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Quality Characterisation and Capability Assessment of a Tobacco Company

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Abstract: This is an empirical study on the application of SPC techniques for monitoring and detecting variation in the quality of locally produced tobacco in Nigeria. The result provides base evidence for intervention in the quality behavior of the heavily automated tobacco production process in which slight undetected deviation can result in significant wastes. An observational study was carried out within the primary manufacturing department of the tobacco company. The study analysis was conducted using descriptive statistics, goodness of fit test and SPC charts.. These charts were constructed and examined for significant variation in expected output quality as well as the capability of the process. The goodness of fit test and SPC identified CTQs that were approximately normally distributed and out of process control across periods of observations. These deviations were not evident with the summary data or its presentation on the histogram. Subsequently, the out of control process charts were transformed to in-control charts by repetitive elimination of out-of-control instances. At this state, it was observed that the process was only capable of meeting specification for the dust level for all capability measures. These results illustrate a proof of SPC for process monitoring and product quality improvement.

Keywords: Critical-to-Quality, Goodness of Fit, Process Capability, Process Improvement

1. Introduction

Global competitive pressures now compel organisations to find better ways to meet customer's needs, reduce cost and increase productivity [1]. While this market competiveness increases alternatives at customer's disposal, production managers are faced with issues relating to increased process complexity, quality assessment and improvement. The overall goal of the quality assessment and improvement techniques is to reduce the number of defective products and in turn improve process capability [2].

Although, numerous statistical process control (SPC) techniques have been proposed for continuous quality improvement [4, 5], an important aspect not readily discussed in the literature is associated with implementation. Successful application of SPC is not well reported among practitioners [6]. Several studies [1, 7] have emphasized that very few managers have good knowledge about the implementation of SPC tools. They argued that the "how to get started" and "where to get started are important problem areas of SPC implementation studies. Madanhire and Mbonwa [9] emphasized the deficiency of SPC implementation in Zimbabwean manufacturing companies. Nigerian based manufacturing firms are not left out of this ordeal.

With increasing willingness to benchmark Nigerian products against global standards, manufacturers face similar challenges as the counterpart in other parts of the world. Specifically, a leading tobacco manufacturing company wants process analysis study of its primary production system. The study aims to enable process managers have insight into the performance of their primary manufacturing processes for effective decision making. This study is very essential to the company as low quality of product can lead to loss of customers' goodwill and a lot of their products can be lost to rework which attract rework cost hereby leading to increased production cost and low productivity. Also, it enables timely knowledge of quality variation to prevent significant wastes. This process capability analysis provides a baseline for measuring process variability relative to the specifications. This is the thrust of this study.

The article is structured as follows: relevant literature on SPC, this is followed by the description of the study method and the discussion of results. Finally, the implication of the results is offered as the conclusion of the study.

2. Overview of Statistical Process Control

The theory of variation was first proposed by Walter Shewhart in the 1920 [14]. He proposed that variation in product quality characteristics have two types of causes known as the random (common) causes and the assignable (special) causes of variation. Regardless of how well designed or carefully maintained a process is, there is always a certain amount of inherent variability. A system subjected to only this type of variation is said to be in a state of statistical control. A reduction of this variation must be by acting on the process. On the other hand, some variation has identifiable causes which result from some unplanned or unwanted circumstances. They result in unnatural fluctuation in data used for evaluating process variability. Process in such a state is said to be out of statistical control [3]. Therefore, it is incapable of producing according to specification [15, 16]. There are several indicators of process capability. They differ in application but the basis of their formulation is approximately the same. The index relates the specified accuracy to the actual process accuracy [17]. Nowadays there are many researches about process capability indices (PCIs) and they have been applied in many organizations. The first index was developed by Kane [18] for single CTQ in mass production. Cp also known as the process capability potential index which measures process capability for a two sided specification limit without a reference to the process center or mean. To overcome the weakness of Cp, Kane [18] proposed another PCI which take into consideration the location of the mean of the distribution [19]. This index usually denoted as Cpk compares the distance between the process mean and each of the specification limits. It is however observed that Cpk does not completely project process capability accurately, since it does not consider the difference between the process average and set target value [19]. As such, a process not centered may have the same Cpk with another centered process, if it has a lower standard deviation.

The Cpm is a capability index developed by Chan *et al.,* [20] which takes into account the limitation of Cpk index. The index was also proposed independently by Hsiang and Taguchi [21] based on squared error loss of Taguchi loss functions [19]. Kotz and Johnson [22] expressed a relation of the PCIs as; $C_p \geq C_{pk}$ and $C_p \geq C_{pm}$. Spiring et al., [23] also emphasized that C_p and C_{pk} are; related to marginal expectation inparts per million and sensitive to data symmetry while Cpm is unrelated to number of nonconforming product in the process while Cpm is insensitive with respect to the distribution. However, it seems that Cpk is the most extensively used PCIs in the industry. It is also interpreted as the measure of nonconformity. Although, most studies on process capability analysis often overlook it, the underlying assumption of existing process capability measures is that quality characteristic is normally distributed.

3. Methodology

3.1. Case Study and Data Collection

The study was conducted in a tobacco company in South West Nigeria. The company has over century operational presence in Nigeria with various brands of cigarettes produced from locally grown tobacco. The company is committed to delivery of superior quality products and ensures consumers' demands are met. This reflected in their commitment in ensuring product innovation and quality initiatives. The company manufacturing section has primary manufacturing section and secondary manufacturing section.

The aim of the primary manufacturing section is to pre-process the raw materials and deliver tobacco which meets the demand of secondary manufacturing section at the right time and quality. The manufacturing process is fully automated and the output of the primary manufacturing process was given a slight undetected deviation in quality characteristics. The larger percentage of tobacco which is the product of the primary manufacturing section were not meeting up quality checks and this leads to a lot of rejects and rework. Observation of the manufacturing process was done through visits to the primary manufacturing section of the plant. Observation of the activities of those in the quality control department and the procedure. Personal interview and dialogue with relevant personnel in the primary manufacturing department. The critical to quality (CTQ) characteristics of interest were identified. The target and specification limits for each quality characteristic were obtained. Also, customers must agree with a specification limits for each quality characteristic to be measured. The samples (with subgroup size n) were obtained for the product at different intervals of production and the measurements were recorded for each subgroup.

3.2. Process Capability Analysis

A longitudinal case study approach was used to investigate statistical state of a tobacco manufacturing company through collection of critical to quality (CTQ) related data for tobacco, investigate data statistical distribution, analyze the data obtained using Shewhart control chart, and determine the process capability indices using suitable capability index for the manufacturing company. The flowchart to carry out the process capability analysis is given in Figure 1. The activities are as follows;

Step 1: Determination of data distribution.

Step 2: Testing the Normality of the Data. For normality test using the SPSS 14.0 the following numerical outputs are investigated:

Skewness and kurtosis z-value (which should be somewhere in the span of ± 1.96)

The null hypothesis H_0: The observed CTQ data belongs to a class of normal distribution

The alternative hypothesis H_1: The observed CTQ data does not belongs to a class of normal distribution.

The null hypothesis is rejected if the $p - value$ is below 0.05

The normality test was conducted usingKolmogorov-Smirnov (KS) and the Shapiro-Wilk test p-value (which

Step 3: Control Chart Procedure

The following steps are taken in drawing the process control chart and finding if it is in control

Estimate subgroup average ($\bar{x}$)

Find the grand mean of all of the subgroup average $\bar{\bar{x}}$. This gives the overall or grand average for all observations.

Estimate the standard deviation $\bar{\bar{s}}$ of the data points

Find the grand mean of all of the subgroup standard deviation $\bar{s}$.

Estimate the lowercontrol limits (LCL) and the upper control limits (UCL) as follows:

$$UCL = \bar{\bar{x}} + A_3\bar{s}. \quad (1)$$

$$lCL = \bar{\bar{x}} - A_3\bar{s} \quad (2)$$

[24].

Step 4: Process Capability Indexes

C_p $Index$: Cp is a performance index that does not take into consideration process centering. It relates the designed process tolerance (i.e. difference between the upper specification limit and the lower specification limit) to process variability.

$$C_p = \frac{USL-LSL}{6\bar{s}} \quad (3)$$

C_{pk} $Index$: Cpk makes allowance for process centering. It relates the process average to the designed limits.

$$C_{pk} = minimum\left[\left(\frac{\mu-LSL}{3\bar{s}}\right), \frac{USL-\mu}{6\bar{s}}\right] \quad (4)$$

P_p Index: Pp is regarded as an overall capability index similar to Cp but uses process total variability.

$$P_p = \frac{USL-LSL}{6\bar{\sigma}} \quad (5)$$

P_{pk} $Index$: Ppk is a capability index similar to Cpk. It also relates process average to the specification but uses process total variability as a denominator.

$$P_{pk} = minimum\left[\left(\frac{\mu-LSL}{3\bar{\sigma}}\right), \frac{USL-\mu}{6\bar{\sigma}}\right] \quad (6)$$

4. Result and Discussion

The study started with visitation to the manufacturing company situated in Ibadan. The company produces tobacco which has had an operational presence in Nigeria since over a century. In the tobacco business, it is a household name and they produce most of the brand of tobacco that are available in the country today. In order to understand activities of the primary department of this company, several meetings and interviews were held with the process manager and other relevant personnel of the company, operations of its production and quality control section was observed, past and on-going production records were vetted.

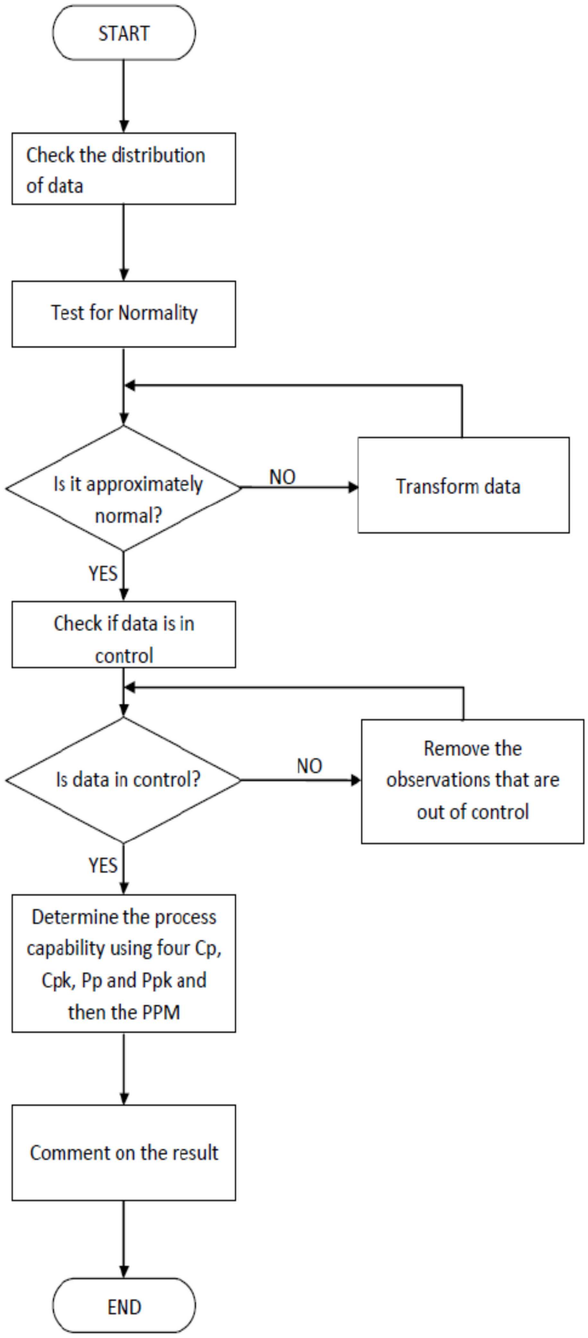


Figure 1. *Flow chart for process capability analysis.*

Six quality characteristics measures were collected from the month of June to August 2015 with their respective specification limits. The quality characteristics measured were Moisture content, Fill value, and Dust content. These quality characteristics are very important to the product of primary manufacturing section and also determine the output of the product at the secondary section. Low moisture content in most cases makes the cigarette to burn very fast and this could lead customers' dissatisfaction. High moisture content leads to spotting on the cigarette paper. High fill value makes the puff on the cigarette to be high when the customers inhale it. High fill value increases the quantity of the tobacco in the cigarette which will be a loss to the company. High dust content causes lose end and the tobacco will fall out of the cigarette paper even before it gets to the consumers, this occurs most times during transportation.

During the information gathering process, measures of the six Critical-To-Quality (CTQ) characteristics and their respective specification limits were identified and appropriate sample data obtained at intervals over different production runs. Table 1 shows the targets and the tolerance/specification limits of the different CTQ.

Table 1. *Tolerance Limits of The Quality Characteristics.*

QUALITY MEASURED	TARGET	TOLERANCE
MC_B	21	± 2
MC_A	14.5	± 0.5
MC_{CRS}	12	± 0.5
MC_{MM}	12	± 0.5
FV	48	± 0.3
DL	< 10	

MC_B: measures the moisture content before drying
MMC_B: measures Moisture Content after drying
MMC_{CRS}measures Moisture Content done in the CRS Lab
$MC_{MM:}$ Moisture Content measured using the Moisture Metre (an online measurement)
FV: measures the Fill Value of the grounded leaf in the wrap
DL: measures the Dust Level in the product

Statistical fit of the collected CTQ sample data was investigated by calculating the sample statistics and relating them to the statistics of the normal distribution using Kolmogorov-Smirnov (KS) and the Shapiro-Wilk test p-value (which should above 0.05). The skewness and kurtosis z-value was also analyzed using the EasyFit software. Table 2 and Table 3 shows results per month of investigation and sample histogram of the respective probability distribution function (pdf) for the month of June is shown in Figure 2.

Table 2. *Data Distribution per Month.*

Distributions of the data collected in the Month of June		
CTQ	**DISTRIBUTION**	**PROPERTIES**
MC_B	1Johnson SB	γ=0.36129, δ=0.74792, λ=6.0218, ξ=18.48
MC_A	2Log-Logistic (3P)	α=3.1726E+8, β=1.3296E+8, γ=-1.3296E+8
MC_{CRS}	3Lognormal	σ=0.08466, μ =1.1298, γ=9.813
MC_{MM}	4Weibull	α =50.839, β=12.848, γ=0
FV	5Cauchy	σ=0.44429, μ =48.857
DL	6Log-Logistic	α =39.363, β=8.809, γ=0

Distributions of the data collected in the Month of July		
CTQ	**DISTRIBUTION**	**PROPERTIES**
MC_B	7 Johnson SB	γ=0.25298, δ=0.92482, λ=6.5174, ξ=18.505
MC_A	8 Dagum (4P)	k=0.39853, α=11.186, β=2.3321, γ=13.57
MC_{CRS}	9 Dagum (4P)	k=0.35925, α=8.0246, β=0.97679, γ=11.965
MC_{MM}	10 Johnson SB	γ=0.83357, δ=1.5745, λ=2.0172, ξ=11.743
FV	11 Burr	k=0.37275, α=121.49, β=48.71, γ=0
DL	12 Gen Extreme Value	k=-0.19701, σ=0.27607, μ=8.6465

Distributions of the data collected in the Month of August		
CTQ	**DISTRIBUTION**	**PROPERTIES**
MC_B	13 Error	k=3.6825, σ=1.661, μ=21.028
MC_A	14 Cauchy	σ=0.18188, μ=15.403
MC_{CRS}	15 Weibull (3P)	α=2.7843, β=0.49681, γ=12.206
MC_{MM}	16 Burr (4P)	k=2.7158, α=6.0195, β=1.3762, γ=11.411
FV	17 Log-Logistic (3P)	α=6.2807, β=4.3149, γ=45.244
DL	18 Burr	k=0.97422, α=42.058, β=8.8655, γ=0

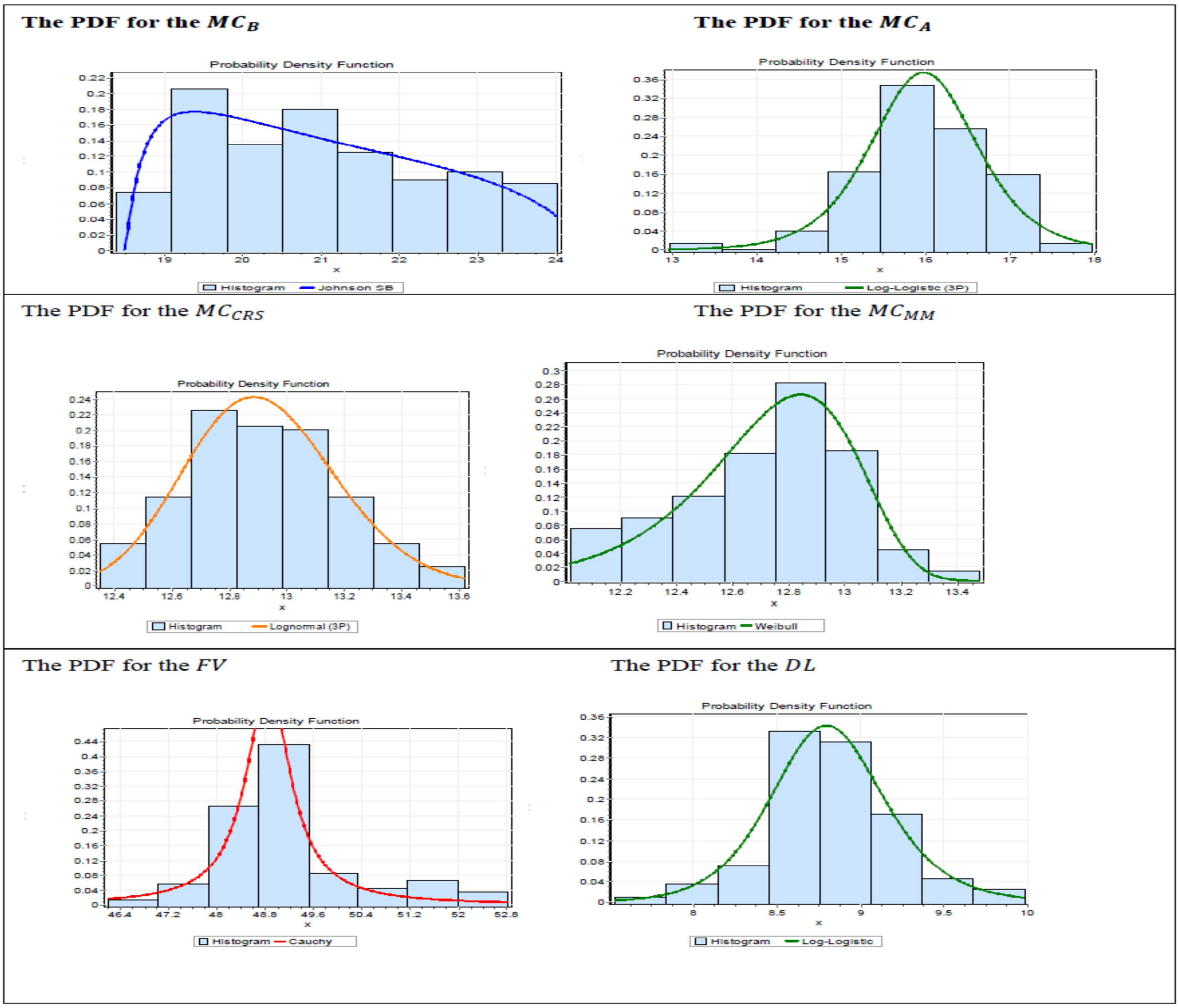
The skewness, kurtosis z-value and normality test was carried out using Shapiro-Wilk testp-value and the results are presented in Table 3.

Table 3. *Normality test of CTQs.*

Normality test of the quality characteristics for the month of June						
STATISTICS	MC_B	MC_A	MC_{CRS}	MC_{MM}	FV	DL
SKEWNESS	1.99	-1.36	1.14	-1.82	5.68	0.57
KURTOSIS	-2.72	1.77	-0.94	0.98	3.88	1.8
K-S	0.01	0.2	0.2	0.001	0	0.2
SHAPIRO-WILK	0	0.001	0.3	0.006	0	0.061
Normality test of the quality characteristics for the month of July						
SKEWNESS	1.08	-0.4	2.04	1.9	5.66	2.24
KURTOSIS	-2.42	0.99	2.83	-0.9	6.79	1.48
K-S	0.062	0.2	0.2	0.024	0	0.2
SHAPIRO-WILK	0.002	0.504	0.089	0.052	0	0.061
Normality test of the quality characteristics for the month of August						
SKEWNESS	-0.4	0.39	1.23	0.36	3.52	0.97
KURTOSIS	-1.65	6.29	0.2	0.1	2.26	0.46
K-S	0.061	0	0.2	0.2	0.024	0.2
SHAPIRO-WILK	0.036	0	0.74	0.271	0.002	0.194

In the month of June, Shapiro-Wilk's test ($p>0.05$) showed that MC_A , MC_{CRS} , and DL were approximately normally distributed with skewness 1.36, 1.14 and 0.57 and kurtosis of 1.77, -0.94 and 1.80 respectively. In July, MC_B, MC_A , MC_{CRS} , MC_{MM} and DL were approximately normally distributed with skewness 1.08, -0.40, 2.04, 1.90 and 2.24 and kurtosis of 2.42, 0.99, 2.83, -0.9 and 1.48 respectively while the Shapiro-Wilk's test ($p>0.05$) showed that, MC_{CRS} , MC_{MM} and DL were approximately normally distributed with skewness 1.23, 0.36 and 0.97 and kurtosis of 0.2, 0.1 and 0.46 respectively for the month of August.

Following the guides in step 3, the control charts were drawn (as shown in figure 1) using the SPC for MS Excel application which is an add-In in Microsoft excel. The red ticks in figure of the CTQ 3-6 represent the out of observations while the blue represent the in-control observations. 199, 180 and 109 sets of observations were taken for all the quality characteristics for the Month of June, July and August respectively, their respective means and standard deviations were calculated.



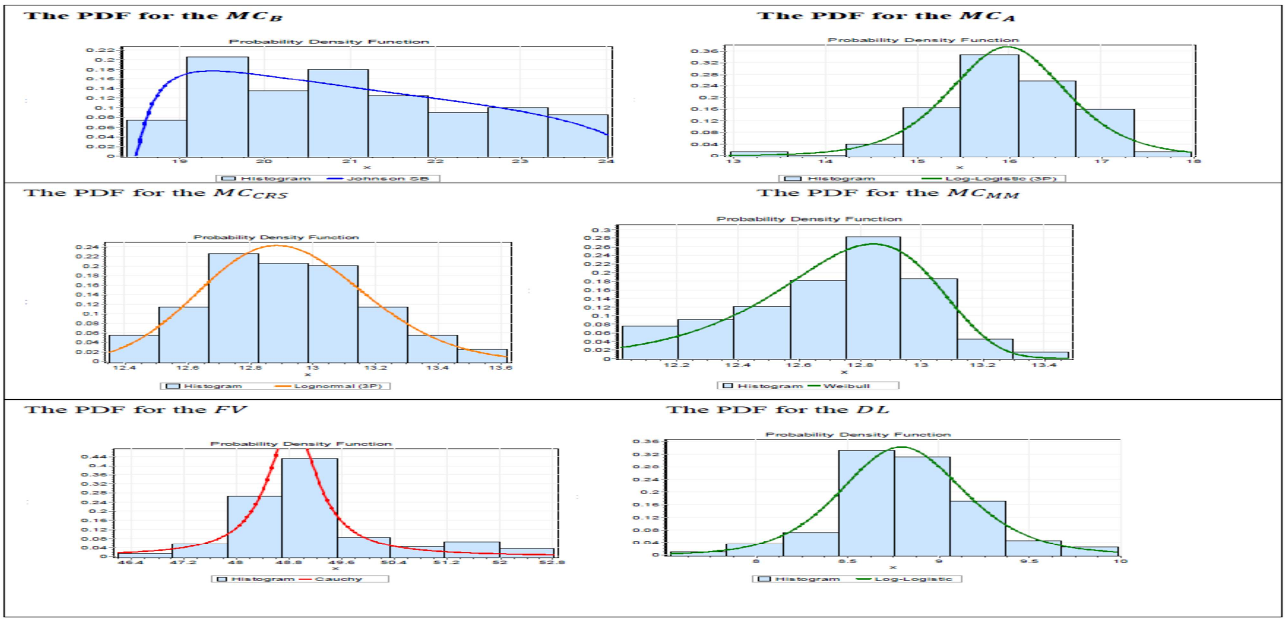


Figure 2. *Histogram for CTQs (June).*

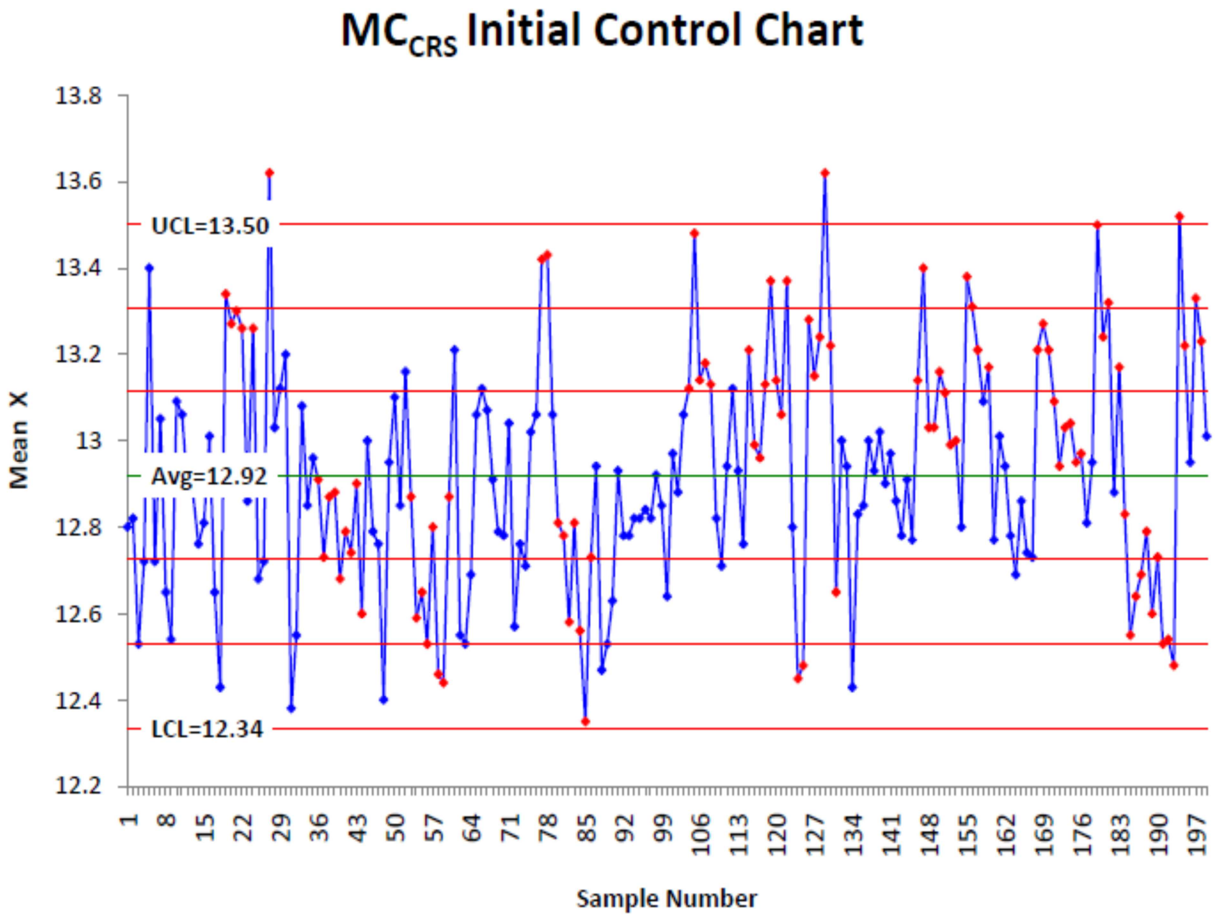


Figure 3. *Control Chart for* MC_{CRS}.

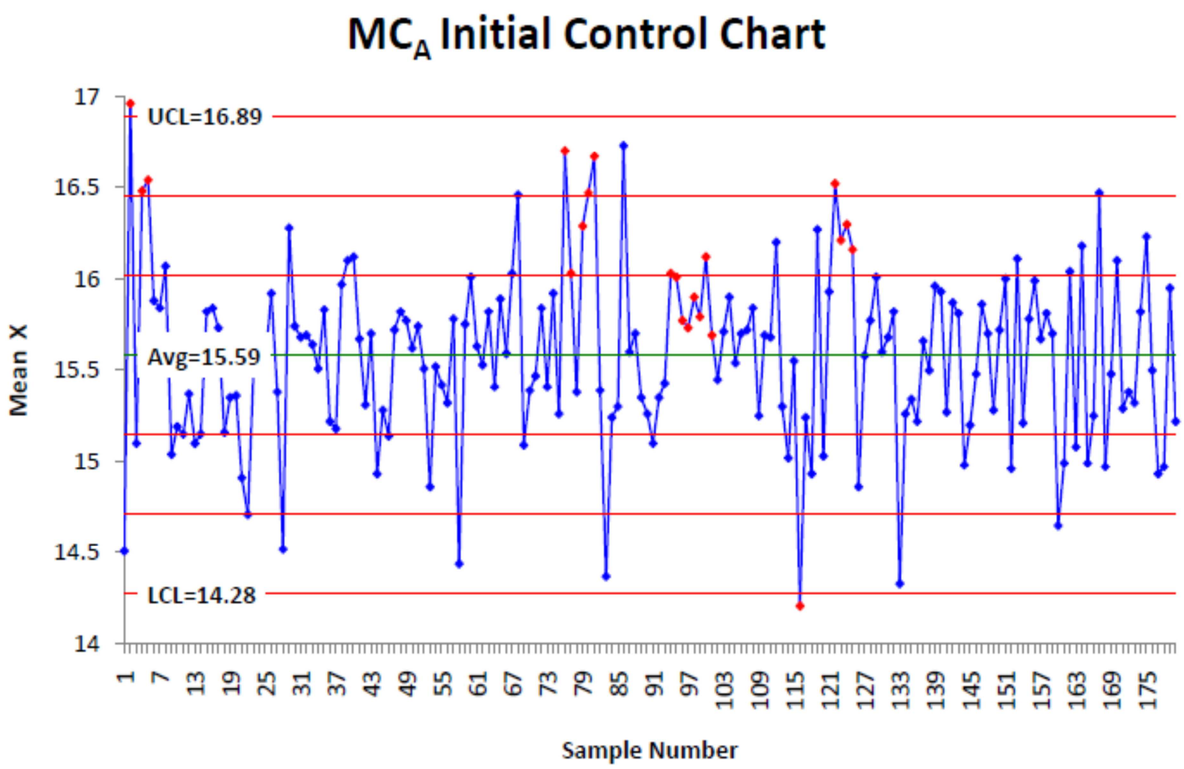


Figure 4. *Control Chart for* MC_A.

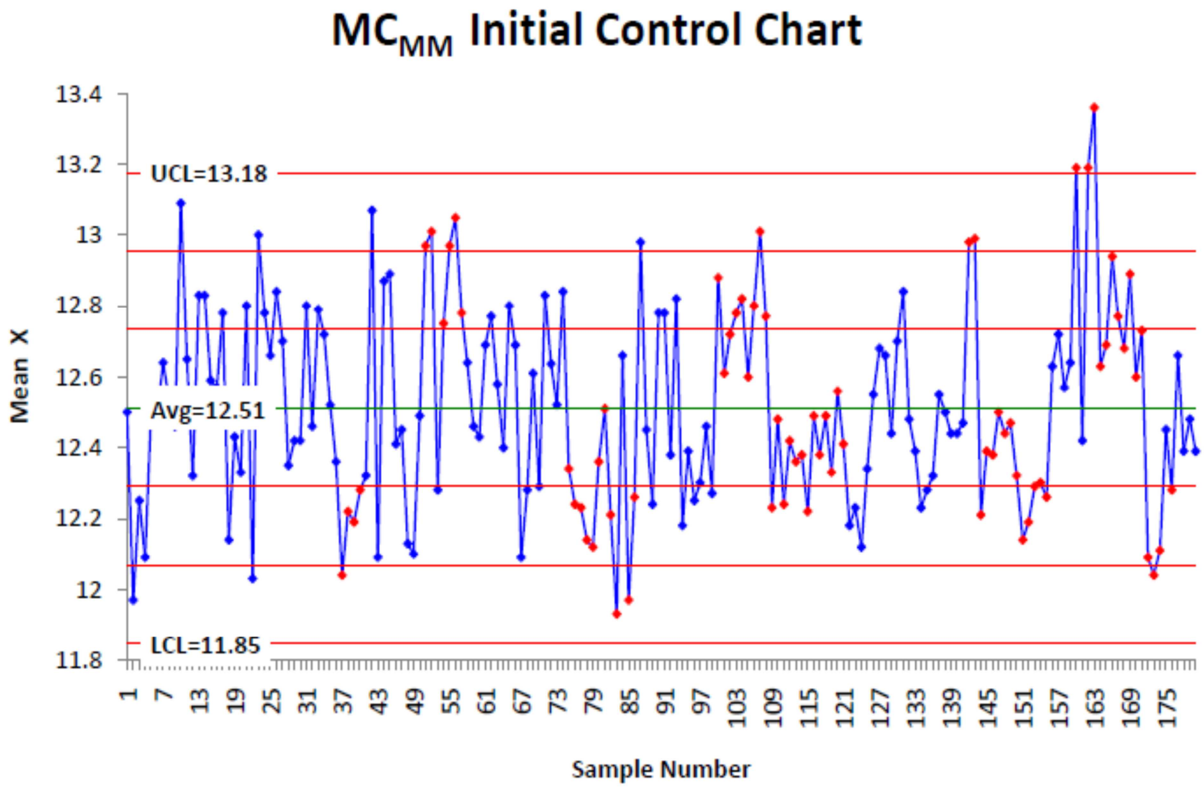


Figure 5. *Control Chart for* MC_{MM}.

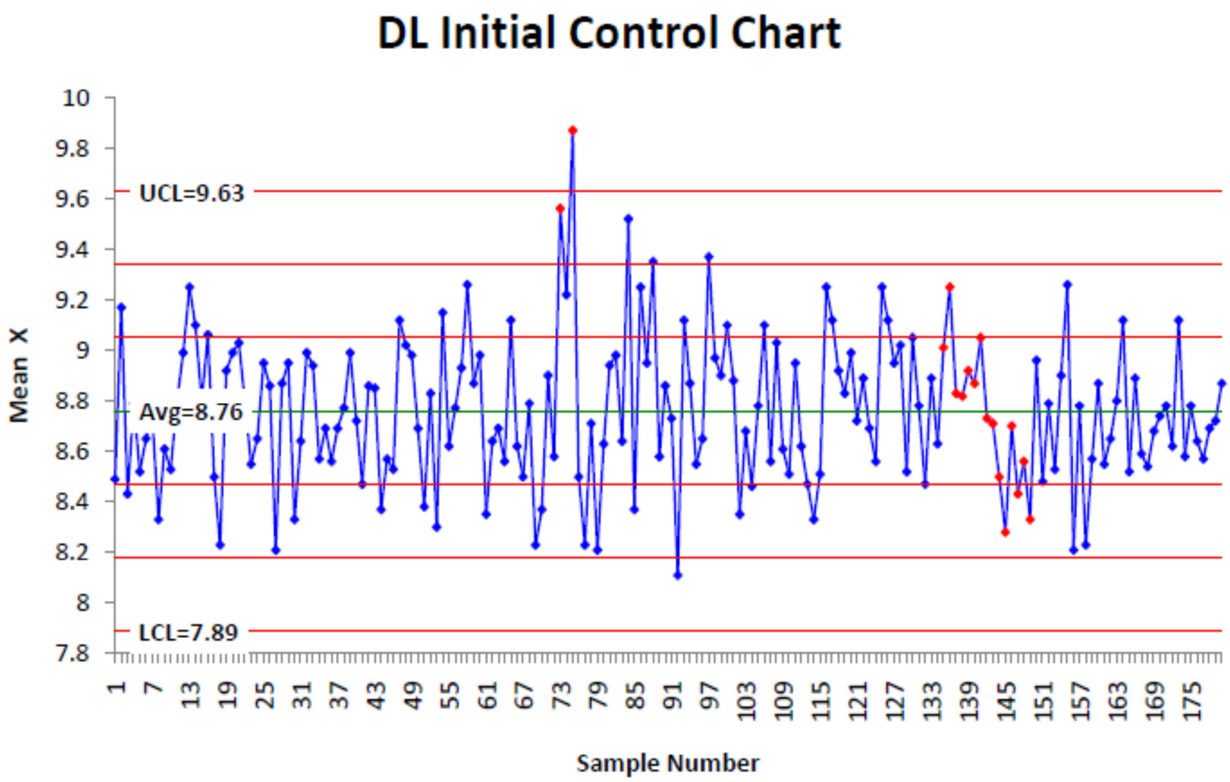


Figure 6. *Control Chart for* DL.

The process charts were drawn and none of the quality characteristics was found to be in control. To transform the out of control process chart to in control process, observations out of control were removed and the process charts redrawn. This continues until none of the observation was found to be out of control. Table 4 shows the number of observations that were removed and the ones left after the process is in control per month.

***Table 4.** Number of observations for the Out-of Control and In-control process.*

CTQ	Out of Control	In-Control	Removed
June			
MC_A	199	146	53
MC_{CRS}	199	84	115
DL	199	109	90
MC_B	199	129	70
MC_{MM}	199	144	55
July			
MC_A	180	151	29
MC_{CRS}	180	142	38
DL	180	163	17
MC_B	180	142	38
MC_{MM}	180	82	98
August			
MC_A	109	104	5
MC_{CRS}	109	103	6
DL	109	85	24
MC_B	109	79	30
MC_{MM}	109	51	58

The study considered four different process capability indices Cp, C_{pk}, P_p and P_{pk}. The process capability analysis was carried out for the quality characteristics which are approximately normally distributed and with statistically controlled processes. For the month of June the Table 5 shows the results of the process capability indices.

***Table 5.** Process Capability Indices of the quality characteristics for the month of June.*

JUNE	MC_A	MC_{CRS}	DL
LSL	14	11.5	n/a
Target	14.5	12	n/a
USL	15	12.5	10
LCL	13.67	12.39	7.801
CL	15.96	12.83	8.787
UCL	18.25	13.28	9.773
Cp	0.22	1.12	n/a
Cpk	0.42	0.75	1.23
Pp	0.24	1.05	n/a
Ppk	0.46	0.7	1.23
LSL	14	11.5	n/a

The three quality characteristics have variables that are normally distributed and their processes are not out of control. Only *DL* appeared to be capable since Cpk and Ppk are both greater than 1 (with value 1.23). For the month of July the Table 6 shows the results of the process capability indices

***Table 6.** Process Capability Indices of the quality characteristics for the month of July.*

JULY	MC_B	MC_A	MC_{CRS}	DL
LSL	19	14	11.5	n/a
Target	21	14.5	12	n/a
USL	23	15	12.5	10
LCL	16.45	14.3	12.07	7.88
CL	21.32	15.49	12.77	8.751
UCL	26.2	16.69	13.47	9.622
Cp	0.41	0.42	0.71	n/a
Cpk	0.34	0.41	0.39	1.43
Pp	0.46	0.4	0.7	n/a
Ppk	0.38	0.39	0.38	1.51

Four of the five quality characteristics whose process capabilities are to be obtained have their variables to be approximately normally distributed and their processes are not out of control. Only *DL* appeared to be capable since Cpk and Ppk are both greater than 1 (with value 1.43 and 1.51 respectively). For the month of August the Table 7 shows the results of the process capability indices

***Table 7.** Process Capability Indices of the quality characteristics for the month of August.*

AUGUST	MC_B	MC_A	DL
LSL	19	11.5	n/a
Target	21	12	n/a
USL	23	12.5	10
LCL	16.73	12.1	7.976
CL	21.13	12.63	8.86
UCL	25.53	13.16	9.744
Cp	0.45	0.94	n/a
Cpk	0.42	0.25	1.29
Pp	0.42	1.07	n/a
Ppk	0.39	0.28	1.31

Four of the five quality characteristics whose process capabilities are to be obtained have their variables to be approximately normally distributed and their processes are not out of control.

Only DL appeared to be capable since Cpk and Ppk are both greater than 1 (with values 1.29 and 1.31 respectively).

5. Conclusion

The purpose of the study was to examine product quality in relation to process capability of a manufacturing company. Specifically, the study addressed the processes used in the production of a product and how much the product meets consumers' quality requirement.

Consequently, the study was able to identify the CTQ distribution, process variability and capability using four capability measures, C_p, C_{pk}, P_p and P_{pk}. From the study, it was observed that none of the CTQ data sets was perfectly normally distributed. In the month of June, three quality characteristics were approximately normally distributed. Similarly, in July and August, four of the five quality characteristics were approximately normal. Also, none of the processes was found to be in a state of statistical control within the months of observation. To determine, process capability, the out of control processes was transformed to in- control state. The capability index shows that the process was capable of producing products within dust level specification for June since it has both Cpk and Ppkvalues of 1.23 and Cpk and Ppk values of 1.43 and 1.51 and 1.29 and 1.31 for the months of July and August respectively.

The results clearly show that the control chart, a key SPC technique, is applicable in process monitoring and initiation of product quality improvement

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