Improving the Quality and Operations of a Cable Manufacturing Company by Implementing Six Sigma-DMAIC Technique

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Abstract
This research is focused on the application of Six Sigma-DMAIC (SS-DMAIC) technique to monitor the changing distribution of process capabilities in a cable manufacturing company for better operational performance. Most cable manufacturing organizations (CMOs) focus on classical methods and often pay less attention to inventive techniques for system improvement. Hence, the method adopted in this research is focused on comparing the initial and final process capability of executed projects, using the initial and final Sigma level and comparing initial and final economic impact assessment of the implemented project. The root causes of variation in cable manufacturing were identified as designs, parameter settings, materials, operation techniques, and measurement system errors. Improvement in materials and operations of a cable manufacturing company was attained by implementing SS-DMAIC technique in terms of the increased Sigma level. The organizational measurement system was assessed as well as the baseline performance of the system. In conclusion, the integration of SS-DMAIC with other business management initiatives in a dynamic cable manufacturing environment eliminated non-value-added activities from the process and the expected productivity rate for the extrusion start-up operation was achieved.

Keywords
Material improvement, Quality management, process capability, Six Sigma DMAIC

1. Introduction
The Speedy growth in economic activities across the globe in recent time has resulted in progressively close competition in product and service-based systems. At present, organizations are determined and continuously striving to meet up customers' expectations by focusing on product quality at every level. The spontaneity of markets evolutions and processes has propelled the product and service-based organizations around the world into developing new concepts of business management strategies to sustain their operational efficiency. Many companies have witnessed a paradigm shift from classical techniques to high-level methodologies/initiatives designed to help organizations tackle process improvement problems towards the rapid dynamic business challenges. Each of these business improvement initiatives is aimed to help business processes identify process issues, fix them and analyze the success or failure of those changes. Quality plays an important role in the success and failure of an organization.

The efficiency of a process is determined by its ability to produce goods or services reliably within specification limits. Every organization strive to produce good quality products, it is possible to manufacture products at a high cost, using inefficient methods. Unfortunately, such an inefficient process can generate defective products incurring so much cost to the company. It is, therefore, very important to adopt strategies to help facilitate and optimize the production process in a manufacturing setting (Momani and Mumani 2017; Maesa et al. 2017; Tartibu et al. 2020). The introduction of Motorola's Six Sigma approach in the late 1980s enabled many companies to efficiently boost their manufacturing capability, minimize waste and maximize productivity (Chen and Chen 2016; Chen et al. 2017 and Huang et al. 2010). Six Sigma grew rapidly from a mathematical procedure for minimizing manufacturing defects to becoming a marketed and standardized technique of management for innovative expression and problem solving. Its maxim of operation is hinged on labelling any process that does not lead to customer satisfaction as a defect and be eliminated from the system to ensure superior quality of product and services.

2. Review of Literature on Six Sigma-DMAIC

Six Sigma (SS) is a business strategy that seeks to identify and eliminate causes of defects or failures in business processes by focusing on outputs that are critical to the customer (Ninerola et al. 2020). SS-DMAIC is a problem-solving method mainly used in manufacturing processes. The objectives of SS are to increase the profit margin and improve financial gain through minimizing the defects rate of products. Successful implementation of SS-DMAIC approach has been widely reported in the literature. Research on SS subject irrespective of its impressive track records in practices is still at the low level (Zhang et al. 2009). The DMAIC steps are basically used for any process improvement project. DMAIC is concerned about removing variability out of the existing processes. DMAIC methodology forces project leaders to capture problems in terms of facts and measurable variables. Typical DMAIC projects are selected based on their expected contribution to improving efficiency, cost or customer value (Pande et al. 2000). SS has been used intensively in healthcare (Bhat et al. 2016; Antony et al. 2018; Castle et al. 2005; Chen and Chen 2016; Gleich et al. 2016; Ninerola et al. 2020; Ortiz et al. 2016).

The impact SS has on improving business performance is dramatic and well documented. Its goal is to increase process capability in the value stream by aiming for zero defects and reduced process variations (Gutom and Wibisono 2019). Specifically, the method can be designed to fit a variety of business goals, allowing organizations to define objectives around specific industry needs. (Chen et al. 2017). Based on this premise, a standardized way of applying SS is typically a myth (Moosa and Sajid 2010) and its application is still novel. Hybrid methods have been applied in literature (Gutom and Wibisono 2019; Feng and Antony 2010; Dreachslin and Lee 2007; Jairaman et al. 2017). The methodology is continually evolving and can concentrate on a given division of manufacturing or service system with strong emphasis on a mathematical model and statistical analysis in industrial, design and customer-focused activities. The methodology is also aimed at building a culture among process management practitioners to always strive for steady improvement**.** This research is focused on the improvement of materials and operations in a cable manufacturing company using the hybrid SS-DMAIC method.

3. Methodology

A medium-sized cable manufacturing company, making various sizes of cables and colours is considered in this research. The case organization has over the years been overwhelmed with several production challenges in the form of high rejection percentage of cable after extrusion due to insulation surface flaws, failed insulation thickness, low conductor diameter, and inconsistency in cable dimension etc. Although various consulting firms have been hired previously by the organization in the past to help solve some of these problems to no avail. It is therefore important to deploy logical and systematic solutions/procedures to determine the origin of these defects in a processing line and eliminate possible defects using SS-DMAIC methodology in chronological order as shown in Figure 1. Minitab-17 and the Design Expert-11Softwares were used for the statistical and experimental design analysis.

4. Six Sigma-DMAIC Application in Cable Manufacturing

4.1 Define Phase

In this phase, real-life problems which deal with the variations that occurred during the production of single-core house wiring cables in the extrusion process were clarified. The selection criterion for the eventual projects was based on the rejection percentage on cable products, associated financial cost, and material waste. A project charter was drafted as shown in Table 1, containing necessary information on the projects selected.

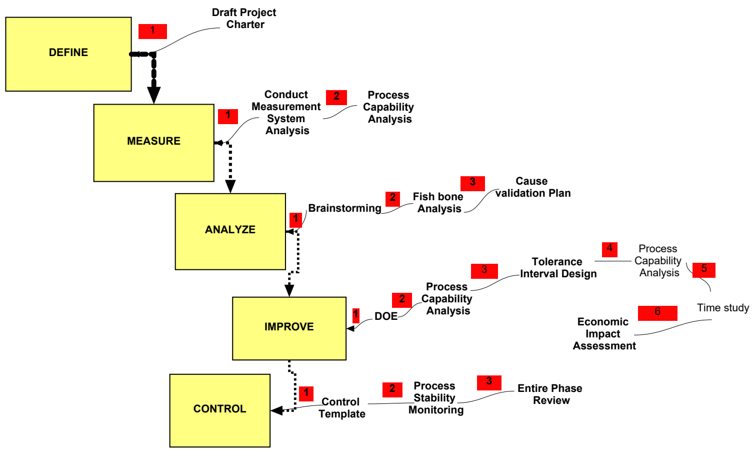

Figure 1. The Deployment framework using the Six Sigma-DMAIC Methodology

Table 1: Project Charter

Project Title: Project I: Reduce the rate of extruding inconsistent dimensioned cables. Project II: Reduce the rate of extruding cables with Insulation Surface Flaws.	
Background and reasons for selecting the projects **Project I:** The quality problem is inconsistency in the dimension of cable extruded, thus the CTQ characteristics considered is cable diameter uniformity. The impact of these quality defects is seen as: 1. As over-dimensioned cable, and 2. As under dimensioned cable. These are the two notable production odd consequences attached to inconsistent cables. Firstly, the 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 a high chance that the cable will fail the insulation thickness test. This production odd if neglected and the defective products are sold to the market will lead to electric shocks as a result of energy leaks and chances of electrocution incidence. These defects affect the aesthetic aspect, barrier properties and mechanical strength of the coated substrate. **Project II:** Insulation Surface flaws occur when the insulation integrity of the conductors is compromised and are the most common cause of problems in electrical equipment. When there are insulation flaws, there is always leakage of current exceedingly above a specific design limit and can lead to defective cable products as it would be difficult for the product to deliver electrical energy to a load efficiently. Insulation Surface Flaws manifest in the form of dark spots, dimples, pimples, cavity, pinholes, air cavity etc. Its odd consequences are seen in the form of electric shocks, high voltage failures, and electrocution, due to isolation faults.	
Aim: This research aims to enhance process performance in cable manufacturing using SS-DMAIC.	
Critical to Quality Characteristics	1. Uniform cable diameter 2. Surface smoothness of the cable
Project scope	Extrusion Process of 1.0mm single house wire.
Project Boundary	Focusing solely on the extrusion process of 1.0mm single house wire from a TEKO-50 extrusion line.
Project Team	The management support was sought that enabled the availability of resources for the study. These resources comprise of humans (The researchers, two Personnel from QAD, and two personnel from the Manufacturing department (MD) that constitute the project team, money for the procurement of the statistical training tools and software package.

4.2 Measure Phase

The major activity in the measure phase is to understand the baseline condition of the system to be improved. Two sets of analysis are being conducted at this stage, Measurement System Analysis (MSA) and Process Capability Analysis (PCA). MSA was first conducted to validate that the measurement systems are good enough to be used in the study. Under the MSA studies, two analyses were conducted, Attribute Gage Repeatability and Reproducibility (R & R) for attribute data (Insulation smoothness) and Gage R & R analysis for variable data (Cable diameter/dimension). The cable core diameter measurements by operators are within the control as shown in Figure 2 and attribute data evaluation of the operators were in agreement with each other 90% of the time and were in agreement with the expected (standard) result in 90% of the time. The Kappa Value for all appraisers versus the standard values was 0.90, indicative of excellent agreement between the appraised values and reference values. The analytical results from Minitab-17 Software for the variable data show that the percentage contribution of Var Comp = 0.05%, percentage Study Var = 2.30%, percentage Tolerance = 2.92%, while the number of distinct categories NDC = 61. Comparing these results with the benchmark values in the Automotive Industry Action Group (AIAG 2010) reference manual, we found the measurement system was good enough for the study. After the measurement system has been validated and found reliable, process capability studies were conducted.

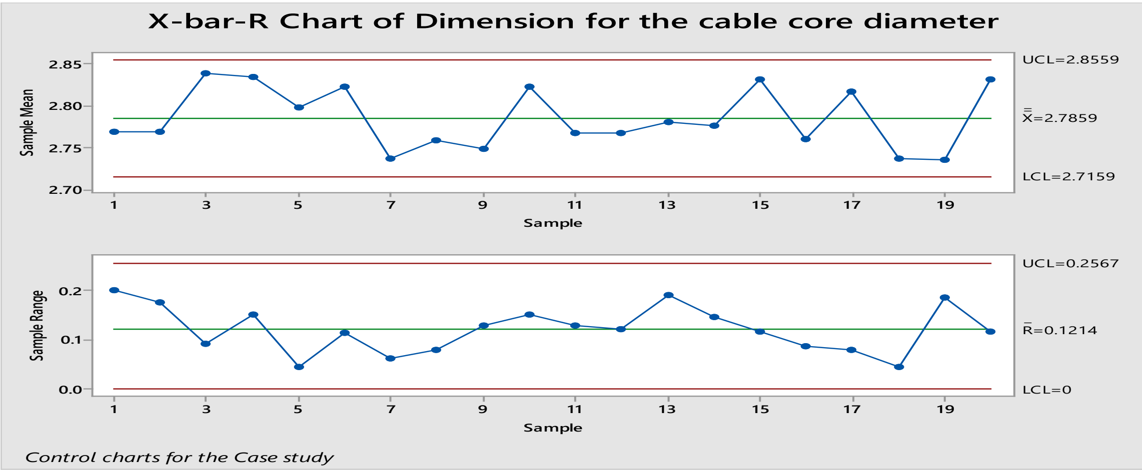

Figure 2. $\bar{X}$ and R- Chart for stability assessment

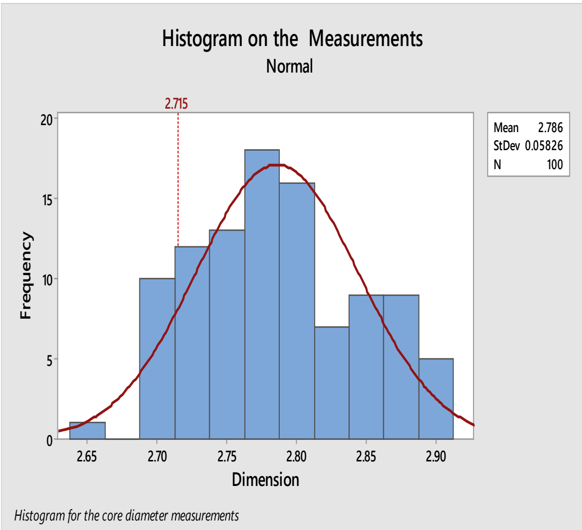

Figure 3. Histogram on the Baseline data

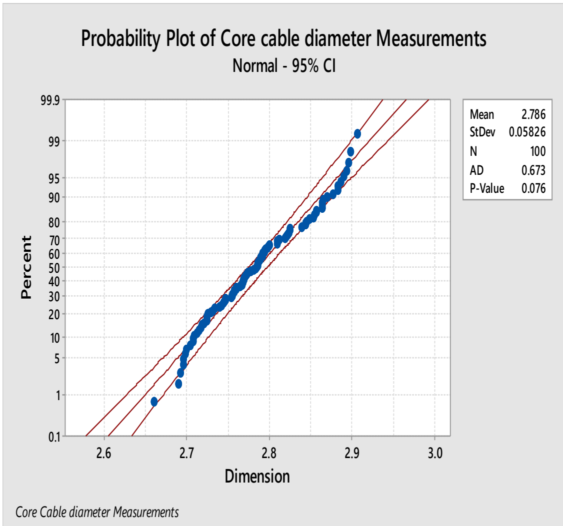

Figure 4. Probability plot on the Baseline data

Histogram and normal probability plot were used to check the normality of the data used for the case study. Figure 3 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) as shown in Figure 4. Figure 5, is the pictorial presentation of the capability report: USL = 2.90, LSL = 2.53, and the test equipment = Outer wall thickness projector cable tester (Profile enlarger).

The index results are as follows: 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.

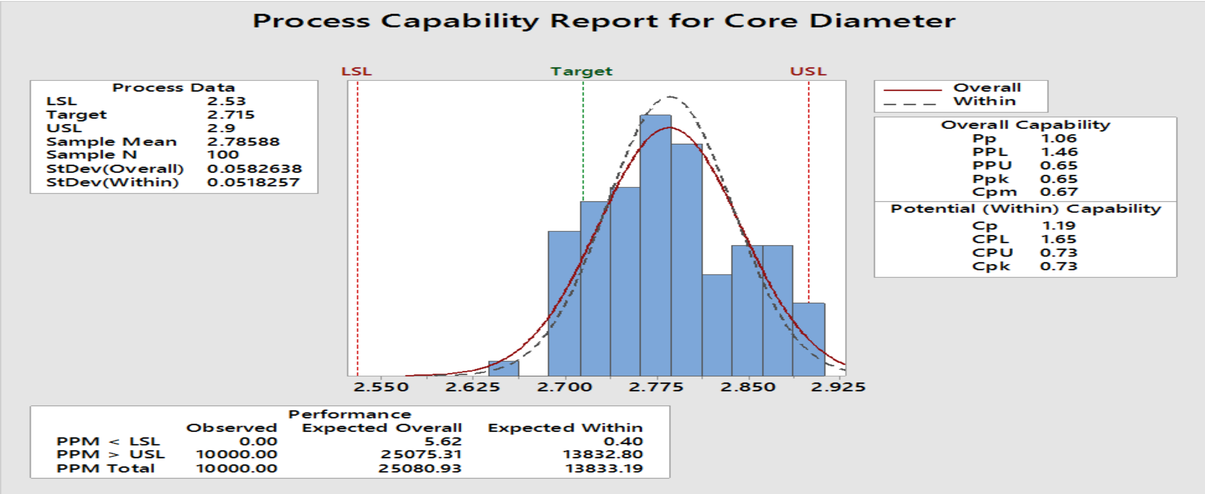

Figure 5. Process Capability Report on the Baseline Measurements

4.3 Analyze Phase

Analysis of the root causes behind the gap between the current performance and the goals identified in the first phase was performed using the data obtained in the Measure phase. The results obtained were arranged in rational categories as presented in Figure 6 after the brainstorming session, and cause-and-effect diagram that accurately displays the relationships of all the data in each category was prepared at the course of the session.

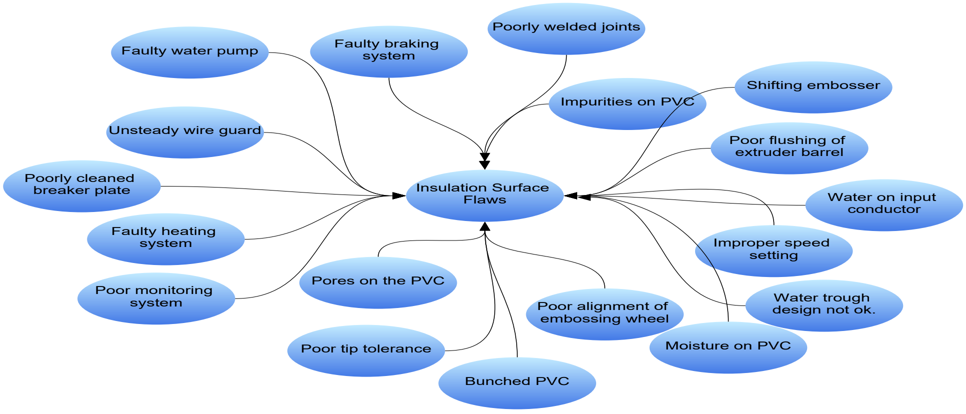

Figure 6. Brainstorming diagram of Insulation Surface defect and causatives.

Based on the team's interaction, a cause validation plan was prepared as depicted in Table 2. Table 2. represents the detailed type of data that was collected and the possible analysis for each of these causes. After listing the causes, every cause was validated and the methodology for the validation is as shown in Table 3.

Table 2. Cause Validation Matrix for Insulation Surface Flaws

S/N	Causes	Error Description / Quality Consequences	Confirmation Plan
1	Faulty heating system	When the heating system is faulty and the heating temperature gets too high, it can lead to pores and a rough surface on the cable. On the other hand, when the heating temperature is too low, it can as well lead to coarse and dull cable colouration.	GEMBA/ water spray
2	Faulty water Pump	If the water pump is erratic in passing water at the extruding chamber's cooling canal, the temperature of the extruder becomes unregulated leading to burnt PVC.	GEMBA
3	Presence of water on the input conductor	When there is water on the input conductor, it results in a poor coating of the conductor and also leads to bumps on the PVC during extrusion.	GEMBA/ Touch
4	Pores in the PVC	When there are pores in PVC's, the density is usually low, and these lead to the presence of a balloon-like spot on the body of the cable when used for production.	Visual inspection

5	Poor Monitoring System	When the process engineer on duty does not keep with the monitoring regimen of the extrusion processes	GEMBA
6	Presence of moisture on the PVC	If PVC's exceed 24hrs of production and were not preheated before use, it will likely absorbs moisture and leads to Cable surface defects.	GEMBA
7	Improper setting of speed	When the speed of the Capstan and the Extruder are not properly set, it could either lead to coarse or presence of burnt particles on the insulation surface	(DOE)
8	Poor flushing of the extrusion barrel	When the extruding barrel is not properly flushed, it could lead to colouration, insulation surface pores due to the presence of burnt PVC, leading to subsequent High voltage test failures.	GEMBA
9	Water trough design not ok.	Unsteady cable guide on the water trough causes the extruding cables to scratch on the wall of trough outlet.	GEMBA
10	Poor alignment of the embossing wheel or shifting embosser.	1. When the embossing wheel is pressing too tight on the extruding cable. 2. When the embosser is dangling at its position, thereby scratching the insulation surface. 3.When the embosser is in loose contact with the extruding cable, there are always faint imprints because the embosser groove is too deep	GEMBA
11	Bunched PVC (pellets stringing together)	PVC blocking the hopper base, thereby minimizing the inflow of the molten PVC to the Crosshead	GEMBA

Table 3. Cause Validation Matrix for Insulation Surface Flaws

S/N	Causes	Error Description / Quality Consequences	Confirmation Plan
12	Poor tip tolerance	When the tip tolerance is too small and the conductor is a bit bigger than the tip dimension, there is often a restriction on the movement of the conductor through the tip, and when this occurs, insulation surface bumps becomes a common occurrence.	Measurement
13	Faulty braking system / Low tension	If the input is supplying more input wire than what the capstan can draw. So when the capstan draws and releases the wire, there are always bumps on the cable insulation surface.	GEMBA
14	Inadequate skill/ negligence	1. Not allowing the heating system to get to the designed temperature setting. The result of this negligence often leads to the production of cables with a coarse surface. 2. Reuse of wire mesh after a particular product colour has been changed the result in colour variation.	GEMBA
15	Impurities on PVC	When there are sands or dirt's on the PVC material.	GEMBA
16	Poorly Welded Joints.	When the wire is not properly welded, it often obstructs the free movement of the wire across the tip, and when this happens, there is always bumps at the surface of the insulation.	Measurement
17	Management Interferences/ Poor material Logistic / lack of motivation	1. Management interference during production activities in terms of abrupt decisions on product colour change. 2. Complacency to provide necessary replacement materials when minor production defects are noticed. 3. Management inability to document the operator's intuitive knowledge of the process. 4. No incentives program for operators that meet the production target.	GEMBA Survey

5. Results and Discussion

5.1 Improve Phase

After the root causes have been determined at the Analyze phase. The DMAIC "Improve" phase was aimed at identifying solutions to reduce and tackle the causes. The cause validation plan that was drawn in the Analyze phase has beneficially aided in the identification of the root causes of these defects. Solutions to the identified defect causes were highlighted and documented as shown in Table 4. Through a qualitative assessment, by the use of an open-ended questionnaire, solutions to the identified defect causes were proffered based on the experiences members have previously on extrusion processes.

Table 4. Solutions for Reducing Insulation Surface Flaws in Cable Extrusion Process

S/N	Causes of cable Insulation Surface flaws.	Solutions for reducing the rate of cable failures due to Insulation surface flaws.
1	Faulty heating system	Use of high-quality heater bands. Temperature settings have to be reduced while the machine operators are on break.
2	Presence of water on the input conductor	Use of oxyacetylene gas flame on every input conductor before extrusion and at intervals while extruding.
3	Pores in the PVC	Compromised quality must not be used
4	Poor monitoring system	Review monitoring strategy by ensuring that during extrusion that both process-based monitoring and product-based monitoring are used to achieve product improvement. [Process-based monitoring watches production process conditions such as melt temperature and pressure while Product-based monitoring follows properties of the product, such as clarity and thickness].
5	Improper setting of speed	Optimal parameter settings through experimental designs.
6	Poor flushing of the extrusion barrel	Proper flushing and adequate monitoring. The process engineer has to certify it ready before the next activities
7	Water trough design not ok.	Redesigning of the water trough guide, interval check on the cable guide.
8	Poor alignment of the embossing wheel or shifting embosser.	Interval check and proper tightening of the wheel.
9	Poor tip tolerance	Not to be used.
10	Faulty braking system	Maintenance/ Overhaul of the braking system.
11	Inadequate skill/ negligence	Adequate training, monitoring and also make sure that the operators always adhere to standard operating procedure.
12	Poorly welded wire.	Careful filing of the welded joint (measure the welded point after weld)
13	Management problems/lack of motivation	Review the existing incentive programme, improvise an adequate resource planning system that will ensure needed parts and materials are readily available.

The process was improved to minimize further the rate at which cables with inconsistent diameter are produced. The optimal parameter setting for the extruder machine was attained through experimental Design. In other to achieve the global optimum for the control setting, statistical Software, Design Expert (Version 11, State-Ease Inc, USA) was used to create the Response Surface Design, specifically the Central Composite Design (CCD) for the preheated PVC and non-preheated PVC. After the experimental design, the capability study was taken to ascertain the level of improvement attained. The models for the quality of extruded cable dimensions were developed to evaluate the relationship of extruding parameters to the cable dimension. Through these models, experimental results of cable dimension by any combination of the extruding parameters can be estimated. The developed mathematical models are listed below in terms of actual factors.

$$CD_{\textbf{preheated PVC}} = 1.81243 + -0.00126332*A + 0.00156569*B, \quad (1)$$
$$CD_{\textbf{non-preheated PVC}} = 1.67344 + -0.0013576*A + 0.00176569*B \quad (2)$$

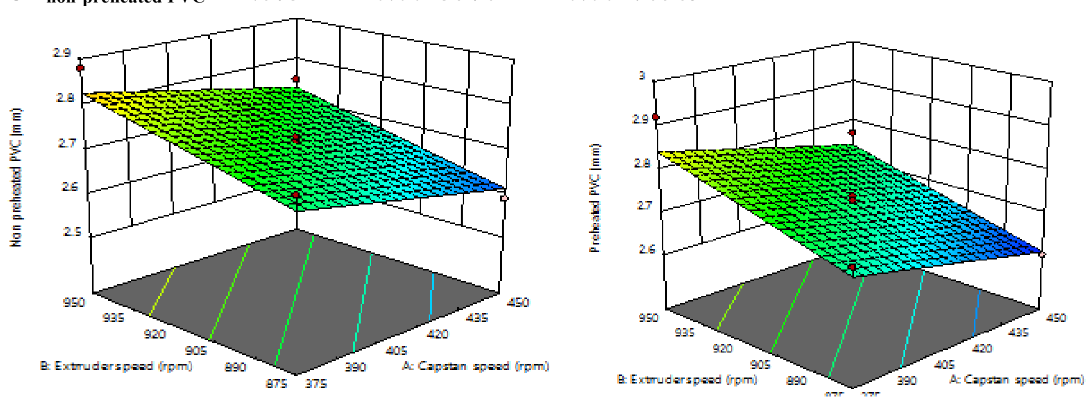

Figure 7. 3D Contour Plot　　　　Figure 8. 3D Contour Plot

Figures 7 and 8 show three-dimensional (3D) cable diameter measurement values for the preheated and non-preheated PVC's, varying Extruder and Capstan speed. It shows that when the Extruder speed increases, the cable dimension/diameter value tends to increase noticeably. Again, the decrease in the cable diameter values was also noticed when there is an increase in the Capstan speed. The point estimation method was conducted to optimize the level of each variable for a nominal response. The combination of different optimized variables to yield the expected response was determined to verify the validity of the model. This study involves two responses R1 for preheated PVC and R2 for non-preheated PVC.

Table 5. Optimization Using Desirability Criterion

Number	Capstan speed(rpm)	Extruder speed (rpm)	Preheated PVC (mm)	Non-Preheated PVC (mm)	Desirability	
1	416.992	906.790	2.715	2.710	1.000	Selected

From Table 5, the designed output has shown that the optimal control settings that would lead to the attainment of the objective (nominal cable dimension) are A (Capstan speed) equal to 416.992 rpm and B (Extruder speed) equal to 906.790 rpm; these settings will yield a cable with a nominal dimension of 2,715mm. The confirmation test was performed, and conclusions drawn from the analysis were validated. In practice, the Capstan speed and Extruder speed could only be set at 417rpm and 907rpm respectively. An experiment was conducted using the new combination, and with the designed parameters, it now becomes possible for the organization to avoid the trial-and-error methods that are traditionally used for improvement. The results have shown that the optimization engineering of RSM makes it possible to obtain a nominal cable dimension at the near range of 2.715. The extruding machine was operated at the new parameter settings and further readings were also taken. A capability study was conducted on the new sample to ascertain the level of improvement attained after the experimental design. However, the test data after the improvement failed the normality test and were subjected to Box-Cox transformation using a lambda (λ) value of 0.5. Test assumptions were also validated for the data collected after the process improvement as depicted in Figure 9.

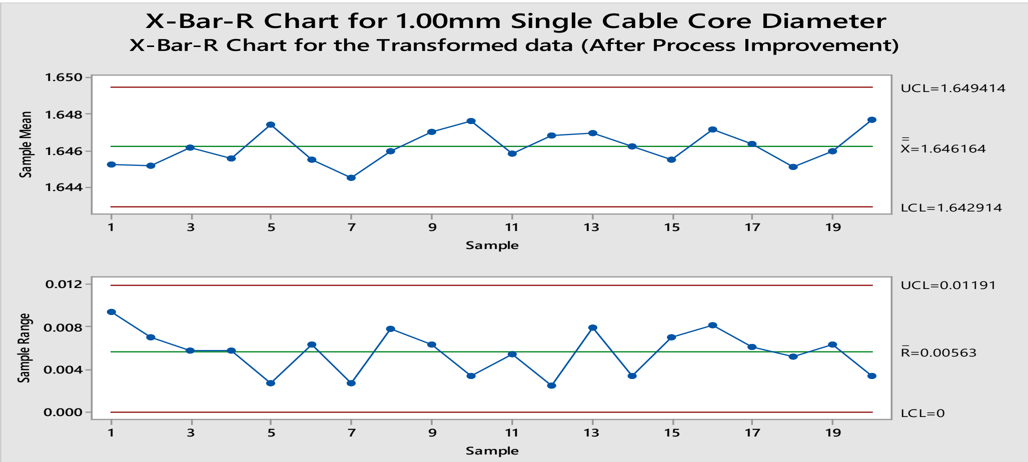

Figure 9. X-Bar-R chart for the transformed data after the process improvement

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. as shown in Figure 10.

However, from the index report on the process after improvement, it is clear that the index values were on the high side, an indication that the existing engineering tolerance is far apart from each other with a large standard deviation. The next step was to derive an appropriate tolerance interval that can depict the Six Sigma Process. The tolerance intervals were tighten to become 2.7114±0.032 (USL = 2.74, LSL = 2.67) as shown in Figure 11. 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. 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.

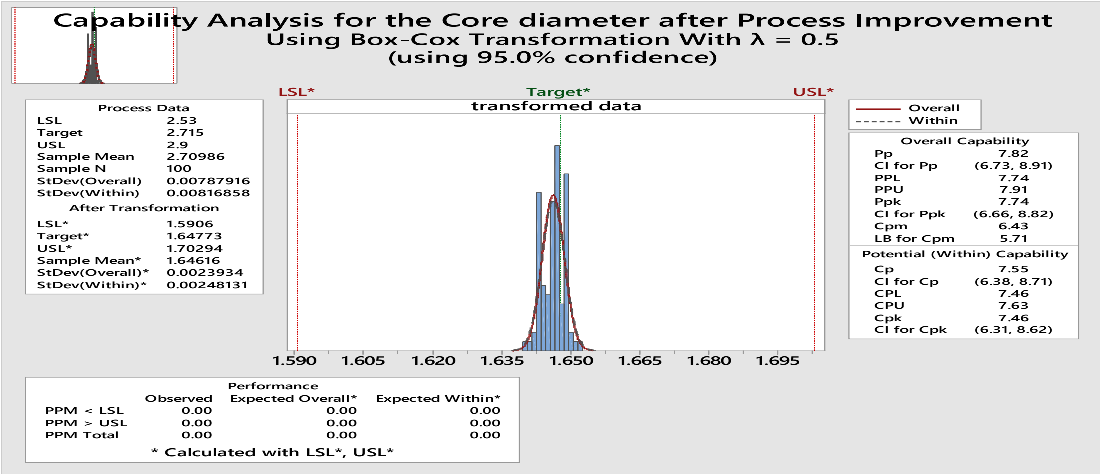

Figure 10. Capability Analysis for the Cable diameter measurements after the process improvement.

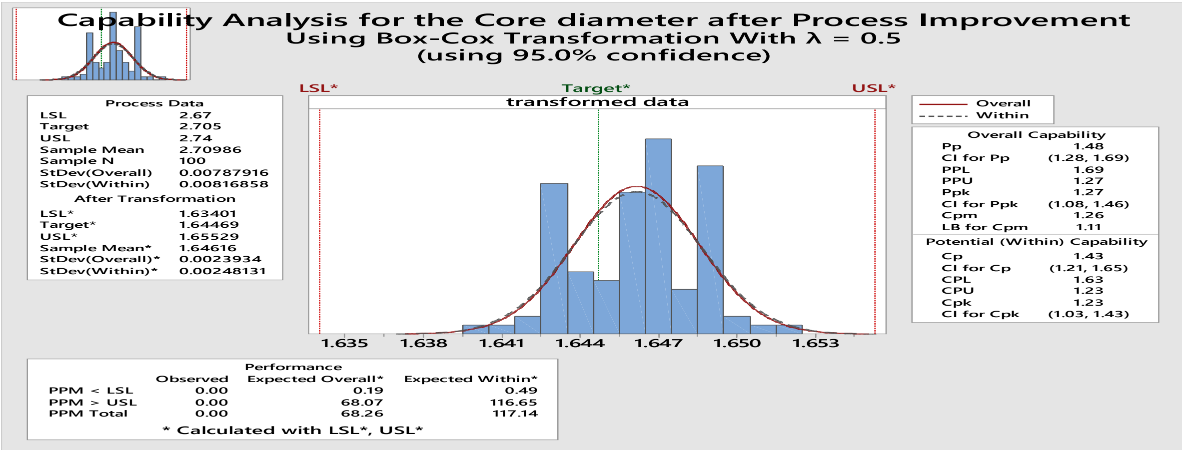

Figure 11. Capability analysis for the Cable diameter after the process improvement.

Further attempts for solutions on the identified root causes of these defects were made by the team through "Time study" to reduce the high rate of producing defective cables due to unrealistic work target being created by the management. At the new optimal control settings, the standard time of extrusion operation which is a common denominator for measuring productivity was derived. Taking into account rests, possible breakdowns and personal fatigue, time allowances, tediousness-very tedious, noise level, close attention-very exacting, atmospheric condition, standing allowance, constant allowance, awkward bending, lifting (20kg), monotony-medium, and mental strain to a maximum of 30%. The computed standard time was used to estimate realistic production throughput for an 8-hour shift. The next step after the Time study was to express the level of the improvement attained with the experimental design in financial terms for the cable diameter using the new tolerance intervals. The new tolerance intervals for the process was changed from 2.90 to 2.74 for USL, and 2.53 to 2.67 for LSL through appropriate SS tolerance Interval design procedures. Using the Taguchi loss function approach, the quality levels of the production process for the cable diameter attributes before and after the process improvement was determined. Assuming an estimated warranty cost of ₦30 for any 1.0mm single-coil produced that does not meet with the target value, and also considering that customers will complain if the diameter is a bit less, and the organization stands also to lose materials if the prescribed diameter value is above by a bit. Tolerance interval range from T-Δ to T +Δ; Δ = 0.035, using the cable diameter values before the Improvement L (2.715) = ₦7.34 per coil and after the Improvement L (2.715) = ₦2.08 per coil.

Assuming the organization worked for 300 days in a year and the daily production capacity is maintained on an average of 810 coils per day, then the estimated overall annual loss amounts to 2.08 x 300 x 810 = ₦505,440. The result of the comparative economic impact analysis between the baseline measurements and improved measurements with the tightened tolerance limit depicts a remarkable improvement. A whole lot of positive deviations were noticed in the baseline measurements compared to the after improvement measurements, thus an indication that there were more material usage in the production process before the improvement process. Net yearly improvement due to redesigning the tolerance after the experimental design becomes = [7.34-2.08]*243,000 = ₦1,278,180. The percentage decrease in the annual loss estimation after improvement is calculated to be 72% using the formula below:

Decrease in annual loss estimation= Orignal loss estimation-New estimated loss (3)

% Decrease in annual loss estimation = Decrease in cost/Original cost x 100 (4)

Table 6. The quality improvement achieved due to the designed experiment

	Tolerance	MSD	K	Expected quality loss per unit (₦)	Expected annual loss (₦)	Net annual Improvement due to new design (₦)
Original	T±0.185	8.38478E-03	876.55	7.34	1,783,620	*******
Tightened	T± 0.032	8.5088E-05	24489.8	2.08	505,440	1,278,180

Table 6 contains the results of the improvement study as translated in financial terms. With the original tolerance of the process T±0.185, the expected quality loss per unit of the coil is ₦7.43, but with the tightened tolerance T ±0.032, the expected quality loss per unit of coil now reduced to ₦2.08.

Control limits for $\bar{X}$ –Chart: UCL = 2.8559, LCL = 2.71585

Control limits for R-Chart: UCL) = 0.2566, LCL = 0.000

T (Original) = 2.715, T (New) =2.705±0.035, New Δ = 0.035, MSD = 0.00838478, L (2.715) = ₦2.08 per coil

5.2 Control Phase

This phase is concerned with establishing procedures to sustain the improvements made and emphasize the operators, materials, machine, and method of operation. A detailed control plan was drafted, listing necessary measures, the target for each measure, how the measure will be checked, how often the measure will be checked and who will check the measure, as well as actions that will be taken for an out-of-control event, etc. in Table 7.

Table 7. Control Plan Template for Monitoring the Improved Process

CTQ Characteristics	USL	LSL	Target	UOM	Cpk	CR	Data Description	Measurement Method	Sample size	Freq. of Measurement	Who Measures	Corrective Actions
Cable Dimension	2.74	2.67	2.705	mm	≥ 1.33	≤ 75 %	Variable	Profile enlarge	10 parts/reel	End of every shift	Process Engineers	Ref. updated SOP
Cable Smoothness	N/A	N/A	100 %	m	N/A	N/A	Attribute	Visual Inspection/Touching	All the extrusion length	Each extruded length	Shift Operator/ Process Engineers	Ref. updated SOP

As part of the monitoring regimen for the improved process, I-MR-R/S (Between/within) chart consisting of an individual chart, a moving range chart and R/S chart was used to assess the stability of process location, between-sample component of variation, and the within-sample component of variation. During the assessment period, the control template as shown in table 7 was followed and the assessment lasted for three days, during which nine consecutive operational shifts were assessed to ensure that the improved process was stable and devoid of any special cause variation. The last activity on the Control phase is the **"Entire Process Review".** Here; recommendations were made based on the findings from the entire study to overcome the problems that lead to defects and inefficiencies in the cable production process. The recommendations and the proposed improvement program are as follows:

- ***Crosshead and Extrusion Cavity Design***: To achieve continuous improvement of the process, the company should always attempt to redefine the voice of the process to match the expectation of the customers.
- ***Job Rotation and Transfers:*** To pair the experienced with the newly trained personnel together in all the shifts.
- ***Training System:*** Proper training of the new operators on machine principles, alongside specific work procedures, is advised. An operator should be certified fit to manage all the likely production challenges.
- ***Worn-out Centering Bolts/Nuts:*** Since changing and mounting a centering bolts is time-consuming, it will be better to use a high material composition of bolts, so that the incessant bolt breaks will be reduced.

- ***Design of Experiment****:* All adjustment should be carried out by trained personnel using the SOP developed in the course of this project.
- ***Poor Logistics and Material Resource Planning:*** The store section should always retain a staff member to assist in parts delivery during machine breakdowns for both day and night shift operations.
- ***Machine Maintenance:*** Maintenance schedule as reviewed during the project should be strictly adhered to.
- ***Input Material Quality****:* There is also a need to ascertain the composition of the PVC, their constituents and mixture ratios to ensure a compounding section in producing PVC materials that are within the specification.
- ***Re-Assignment of Role:*** Regular quality checks can also to carried out by operators instead of solely depending on QA. This will enable needed adjustment to be effected in time to avoid producing defects.
- ***Wire entanglement****:* Wire entanglement should not be corrected at the time of extrusion. Alternate provision should be made to tackle this production anomaly to avoid the increased time of production and associated costs.
- ***Abrupt Management Decisions / Interference*****:** Proper planning instead of erratic management decision on the product type (size & colour) should be avoided due to its financial cost implications from improper planning.
- ***Process Control Tools:*** Visual Management tools should also be incorporated as part of the tools to be used in the control phase. it will enable quick detection of performance concern and subsequent quick response delivery.

6. Conclusion

This research explored the innate potentials within Six Sigma approach, to monitor the changing distribution of process capabilities in a cable manufacturing organization. The SS-DMAIC approach has been validated in a cable manufacturing company in order to enhance organizational performance. The improvements of project performance and application impacts of the methodology have been investigated by comparing the initial and final capability of the process of the executed projects, by comparing the initial and final Sigma level of the executed projects, by comparing initial and final economic impact assessment of the executed project. The root causes of variation in cable manufacturing were identified, mainly as designs, parameter settings, materials, operation techniques, and measurement system errors. A tremendous improvement was achieved at the end of the projects in terms of the increased Sigma level. The organizational measurement system was assessed as well as the baseline performance of the system with the solution. Non-value-added activities were eliminated from the process and a Standard Time (ST), which is a common denominator for measuring productivity, was derived and implied in the study to ascertain the expected productivity rate for the extrusion start-up operation.

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