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 competitiveness 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: $C_p \geq C_p^{99} \geq C_{pm}$. Spiring et al., [23] also emphasized that $C_p^{99}$ and $C_{pm}$ are related to marginal expectation imparts 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 belong to a class of normal distribution.
The null hypothesis is rejected if the $p$-value is below 0.05
The normality test was conducted using Kolmogorov-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 $\bar{x}$. This gives the overall or grand average for all observations.
Estimate the standard deviation $s$ of the data points
Find the grand mean of all of the subgroup standard deviation $s$.
Estimate the lower control limits (LCL) and the upper control limits (UCL) as follows:

$$UCL = \bar{x} + A_3 s$$

$$LCL = \bar{x} - A_3 s$$

Step 4: Process Capability Indexes
$C_p$ Index: $C_p$ 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.

$$C_p = \frac{USL-LSL}{6\bar{s}}$$

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

$$C_{pk} = \min \left( \frac{\mu - LSL}{3\bar{s}}, \frac{USL - \mu}{3\bar{s}} \right)$$

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

$$P_p = \frac{USL-LSL}{6\bar{s}}$$

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

$$P_{pk} = \min \left( \frac{\mu - LSL}{3\bar{s}}, \frac{USL - \mu}{3\bar{s}} \right)$$

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.

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_R | 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_R: measures the moisture content before drying  
MC_A: measures Moisture Content after drying  
MC_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

| CTQ | DISTRIBUTION | PROPERTIES |
|-----|--------------|------------|
| MC_R | Johnson SB | γ=0.36129, δ=0.74792, λ=6.0218, ζ=18.48 |
| MC_A | Log-Logistic (3P) | α=3.1726E+8, β=1.3296E+8, γ=9.813 |
| MC_CRS | Lognormal | σ=0.08466, μ=1.1298, γ=0.36129 |
| MC_MM | Weibull | a=0.44429, μ=48.857 |
| FV | Cauchy | a=-39.363, b=8.809, γ=0 |
| DL | Logistic | a=39.363, b=8.809, γ=0 |

Table 3. Normality test of CTQs

| CTQ | DISTRIBUTION | PROPERTIES |
|-----|--------------|------------|
| MC_R | Johnson SB | γ=0.36129, δ=0.74792, λ=6.0218, ζ=18.48 |
| MC_A | Log-Logistic (3P) | α=3.1726E+8, β=1.3296E+8, γ=9.813 |
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| MC_MM | Weibull | a=0.44429, μ=48.857 |
| FV | Cauchy | a=-39.363, b=8.809, γ=0 |
| DL | Logistic | a=39.363, b=8.809, γ=0 |

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

In the month of June, Shapiro-Wilk’s test (p>0.05) showed that MC_R, 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, 0.36 and 2.44 and kurtosis of 2.24, 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 $MC_{A}$. 

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  | June             | July             | August            |
|------|------------------|------------------|-------------------|
|      | Out of Control   | In-Control       | Removed           |
|      | 199              | 199              | 199               |
|      | 84               | 144              | 144               |
|      | 109              | 144              | 144               |
|      | 84               | 144              | 144               |
|      | 109              | 144              | 144               |
|      | 109              | 144              | 144               |
|      | 109              | 144              | 144               |
|      | 109              | 144              | 144               |

The study considered four different process capability indices Cpk, Cpk, and Ppk. 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 | MCA | MCC | 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 | MCA | MCC | 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 | MCA | MCC | 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, Cp, Cpk, Pp, and Ppk. 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 Ppk values of 1.23 and Cpk and Ppk values of 1.43 and 1.51 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.

References

[1] T. Antony, J., and Taner, “A conceptual framework for the effective implementation of statistical process control,” Bus. Process Manag. J., vol. 9, no. 4, pp. 473–489, 2003.
[2] J. C. Benneyan, “Performance of Number-Between g-Type Statistical Control Charts for Monitoring Adverse Events,” Health Care Manag. Sci., vol. 4, pp. 319–336, 2001.

[3] D. C. Montgomery, Statistical Quality Control, 7th ed. MA: John Wiley & Sons, 2012.

[4] P. Gejdoš, “Continuous Quality Improvement by Statistical Process Control,” Procedia Econ. Financ., vol. 34, no. 15, pp. 565–572, 2015.

[5] S. Sousa, N. Rodrigues, and E. Nunes, “Application of SPC and quality tools for process improvement,” Procedia Manuf., vol. 11, no. June, pp. 1215–1222, 2017.

[6] Djekic, I., Smigic, N., Tomic, A., and Gajkovic, A., “Statistical Process Control in Serbian Food Packaging,” J. Qual. Res., vol. 8, no. 3, pp. 323-334, 2014.

[7] Y. Kano, Manabu and Nakagawa, “Manabu Kano and Yoshiaki Nakagawa (2008), Data-based process monitoring, process control, and quality improvement: Recent developments and applications in steel industry, Computers & Chemical Engineering, Volume 32, Issues 1–2, January 2008, Pages 12-24,” Comput. Chem. Eng., vol. 32, no. 1–2, pp. 12–24, 2008.

[8] J. Mason, B., Antony, “Statistical process control: an essential ingredient for improving service and manufacturing quality”, Manag. Serv. Qual. An Int. J., vol. 10, no. 4, pp. 233–238, 2000.

[9] I. Madanhire and C. Mbohwa, “Application of Statistical Process Control (SPC) in Manufacturing Industry in a Developing Country,” Procedia CIRP 49, vol. 40, pp. 580–583, 2016.

[10] S. Skouteris, G., Webb, D. P., Felix-Shin, K. L., Rahimifard, “Assessment of the capability of an optical sensor for in-line real-time wastewater quality analysis in food manufacturing,” Water Resour. Ind., vol. 20, p. Pages 75-81, 2018.

[11] J. Michalska, “The intellectual capital as a chance on improvement of the quality management in the conditions of globalisation” INTELLECT’. Factors creating the quality management in the enterprise,” in Proceedings of the Scientific International, (in Polish), 2005, pp. 187–191.

[12] W. M. Evans, J. R., and Lindsay, The Management and Control of Quality, 6th Edito. South-Western - Thomson Learning., 2005.

[13] A. M. Farooq, R. Kirchain, H. Novoa, and A. Araujo, “Cost of Quality: Evaluating Cost-Quality Trade-Offs for Inspection Strategies of Manufacturing Processes Cost of quality: Evaluating cost-quality trade-off’s for inspection strategies of manufacturing processes,” Int. J. Prod. Econ., vol. 188, no. April, pp. 156–166, 2017.

[14] W. Shewhart, Statistical Method from the Viewpoint of Quality Control. Dover Publications. New York: Dover Publications, 1939.

[15] Z. Holub, M., Jankovych, R., Anders, O., Kolibal, “Capability assessment of CNC machining centres as measuring devices,” Meas. Vol., vol. 118, pp. 52–60, 2018.

[16] D. T. Wen, C., Xu, J., Ai, Q. S., Liu, Q., Zhou, Z., Phamc, “Manufacturing Capability Assessment for Human-Robot Collaborative Disassembly Based on Multi-Data Fusion,” Procedia Manuf., vol. 10, pp. 26–36, 2017.

[17] E. Kureková, “Measurement Process Capability – Trends and Approaches,” Meas. Sci. Rev., vol. 1, no. 1, 2001.

[18] V. Kane, “Process capability indices,” J. Qual. Technol., vol. 18, pp. 41-52., 1986.

[19] M. J. Chandra, Statistical Quality Control. United States of America: CRC Press LLC, 2001.

[20] F. A. Chan, L. K., Cheng, S. W., Spiring, “A new measure of process capability,” J. Qual. Tech., vol. 20, pp. 162–175, 1988.

[21] T. C. Hsiang, “A tutorial on quality control and assurance- The Taguchi method,” Las Vegas:, 1985.

[22] Kotz, S., Johnson, N. L., “Process Capability Indices – A Review, 1992-2000.,” J. Qual. Technol., vol. 34, no. 1, pp. 2–19, 2002.

[23] B. Spiring, F., Cheng, S., Yeung, A., & Leung, “Discussion,” J. Qual. Technol., vol. 34, no. 1, 2002.

[24] R. C. Gupta, Statistical Quality Control. 7th Ed. Khanna Publishers, 2003.