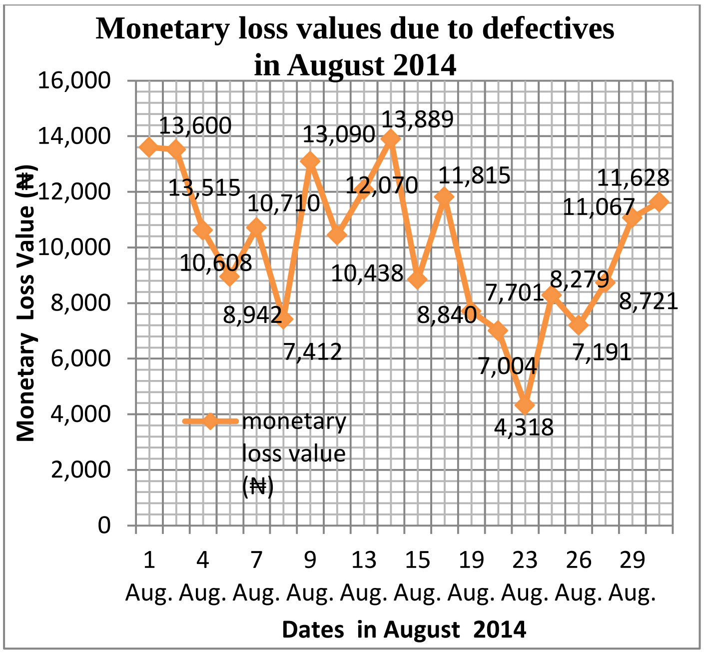

Figure 8: Monetary loss values due to defectives in August 2014.

Figure 7 shows the P- chart for percentage of defectives in water treatment plant for August 2014. From Figure 7, it can be seen that the process was statistically out of control as eleven (11) points representing 55% of the process fall outside the control limits. This clearly depict that the level of wastage is high and can be traceable to the fact that some of the equipments have not been properly aligned after the turnaround maintenance.

Figure 8 shows the monetary loss values associated with the wastage or defectives produced by the plant in August 2014. The total monetary loss due to defects in the month of August 2014 was ₦200,838 (two hundred thousand, eight hundred and thirty eight naira). However, there were no previous records as to the number of defectives or wastage produced by the plant for comparison.

November 2014:

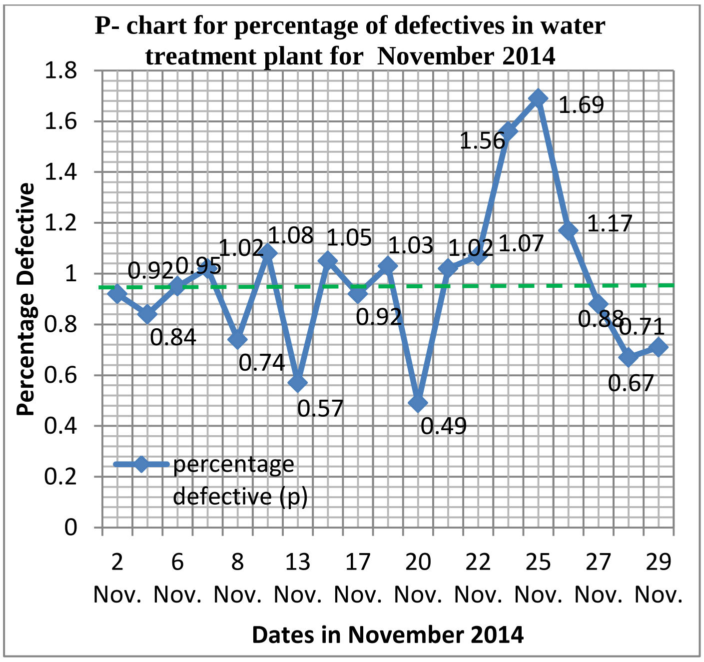

Figure 9: P- chart for percentage of defectives in water treatment plant for November 2014.

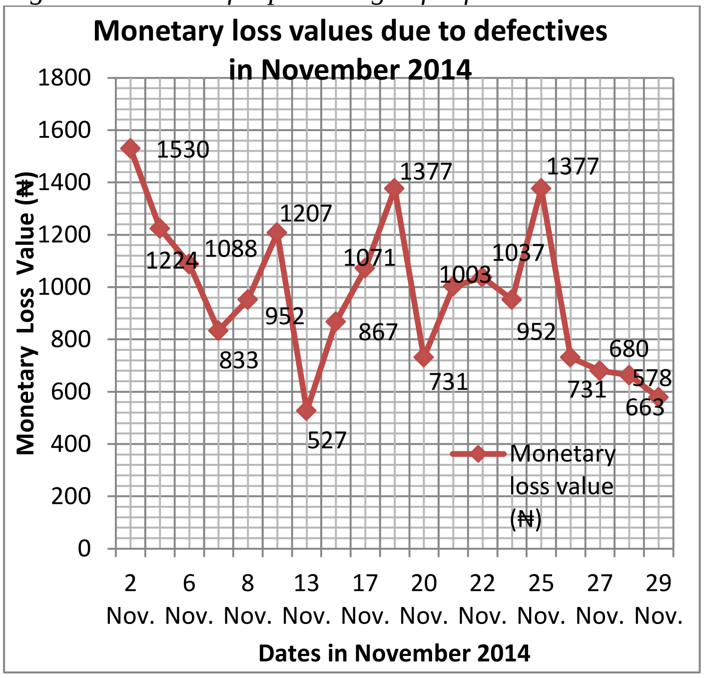

Figure10: Monetary loss values due to defectives in November 2014.

Figure 9 shows the P-chart for percentage of defectives in water treatment plant for November 2014. From the chart, it can be seen that the process was statistically under control. The total monetary loss due to defectives in the plant was ₦18,428 (Eighteen thousand, four hundred and twenty eight naira) and the total number of defectives produced by the plant in November 2014 was 1,084 (One thousand and eighty four). These show that there is a further decrease in the number of defectives produced monthly as well as the amount of monetary loss experienced by the company. Figure 10 shows the distribution of the monetary loss in the month of November 2014.

3.3 Screenshots of the Visual Basic dot net Computer Program developed

Screenshots of the Visual Basic dot net computer program developed to carry out both the qualitative and quantitative analyses are shown in Figures 11 to 15.

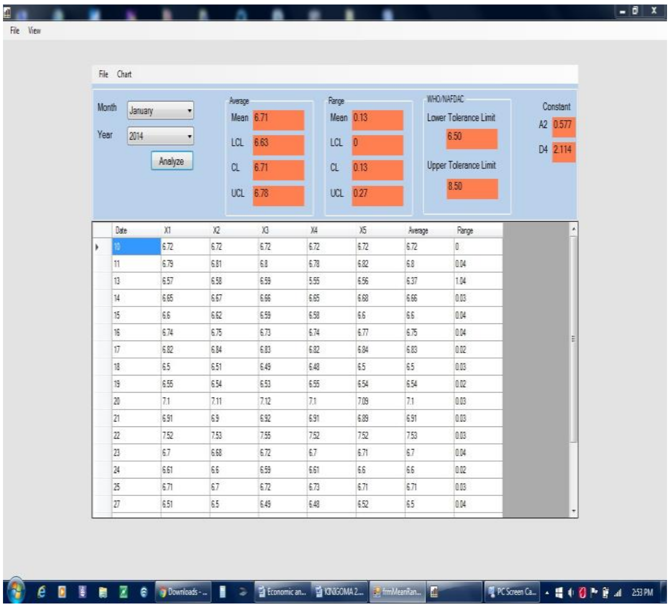

Figure 11: Screenshot showing pH data analysis.

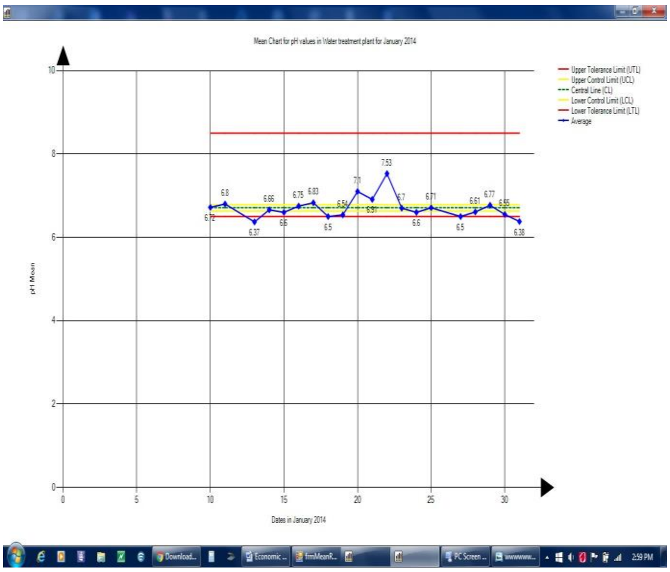

Figure 12: Screenshot showing mean chart.

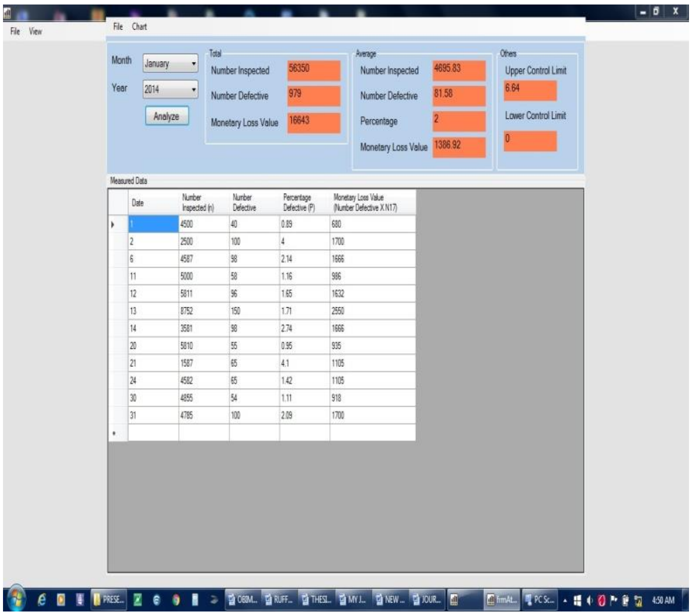

Figure 13: Screenshot showing Quantitative data analysis.

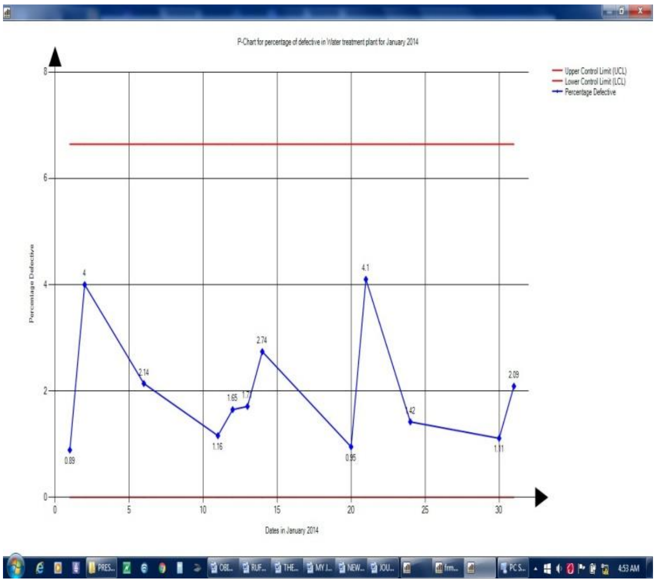

Figure 14: Screenshot showing Percentage defective Chart.

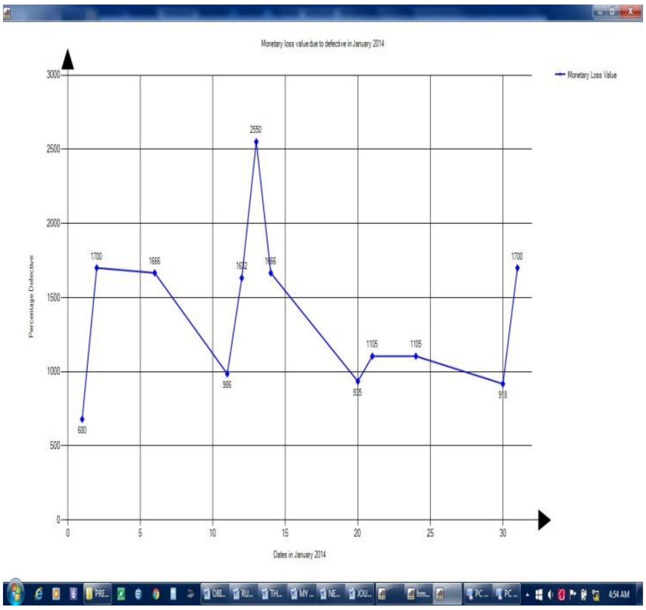

Figure 15: Screenshot showing Monetary Loss Chart.

4.0 Conclusion

In order to efficiently manage the production process of the case study company, the research carefully developed objectives, data collection tools, control charts, and computer software. The research also applied statistical process control to the process. From this research, the following have been achieved:

i. Reduction of waste generated by the production process and its associated monetary losses by 89.6%.

ii. Increase in the awareness of workers as to waste management and reduction to reduce monetary losses.

iii. Sensitization and use of statistical process control for quality production by workers.

iv. Redirection on the way the management sees quality and process improvement.

v. Increase in employee involvement and contributions to troubleshooting the process.

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