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ADAPTIVE CAPABILITY ASSESSMENT OF A PROCESS IN CABLE MANUFACTURING: A CASE STUDY

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Abstract

This paper took a conceptual and exploratory direction to discuss the Process Capability (PC) theme. The literal exploration was concisely taken to adequately capture capability index relationships and their rich practical benefits. The case study assessment was undertaken in a cable manufacturing company located in the Southeast Nigeria to solve industry specific problem. The critical-to-quality characteristic considered in this study is Cable uniformity, and the study quest was developed based on the organization's efforts to maintain process consistency, reduce process loss and improve process yield. The results from the capability assessments before and after the process improvement were used to ascertain the quality level of a specific extruding unit in the case organization. The process stability was steadily maintained in the study through proper identification and careful removal of all the assignable causes of variations in the process. A new engineering tolerance (T±0.032) was derived, and the engineering specification were carefully tightened in such a way that a six sigma process can easily be captured. The quality achievement at the project termination stage depict a peak increment in Sigma level of the process from 0.6 baseline value to 5.2, thus reducing Defects Per Million Opportunities (DPMO) from the 810,000 to 10.

Keyword: Process capability study, box-cox transformation, process capability indices, cable manufacturing.

1.0 Introduction

The intense competition among business organizations globally is becoming more interesting and most organizations are gearing towards manufacturing defect-free products. It has been a common place occurrence in industries that out of specification variations are usually detected too late, most often after part production. Poor inspection of manufacturing processes has rendered most advantaged organizations limping as regards to customer goodwill retainer ship. A critical factor in reducing cost and increasing product quality lies in the ability to predict and then minimize manufacturing variations found in processes (Chen et al., 2005). Process variations can be categories in terms of material, machine, method, manpower, environment, and measurement. The presence of process variations especially the special causes makes prediction impossible and thereby making the meaning of a capability index unclear. As a result of this complex nature of most manufacturing processes, it requires vibrant monitoring and successive improvement strategies. The best way to quantify variation causes and categorically predict the operational state of any given process is through capability studies. Capabilities of processes are monitored through PCs using capability indices to provide the numerical measures of the capability. Process capability Indices (PCIs) relates the engineering specification to the behaviour of the process (Bangphan et al., 2014). These indices are unit less and its numerical value increases when the variability decreases. The capability indices relate the voice of the customer to the voice of the process (Steiner et al., 2014). However, a better understanding of the relationship between the standard specification limit and control limit is required for an adequate understanding of PC (Chowdhurry, 2013). PCs have gained wide recognition for the past four decades, and its deployment has gone deep in industrial and service sector organizations. The concept has been applied in most of the manufacturing industries like in silicon-filler manufacturing process (Chen et al., 2006; in electronic industry (Motton et al., 2008); in aluminum capacitor manufacturing process (Pearn& Road, 1997); in drug manufacturing companies (Akeem et al., 2013); in automotive industry (Kane 1986). It is pertinent to note that in PCs studies, some assumptions and procedural conditions are mandatory so that one does not misrepresent the true capability of a process. These procedural assumptions and conditions includes, having a process under statistical control, having a normally distributed process, use of at least 50 randomly selected samples in a study, ensuring the data chosen in a study represents all natural variations, and that the process of interest is devoid of any special causes of variation.

2.0 Methodology

A medium-sized cable manufacturing company, making various sizes of cables and colours is considered. An appropriate sample size estimate was applied in this study, and the samples were all gotten from the various batch of 1.0mm single core cable produced from TEKO-50 extrusion line. The data for the investigated characteristics were collected for a span of 20 workdays in the company. The data were classified into 20 subgroups of five observations and were randomly collected at the coiling section. All the aforementioned capability assumptions and conditions were observed in the study. The additional assumption observed is that the extruding machine investigated in the study was capable. The effects of the process change were assessed by comparing capability indices calculated before and after the change. The PC approaches followed in this study as shown in figure 1 was adapted based on (Pyzdek& Keller, 2010) recommendations.

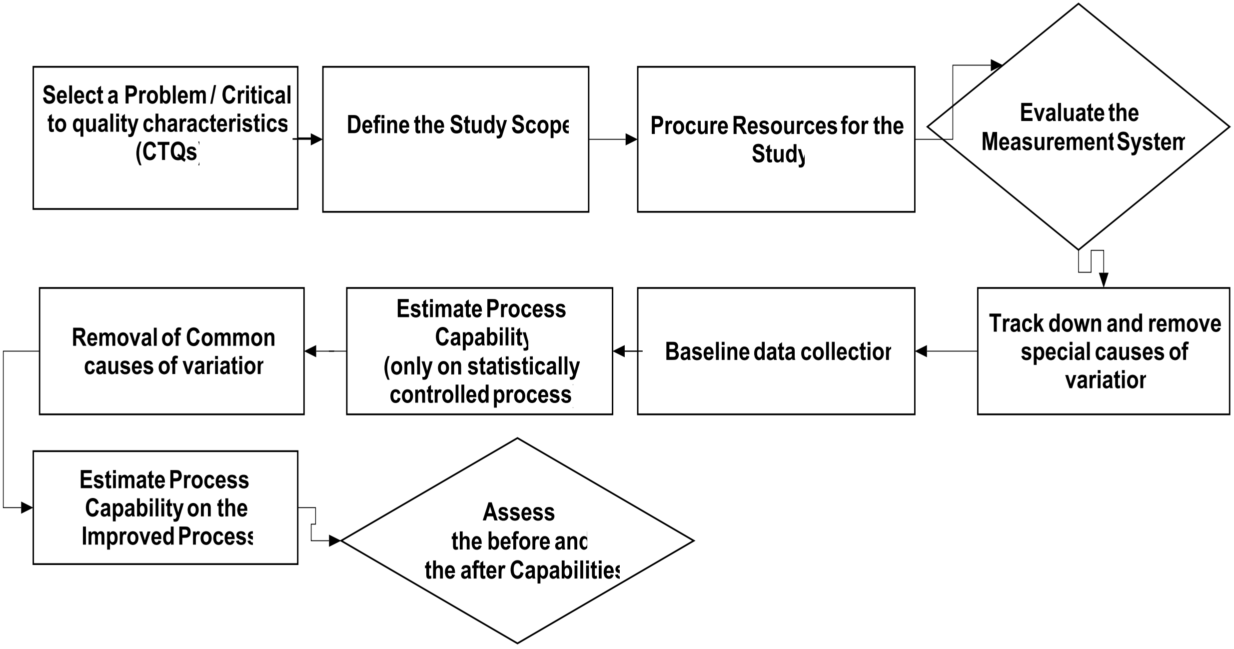


Figure 1: Methodology Flowchart for the Capability Assessment.

The mathematical computations were made in this study using important PC indices and MSA gage R & R metrics as described in with the following equations:

$$C_P = \frac{Allowable\ \ range\ \ of\ measurements}{Actual\ \ range\ \ of\ \ measurements} \tag{1}$$

$$C_{PU} = \frac{USL\ -\ \mu}{3\sigma} = \frac{Allowable\ \ upper\ \ spread}{Actual\ \ upper\ \ spread} \tag{2}$$

$$C_{PL} = \frac{\mu - LSL}{3\sigma} = \frac{Allowable\ \ lower\ \ spread}{Actual\ \ lower\ \ spread} \tag{3}$$

$$CR = 100 \text{ X } \frac{6\hat{\sigma}}{Engineering\ \ tolerance} \tag{4}$$

$$Z_U = \frac{Upper\ \ specification\ \ -\bar{\bar{X}}}{\hat{\sigma}} \tag{5}$$

$$Z_L = \frac{\bar{\bar{X}} - Lower\ \ specification}{\hat{\sigma}} \tag{6}$$

$$C_{PK} = \text{Min}\left\{\frac{USL-\mu}{3\sigma}, \frac{\mu-LSL}{3\sigma}\right\} \tag{7}$$

$$K = \frac{\mu - M}{\frac{(USL-LSL)}{2}} \tag{8}$$

where k represents a measure of the distance that the process lies off center, and is an absolute value.

$$C_{PM} = \frac{USL-LSL}{6\sqrt{\sigma^2 + (\mu-T)^{\ \ 2}}} \qquad \text{(when T = M)} \tag{9}$$

$$C_{PM} = \text{Min}\left\{\frac{USL-T}{3\sqrt{\sigma^2+(\mu-T)2}}, \frac{T-LSL}{3\sqrt{\sigma^2+(\mu-T)2}}\right\}) \qquad \text{(when T} \neq \text{M)} \tag{10}$$

$$T = {}^{1}/_{2}\,[LSL + USL] \tag{11}$$

where $k = \frac{\mu - T}{d}$ and $d = \frac{USL - LSL}{2}$, Note: $C_P = C_{PK} = C_{PM}$, when $\boldsymbol{\mu} = T = M$ but differ when $\boldsymbol{\mu} \neq T$

$$\% \text{ Contribution } = \frac{\sigma^2 \text{ Re } peatability + \sigma^2 \text{ Re } producibility}{\sigma^2 Total} \text{ x } 100 \tag{12}$$

$$\% \text{ Study variation } = \frac{\sigma\ measurement}{\sigma\ total} \text{ X } 100 \tag{13}$$

$$\text{Two-sided Spec \% P/T } = \frac{6\sigma\ measurement}{USL-LSL} \text{ X } 100 \tag{14}$$

$$NDC = 1.41\left[\frac{PV}{\sigma^2 \text{ Re } peatability + \sigma^2 \text{ Re } producibility}\right] \tag{15}$$

The quality problem selected for this study is inconsistency in the dimension of cable extruded, thus the critical-to- quality characteristics considered is cable diameter uniformity. The impact of this quality defects are seen in two forms:

1. As over-dimensioned cable, and
2. As under dimensioned cable.

The objective of the study is to improve the cable extrusion process such that the dimension of the cable produced is within the acceptable customer specification range. There are two notable production odd consequences attached to inconsistent cables. Firstly, over-dimensioned cable is a clear indication of materials wastage, and the associated consequences are seen in increased production cost and customer dissatisfaction due to practical difficulties always encountered when working with over dimensioned cables. Secondly, when a cable is under-dimensioned there is high chance that the cable will fail insulation thickness test. This production odd if neglected and the defect products are sold to market will lead to electric shocks as a result of energy leaks and increased chances of electrocution incidence. The scope of the study was focused on the 1.0mm single core produced from the TEKO-50 machine. The management support was sought that enabled the availability of resources for the study. These resources comprises of humans that constitute the project team, money for the procurement of the statistical training tools and software package.

Thereafter, Measurement System Analysis (MSA) was conducted to validate that the measurement system was good enough to be used in the study and the type of data used is variable data. The result of the analysis on the four most important Gage R & R metrics depict that the percentage contribution of Var Comp = 0.05%, percentage Study Var = 2.30%, percentage Tolerance = 2.92%, and NDC =

61. After the measurement system validation, the improvement team converged in a brainstorm session to identify the potential special causes of variations in cable extrusion.

3.0 Results and Discussions

The brainstorming session was made more effective through the use of fishbone diagram (see fig. 2), and the special causes were identified as shown in table 1, and were eliminated from the process before data collection on the baseline performance of the process. The data used in the study were classified into 20 subgroups of five observations each and were randomly collected at the coiling section.

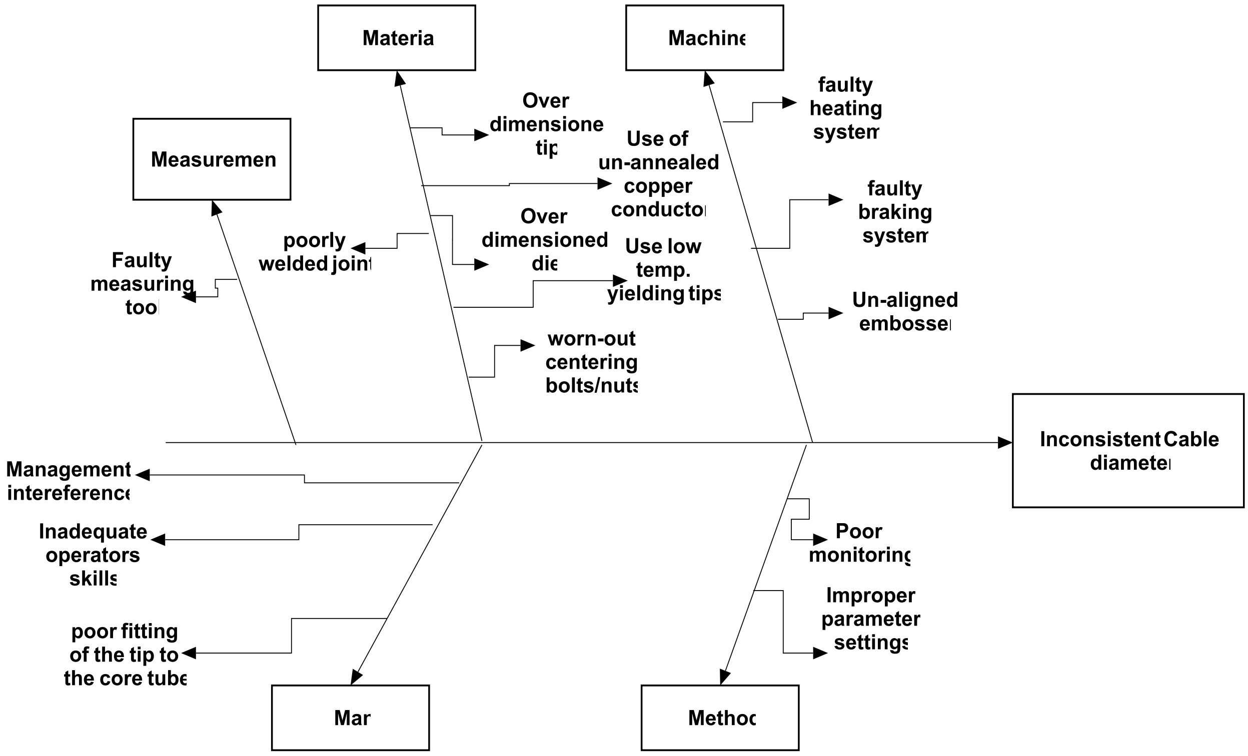


Figure 2: The Fishbone diagram

Test assumption for process stability was validated and the result is as depicted in figure 3.

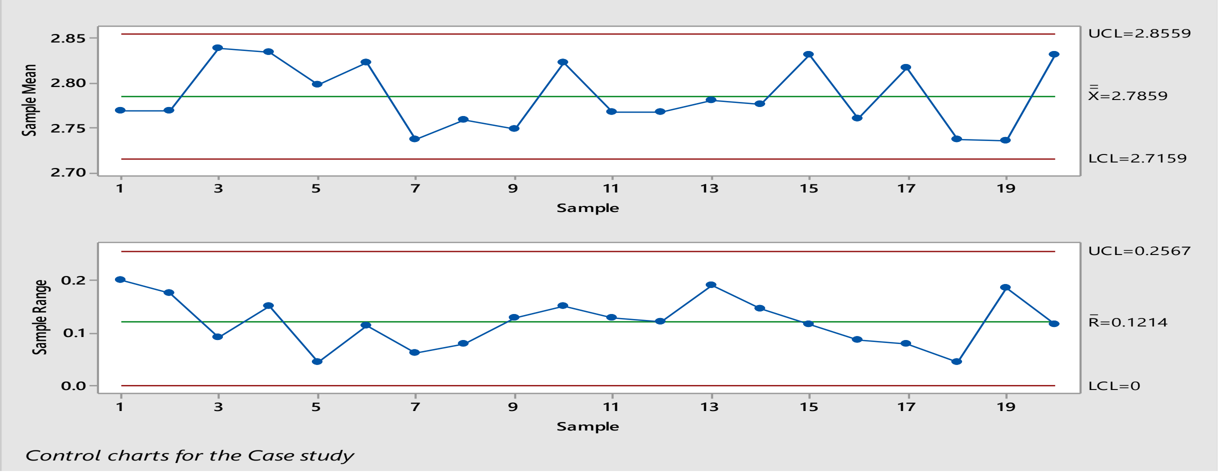


Figure 3: $\overline{X}$ and R- Chart for stability assessment

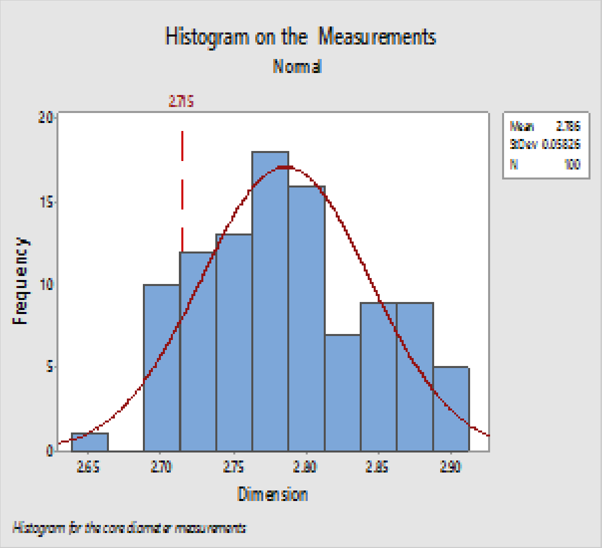
Control limits for $\overline{X}$ –Chart:

$$UCL = \bar{\bar{X}} + A_2\bar{R} = 2.7858 + 0.577(0.1214) = 2.8559$$
$$LCL = \bar{\bar{X}} - A_2\bar{R} = 2.7858 - 0.577(0.1214) = 2.71585$$

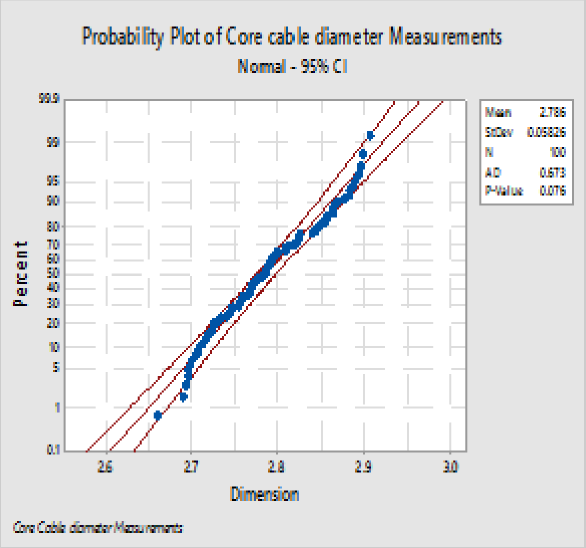
Control limits for R-Chart:

$$UCL = D_4\bar{R} = 2.114(0.1214) = 0.2566$$
$$LCL = D_3\bar{R} = 0.00(0.12145) = 0.000$$

From Table of Control Chart Constants, n= 5, $A_2 = 0.577$, $d_2 = 2.326$, $D_3 = 0$, $D_4 = 2.114$



Histogram for the core diameter measurements



Core Cable diameter Measurements

Histogram and normal probability plot were used to check the normality of the data used for the case study. Figure 4 displays the histogram and the sample data appears to be normal, the output of the normal probability plot has shown; $\boldsymbol{\mu} = 2.786$, $\boldsymbol{\sigma} = 0.05826$, Anderson Darling test statistic value= 0.673, P-value = 0.076 > ά (0.05). Figure 6, is the pictorial presentation of the capability report: USL = 2.90, LSL = 2.53, Test equipment = Insulating outer wall thickness projector cable tester (Profile enlarger).

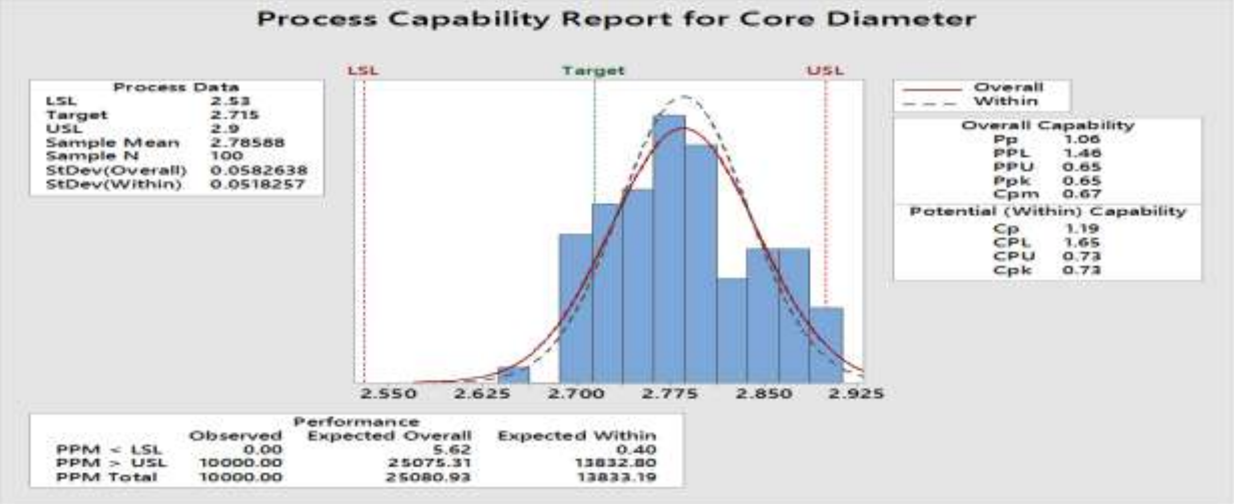


Figure 6: Process Capability report on the baseline measurements

Index results: $C_P = 1.19$; $C_P > 1$ = Acceptable; $C_{PK} = 0.73$, $C_{PK} < 1$= not acceptable; $C_R = 84.67\%$, $C_R > 75\%$ = not acceptable, $C_{PU} = 0.73$, $C_{PL} = 1.65$, $Z_U = 2.18$, checking from standard normal table Z_U = 1-0.9854 = 1.46%, by this estimation approximately 1.46% of the cable produced will exceed the upper specification limit; $Z_L = 4.89$, $Z_L > 3$ = acceptable $C_{PM} = 0.7$.The process was improved to minimize further the rate at which over-dimensioned cables are produced. This was achieved through the design of experiment using Taguchi approach in finding the optimal process parameter settin After the experimental design, capability study was taken to ascertain the level of improvement attained.

However, the test data after the improvement failed the normality test and were subjected to Box-Cox transformation using lambda (λ) value of 0.5. Test assumptions were also validated for the data collected after the process improvement as depicted in figure 7.

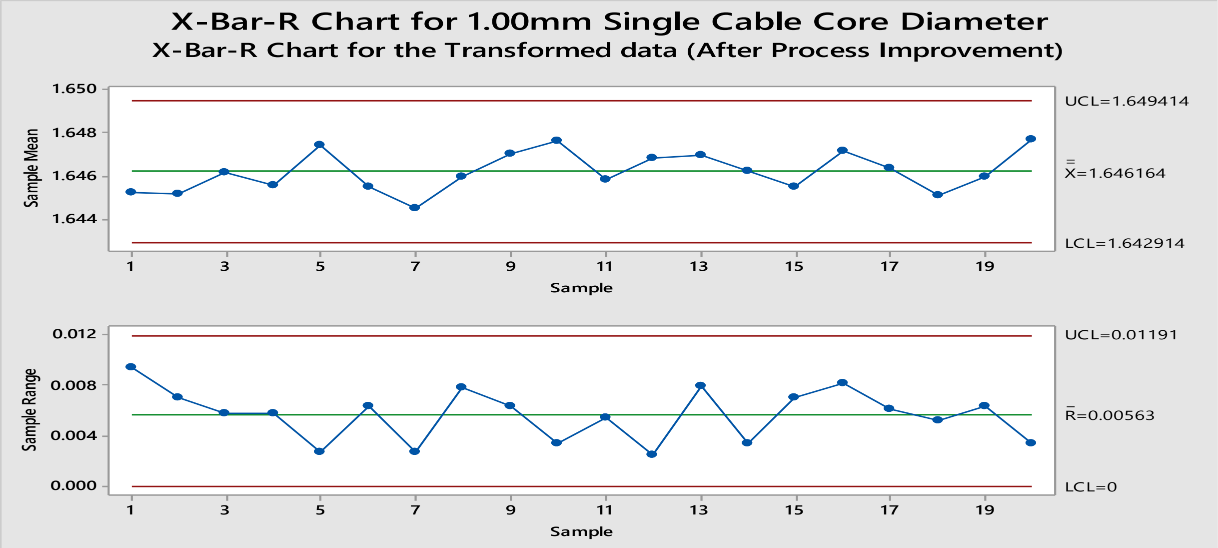


Figure 7: X-Bar-R chart for the transformed data after the process improvement

Control limits for $\bar{X}$ –Chart after transformation:

$$UCL = \bar{\bar{X}} + A_2\bar{R} = 1.646164 + 0.577(0.00563) = 1.64941251$$

$$LCL = \bar{\bar{X}} - A_2\bar{R} = 1.646164 - 0.577(0.00563) = 1.64291549$$

Control limits for R-Chart after transformation:

$$UCL = D_4\bar{R} = 2.114(0.00563) = 0.011901$$

$$LCL = D_3\bar{R} = 0.00(0.00563) = 0.000$$

From the control chart constant for n = 5, $A_2 = 0.577$, $d_2 = 2.326$, $D_3 = 0$, $D_4 = 2.114$. PC study was also conducted on the improved process after test validation of all the necessary assumptions and conditions. Index results were as follows: $C_P = 7.55 > 2$ = (False capability); $C_{PK} = 7.46 > 2$(not acceptable); $C_R = 13.25\%$ (exceptionally clustered), $C_{PU} = 7.63$, $C_{PL} = 7.46$, $Z_U = 22.88 > 6$ (not acceptable); $Z_L = 22.39 > 6$ = (not acceptable); $C_{PM} = 6.4$.

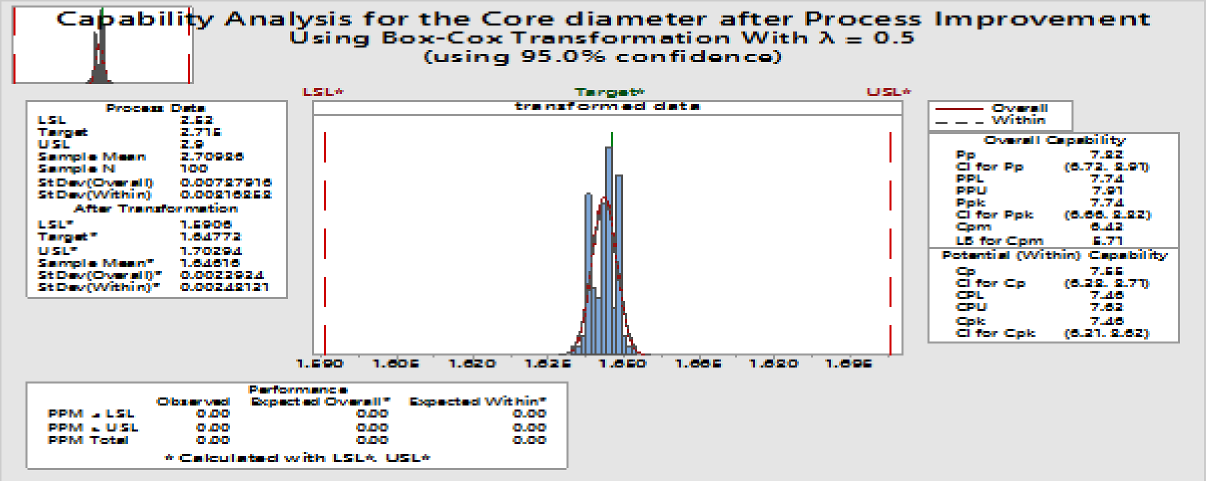


Figure 8: Capability Analysis for the Cable diameter measurements after the process improvement.

However, from the index report on the process after improvement, it was made clear that the ind values were on the high side, an indication that the existing engineering tolerance is far apart fr each other with a large standard deviation. The next step was to derive an appropriate tolerance interval that can clearly depict Six Sigma Process. Equation (15) & (16) were used to tighten the tolerance intervals

$$\overline{X} \pm Ks \qquad (16)$$

$$s = \sqrt{\frac{\sum(x-\overline{x})^2}{N-1}} \qquad (17)$$

where K is a constant and is determined so that the interval will cover a proportion P of the population with confidence Y, s is the sample standard deviation, x = each value in the sample, $\bar{x}$= the mean of the values and N = the sample size. 20 samples were randomly selected from the stable process population, and their standard deviation was found.

$$S = \sqrt{\frac{0.0014706}{19}} = 0.0087977$$

Tolerance intervals now becomes;2.7114 ± K(0.0087977). The K value for two sided limits was found using Table of factors for tolerance intervals,for n=20, P=0.99 and Y = 0.95, K= 3.615. 2.7114±3.615(0.0087977) = 2.7114±0.032 (USL = 2.74, LSL = 2.67). with this tightened engineering tolerance, the capability of the improved process was assessed; C_P = 1.43, C_R = 69.96%, Z_U = 3.68, Z_L = 4.89, C_{PL} = 1.63, C_{PU} = 1.23, C_{PK} = 1.23, C_{PM} = 1.26, Sigma level = 5.2

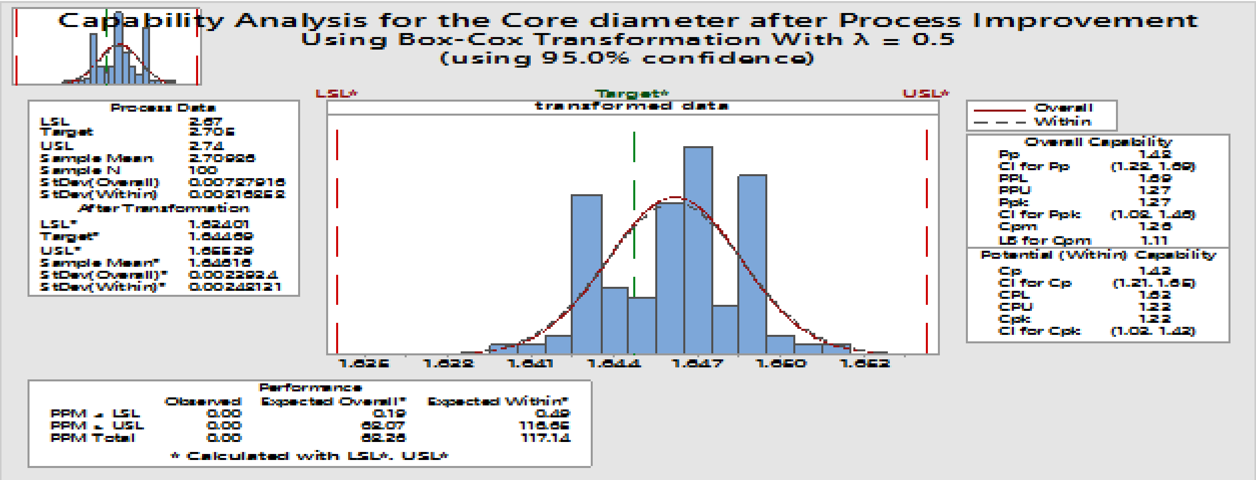


Figure 9:Capability analysis for the cable diameter after the process improvement.

For purpose of clear assessment, the newly-derived engineering tolerance (2.7114±0.032) was used to conduct Capability studies of the baseline measurements, and the capability outcomes are: C_P = 0.22, C_{PU} = 0.75, C_{PL} = -0.30, C_{PK} = 0.3, C_{PM} = 0.12, Z_U = -0.88, Z_L = 2.22, total reject rate = 82.42%, estimated yield = 17.58% and Sigma level = 0.6

4.0 Conclusion

A PC study was conducted in a renowned cable manufacturing industry located in South Eastern Nigeria. This paper detailed insight into PC theories, principles, and ideas to effectively quantify process variations and minimize the rate of producing defective cable products. To this end, this study clearly expounds on the adaptive and the systematic PC approach, in quantifying and assessing quality improvement goals in an industrial setting.

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