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THE DEVELOPMENT AND APPLICATION OF STATISTICAL PROCESS CONTROL SOFTWARE FOR HIGHER PRODUCTIVITY IN MANUFACTURING COMPANIES

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ABSTRACT

Statistical Process Control (SPC) is a numerical procedure that is widely used in performance and productivity monitoring in manufacturing companies. However, the length of time, tedium and cumbersome chat-generation processes associated with this method has necessitated the development faster and more reliable techniques for the analyses of products parameters. The objective of this work is to improve the SPC procedure by developing a faster and more accurate Computer-based Statistical Process Control (CSPC) to be used in analysing manufacturing outfits for higher productivity. The CSPC combines numerical computations, graph-generation, and interactive result presentation to produce a more reliable and a less time- consuming process. The CSPC was applied to a case study of a Coca-Cola bottling company. The net content of the beverage bottle was taken as data and analysed using the CSPC. The charts of the control limits were generated. The lower and upper values obtained for the warning and action limits of the mean chart were 47.78, 51.05, 46.97, and 51.86 respectively. Those for the range chart were 0.972, 6.466, 0.335 and 8.61respectively. The result obtained showed that the process is in control. However the process capability was less than one, indicating that the process was incapable of producing according to the specification of the operation. Strategies such as resetting and complete overhauling of filler equipment were proposed to ensure that process was in control.

Keywords: Statistical process monitoring, Computer-based Manufacturing

1.0 INTRODUCTION

One of the common practices in manufacturing industry is statistical process control. Statistics has been defined as the use and development of theory and methods for the application in design, analysis and interpretation of information in any substantive field of human endeavour (Bamiduro 2005). The investigation on quantitative mechanisms as an aid to control process variation gave rise to the application of SPC since 1930s. Statistical process control (SPC) is the general term used to describe the application of statistics to determine whether observed

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performance is within the expected variation of the process. This is done by repeated sampling of measurements, or counts, to predict results. Under Statistical Process Control, a process behaves predictably to produce results with the least possible waste. Key tools in SPC are control charts, a focus on continuous improvement and designed experiments.

Much of the power of SPC lies in the ability to examine a process, for the sources of variation in that process, by using tools which give weight to objective analysis over subjective opinions and which allow the strength of each source to be determined numerically. Variations in the process, which might affect the quality of the end-product or service can be detected and corrected, thus reducing waste as well as the likelihood that problems will be passed on to the customer. With its emphasis on early detection and prevention of problems, SPC has a distinct advantage over other quality methods, such as inspection, which apply resources to detecting and correcting problems after they have occurred.

1.1 Problem Statement

Industrial process analysts face difficulty in numerical analysis of the data collected from product sample attributes due to lots of data to be analyzed. Numerical analysis of data takes longer time, complex in compiling and there is a high probability of errors. Developing a software package speeds up process control analysis and also solves problems of variation in product quality in manufacturing industries.

Aim and Objectives

The general objective of this work is to develop software for process control and also determine the state of product quality for the selected company with the developed software. The stages of the objective are as follows: (i) develop SPC graphical user interface for data analysis using MATLAB (ii) test and validate the software (iii) determine for the selected company the state of product quality using the developed software that is, if the process is in control or not in control (iv) If the process is not in state of control, make necessary correction and recommendation.

2.0 HISTORICAL DEVELOPMENT OF STATISTICAL QUALITY CONTROL

The origin of statistical quality control is traced to the work of some early researchers at the Bell Telephone laboratories, which developed theories behind many of the quantitative tools of statistical quality control. Dodge and Romig (1959); Edward (1982, 1984) individually and collectively did much developmental work in the areas of Acceptance Continuous Sampling plans and Process Capability Analysis. Others have also made contributions in the application of statistics in engineering (Montgomery, (1991); Montgomery & Runger, (2011); Montgomery, (2001); Montgomery, (2003); Montgomery, (2007); Gordon, *et.al*, (1994)). Control is obtained when a statistical measurement such as means of a group of products are within certain control limits drawn on the statistical process chart. For these charts, there are certain sets of rules to follow that will tell the technicians when a process may be out of control. When these conditions are observed, the technicians are expected to stop the manufacturing process so that corrective actions can be taken. (Dougles 2003). SPC has been widely used in manufacturing industries in order to control variability and improve processes. It is a method that utilizes process data and very basic statistical analyses to determine process stability. SPC is comprised of a group of charts and diagrams that can determine, with respect to time, process efficiency, number and

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frequency of deviant products, and boundaries of chosen process variables. The main analytical tools are flow charts and control charts

2.1 Software Application

Application of Statistical Process Control to Software Processes by Lantzy (1992), presents one of the earliest studies on the debate of applying Statistical Process Control to software processes. In his paper, he summarizes the concept of SPC and gives some practical examples from manufacturing industry. Then he offers a set of transformations on these principles via software quality characteristics revealing the uniqueness of software products. After giving the process-product relationship, Burr and Owen (1996) in their work Statistical Methods for Software Quality, described the statistical techniques currently available for managing and controlling the quality of software during specification, design, production and maintenance. This book is one of the very few resources in the area as it is a full reference on statistical methods from technical background of statistics and measurement to managerial concerns in software industry. The main focus is on control charts as beneficial SPC tools and guidelines are provided for measurement, process improvement and process management within software domain.

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2.2 Control Charts

Various works have been done on quality controls generally (Juran, (2003a); Juran, (2003b). Kaoru, (1986)); Kaoru,(1985)). Control charts are used to identify process variation over time. All processes vary. The degree of variance, and the causes of the variance, can be determined using control charting techniques. While there are many types of control charts, the commonest ones are the X-bar and R charts for variables, with small sample size. They can also be based on a large sample size greater than or equal to ten.

3.0 RESEARCH METHODOLOGY

The methodology applied in this work involved: (i) development of the CSPC for improved analyses using MATLAB. (ii) Numerical analyses of SPC using Coca-Cola bottling company as a case study. The state of production process of Coca-cola bottling company was analysed to ascertain its process control and capability.

Various quality control techniques and activities were thoroughly observed. Checks were carried out on net content parameter of the coca-cola 50cl bottle and recorded over a period of time. The quality characteristic of interest is the net volume of drink in the container. The Graphical User Interface (GUI) developed in (i) was applied in analyzing the data gathered. The two analyses were compared for easy learning and interpretation of result.

3.1 Numerical Analysis of Net content

The volumes in terms of the fill-heights were measured for samples taken from the production line at one hour intervals. The specification for net content is ±2.5% of package. In this case of net content, coke 50cl was chosen. The specification limit $=\frac{2.5}{100} \times \frac{50}{1} = 1.25\text{cl}$

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3.1.1 Numerical analysis for the grand (process mean) chart $(\bar{\bar{X}})$

$$\mu = \bar{\bar{X}} = \sum_{i=1}^{k} \bar{X}i / k = \frac{1235.13}{25} = 49.41\text{cl} \quad (1)$$

$$\bar{R} = \frac{\sum_{i=1}^{k} R_i}{k} = \frac{83.85}{25} = 3.35\text{cl} \quad (2)$$

$$\text{Action Limits} = \bar{\bar{X}} \pm A_2\bar{R} \quad (3)$$

Then the action and warning limits are to be determined based on the mean range:
Mean range calculated: $(\bar{R})$ = 3.35

Table 1: Net content of 50cl coca-cola

Subgroup no.	X_1	X_2	X_3	X_4	Average (X)	Range
1	50.15	48.75	50.25	45.52	48.67	4.73
2	49.05	48.95	47.83	50.25	49.02	2.42
3	51.21	48.75	46.75	51.05	49.44	4.46
4	45.62	48.92	50.85	51.05	49.11	5.43
5	50.25	51.05	51.25	47.44	50.00	3.81
6	47.55	51.15	51.25	51.15	50.28	3.72
7	50.25	46.85	45.95	50.25	48.33	4.31
8	51.25	50.12	50.15	50.02	50.39	1.23
9	51.21	50.12	50.15	49.06	50.14	2.15
10	50.15	50.02	48.37	50.08	49.66	1.78
11	50.06	50.12	50.25	49.02	49.86	1.23
12	50.15	50.15	51.05	48.55	49.98	2.51
13	51.21	50.21	50.65	50.12	50.55	1.09
14	50.05	47.65	50.05	50.12	49.47	2.47
15	49.75	48.13	48.05	50.12	49.01	1.99
16	45.94	50.01	48.75	50.15	48.71	4.21
17	50.14	50.03	49.15	51.25	50.14	2.11
18	50.05	50.12	44.85	51.23	49.06	6.38
19	49.95	51.25	46.83	51.07	49.78	4.42
20	48.75	45.37	50.45	50.62	48.79	5.27
21	48.82	48.95	50.35	47.87	49.00	2.48
22	50.12	48.95	48.75	47.24	48.77	2.88
23	44.93	48.75	50.15	50.05	48.40	5.22
24	50.45	50.25	45.61	50.05	49.09	4.84
25	50.02	47.54	50.12	50.25	49.48	2.71
				Total	**1235.13**	**83.85**

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Hartley's constant (from standard tables when the sample size n=4): d_n= 2.059. Sample range constants (from standard tables: (Appendix 1) when the sample size n=4): A_2 =0.73. Sample range constants (from standard tables: (Appendix 1) when the sample size n=4): = $^2/_3$ A_2 $=^2/_3\ X$ 0.73= 0.49

Upper warning limits ($\mathbf{UWL}_{\bar{\bar{X}}}$) $=\bar{\bar{X}}+ {}^2/_3 A_2 \bar{R}$ (4)

$$49.41 + \frac{2}{3} \times 0.73 \times 3.35 = 51.05$$

Lower warning limits ($\mathbf{LWL}_{\bar{\bar{X}}}$) $= \bar{\bar{X}}+ {}^2/_3 A_2 \bar{R} =$ (5)

$$49.41 - \frac{2}{3} \times 0.73 \times 3.35 = 47.77$$

Upper action limits ($\mathbf{UAL}_{\bar{\bar{X}}}$) $=\bar{\bar{X}}+A_2\bar{R}$ (6)

$$49.41 + 0.73 \times 3.35 = 51.86$$

Lower action limits ($\mathbf{LAL}_{\bar{\bar{X}}}$) $= \bar{\bar{X}}-A_2\bar{R} =$ (7)

$$49.41 - 0.73 \times 3.35 = 46.97$$

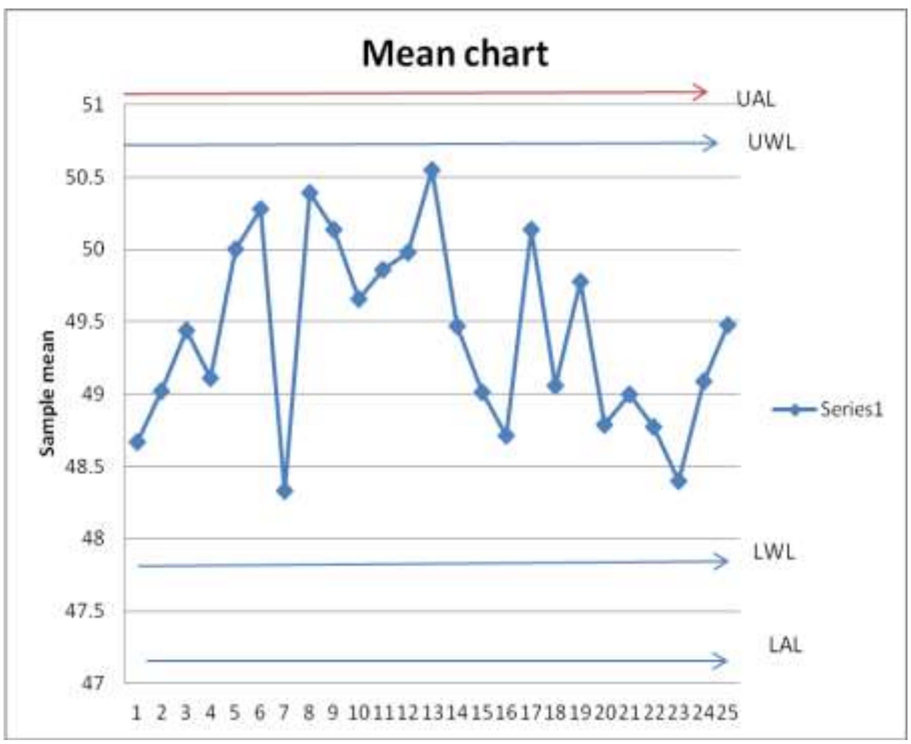

Figure.1 mean control chart for net content

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3.1.2 Numerical analysis for the range chart ($\bar{R}$)

The action and warning limits are determined based on the mean range and constants:

From standard tables (Appendix 2): $D'_{0.001} = 2.57$; $D'_{0.999}=0.10$; $D'_{0.025} = 1.93$; $D'_{0.975} = 0.29$

Upper warning limits ($UWL_{\bar{R}}$) $= D'_{0.025}\bar{R}$ (8)

$1.93 \times 3.35 = 6.466$

Lower warming limits ($LWL_{\bar{R}}$) $= D'_{0.975}\bar{R} =$ (9)

$0.29 \times 3.35 = 0.972$

Upper action limits ($UAL_{\bar{R}}$) $= D'_{0.001}\bar{R} =$ (10)

$2.57 \times 3.35 = 8.61$

Lower action limits ($LAL_{\bar{R}}$) $= D'_{0.999}\bar{R} =$ (11)

$0.10 \times 3.35 = 0.335$

Figure 2: Range control chart for net content

Standard deviation (σ) can also be expressed in terms of the mean range and Hartley's constant (d_n or d_2)

$$\sigma = \bar{R}/D_2 = \bar{R}/D_n$$

Therefore, $\sigma = \frac{3.35}{2.059} = 1.63$ (12)

Also, standard error (SE) of means is defined as the

$$SE = \sigma/\sqrt{n}$$

Therefore, $SE = \frac{1.63}{\sqrt{4}} = 0.815$ (13)

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3.1.3 Capability Index

This shows the predictability of the process to perform within specifications. From the calculation below, it is observed that the value of c_p is less than 1. This shows that the process is incapable of producing within the set specification

$$C_{P} = \frac{USL - LSL}{6\sigma} = \frac{2T}{6\sigma} \qquad (14)$$

USL= net content + specification limit.

USL= 50+1.25 = 51.25; LSL= net content − specification limit. LSL=50−1.25 = 48.75

$$C_{P} = \frac{51.25 - 48.75}{6 \times 1.63} = \frac{2.5}{9.78} \qquad (15)$$

$C_p = 0.26$

3.1.4 Relative Precision Index (RPI)

$$(RPI) = \frac{2T}{\bar{R}} \qquad (16)$$

Where T is the tolerance band 2T=2.5; $\bar{R}$ is the mean range = 3.35

RPI = 2.5/3.35 = 0.75 (17)

3.2 Development of Statistical Process Control/Analyses computer software

The analysis obtained using graphical user interface developed using MATLAB (Gilat 2004; Hunt *et. al.,* 2001) is discussed in this section. The radio button of the graphical user interface was used to create function and call back for the mean of the variation, range, standard deviation and standard error by clicking the push button named "calculate". For the mean chart and range shown in Figs 3 and 4 below, this push button computes the mean and the range. The axes control charts displayed showing the sample mean of the variables to the sample number (Fig. 5) and also the sample range of variable to the sample number (Fig. 6). The actions and warning limits are specified on the axes of the control chart. In Fig. 4 and Fig. 6 the chart below shows the mean control chart and mean range chart respectively with their various control limits. The yellow asterisks shown on the graph represents the upper action limits (UAL), the green line represents the lower Warning limits, the lower action and action chats denoted by the blue and red respectively. The data were input and the result was displayed below showing the process mean (PM), upper action limit (UAL), upper warning limit (UWL), lower warning limit (LWL), lower action limit (LAL).The data were input and the result was displayed below showing the mean range ($\bar{R}$), upper action limit (UAL), upper warning limit (UWL), lower warning limit(LWL), lower action limit (LAL). When the standard deviation radio button is clicked , it displays the value for standard deviation and standard error as shown in Fig. 4.7 and 4.8 respectively. The mean range also displays the value for process capability as shown in Fig. 4.9

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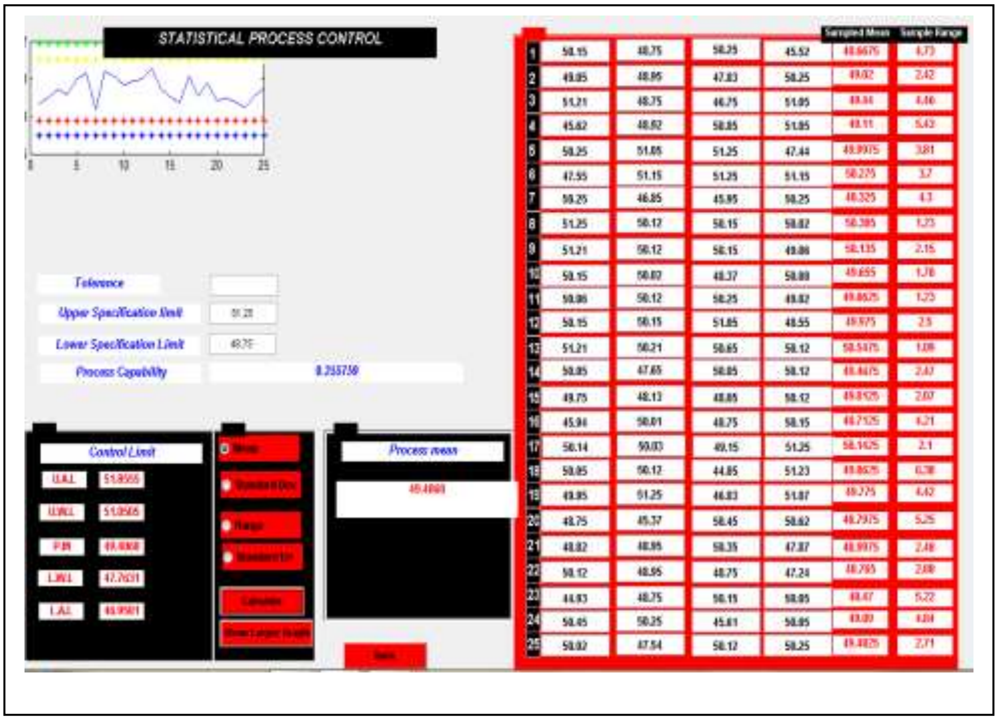
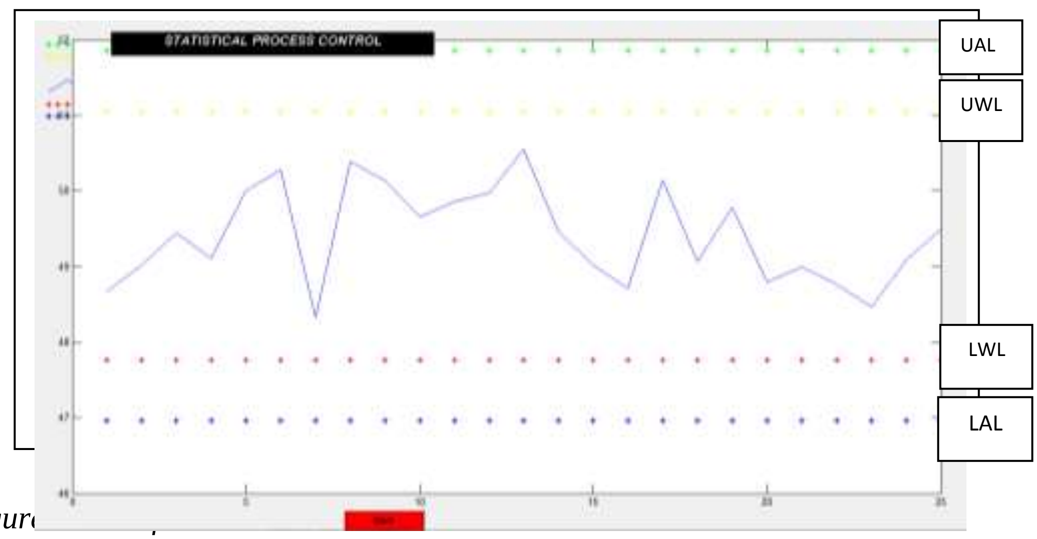


Figure 3: Result of the GUI computed for the process mean



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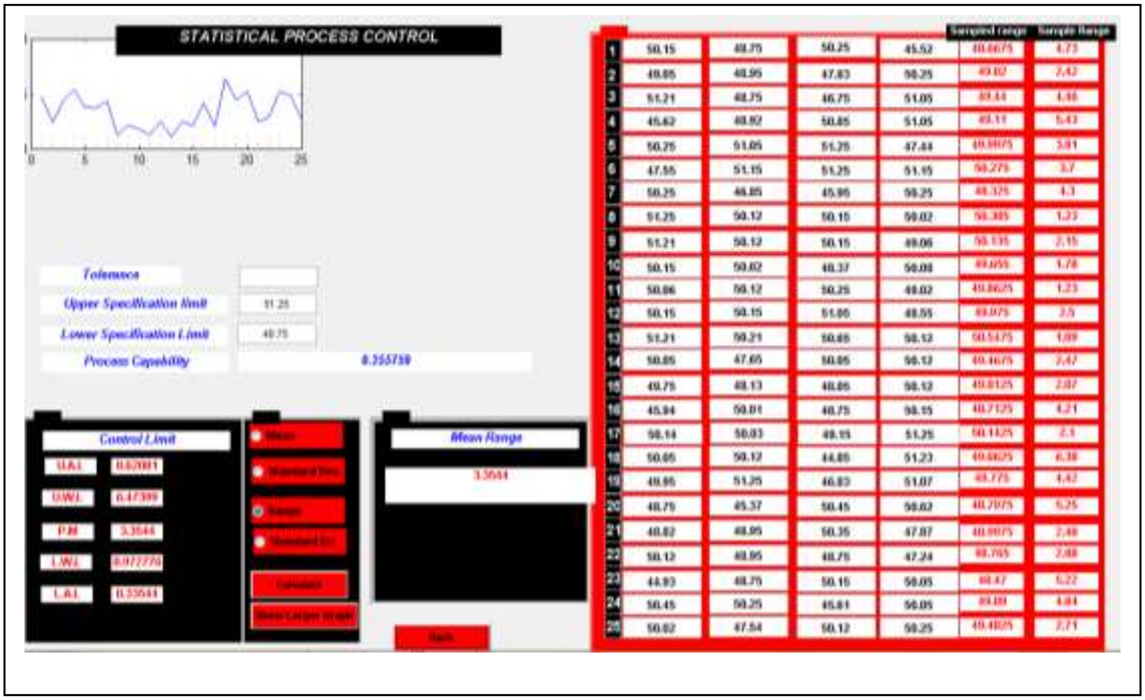

Figure 5: GUI computing the result range.

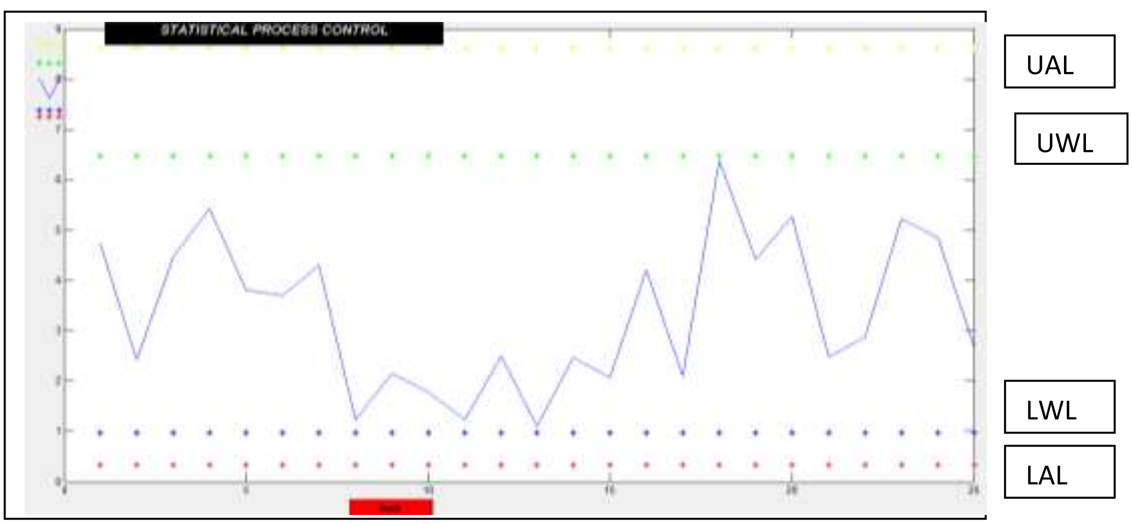

Figure 6: GUI for range control chart.

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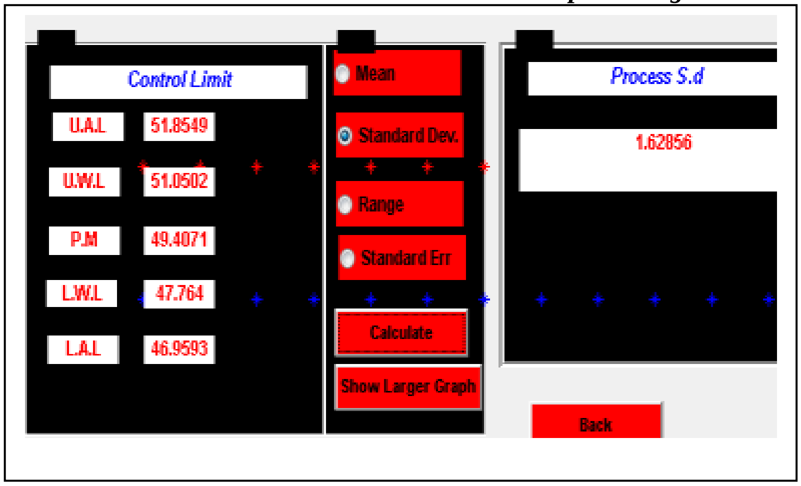

Figure 7: GUI computed result for standard deviation using mean control limit

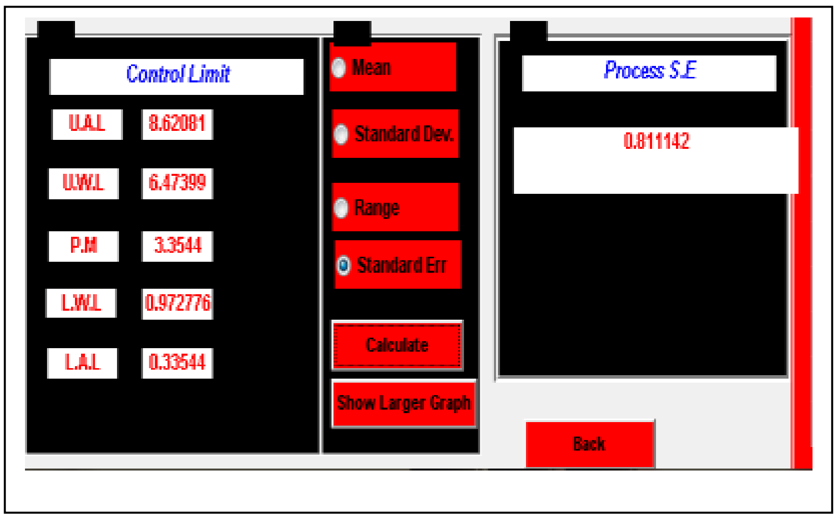

Figure 8: GUI computed result for the standard error using range control limit

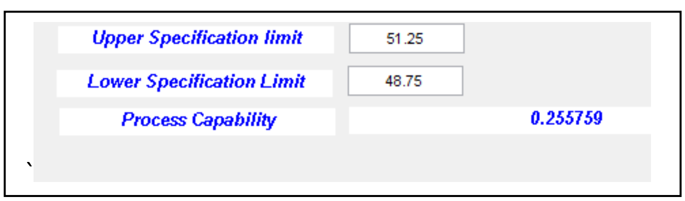

Figure 9: GUI showing Process Capability

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4.0 RESULTS AND PROCESS CORRECTION.

From the mean and range chart in Figs 5 & 6, it is observed that, the points lies within the limits i.e. the action and warning limits and no points lie outside the limits. Therefore it has no out–of–control points. The process is said to be in control but out of specification due to a process capability being less than one. Since some outcomes of Net Content entered Quarantine, the following actions need to be taken by the management. The Filler (an equipment that fills the bottles to specific amount) needs to be reset. The critical part that controls the filling of bottles in the production Line where the samples were taken needs to be repaired. Probably overhaul the machine. However, if it is still out of control action must be taken to increase the mean. In order to ensure that the specified products are obtained the control of the equipment, materials and production methods have to be in place.

5.0 CONCLUSION

Due to the high expectations from consumers and competitive market due to substitute product, it has become a priority to ensure that products are being produced to consumer's satisfaction. Therefore, it is necessary to provide high quality production through continuous monitoring of process parameters. This implies monitoring process stability. The development of a computer-based statistical process control done in this work and its application to a major company shows that process monitoring can be done, and its quality improved with the aid of software. From the observation, analysis and the conclusions made in this study, it is recommended that the software developed should be applied by manufacturing industries for easy and fast analysis of product sample parameters in other to continuously check if products are being produced to specification and if processes are in control. In its application in manufacturing companies, the following recommendations are suggested for proper implementation of the software: (i) new staff, either temporary or permanent should be thoroughly trained on the software before being allowed to carry out their designated functions. (ii) Control charts should regularly generated probably monthly and placed at strategic location or points in the company where it can be seen by operators and supervisors (iii) Out of control points should be critically analyzed to determine causes of variation before sending products to the customer

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NOMENCLATURE

SPC=*Statistical process control;* **n**=*sample size;* $\bar{\bar{x}}$=*Grand (Process) Mean;* μ= *Process or grand mean;* $\overline{R}$= *Mean Range;* σ= *Standard deviation;* **SE**=*Standard; Error;* d_n *or* d_2= *Hartley's constant;* **UAL**= *Upper action Limits;* **LCL**=*Lower Action; Limits;* **UWL**= *Upper Warning Limits;* **LWL**= *Lower Warning Limit;* **T**=*Tolerance;* **RPI**= *Relative process index;* C_p=*Process capability;* **USL**= *Upper Specification Limits;* **LSL**=*Lower Specification limits;* **GUI**= *Graphical User Interface;* **RPI**=*Relative Precision Index*

Appendix 1: Constants A_2 and $2/3A_2$ for the use with Sample Range

Sample size (n)	Hartley's constant (d_n or d_2)	Constant for the use with sample range A_2	$2/3A_2$
2	1.128	1.88	1.25
3	1.693	1.02	0.68
4	2.059	0.73	0.49
5	2.326	0.58	0.39
6	2.534	0.48	0.32
7	2.704	0.42	0.28
8	2.847	0.37	0.25
9	2.970	0.34	0.20
10	3.078	0.31	0.21
11	3.173	0.29	0.19
12	3.258	0.27	0.18

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Appendix 2: Constants for use with Mean Range

Sample size(n)	$D'_{0.999}\bar{R}$	$D'_{0.001}\bar{R}$	$D'_{0.0975}\bar{R}$	$D'_{0.025}\bar{R}$
2	0.00	4.12	0.04	2.81
3	0.04	2.98	0.18	2.17
4	0.10	2.57	0.29	1.93
5	0.16	2.57	0.37	1.81
6	0.21	2.34	0.42	1.72
7	0.26	2.21	0.46	1.66
8	0.29	2.11	0.50	1.62
9	0.32	2.04	0.52	1.58
10	0.35	1.93	0.54	1.56
11	0.38	1.91	0.56	1.53
12	0.40	1.87	0.58	1.51

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