ENHANCING PROCESS PERFORMANCE IN CABLE MANUFACTURING, USING A SYNERGETIC SUPPORT OF SIX SIGMA-DMAIC AND KNOWLEDGE MANAGEMENT CONCEPTS

BY

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2019.

CERTIFICATION

I, CHUKWUEBUKA MARTINJOE U-DOMINIC, hereby certify that I am responsible for the work submitted in this dissertation and that this is an original work, which has not been submitted to this university or any other institution for the award of a degree or diploma.

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APPROVAL PAGE

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DEDICATION

Dedicated to God Almighty, my comforter.

And

My family

ACKNOWLEDGEMENT

My sincere gratitude goes to God Almighty, the Omni potent God, who has always been with me throughout this programme.

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ABSTRACT

Cable manufacturing industry is a field with a lot of variations and defects in its processes, the product quality is essential and variation in products is also a critical concern. The level of commitment to quality required to manufacture cable products in the country is enriching day by day. Making defective products in cable manufacturing, even though they can all be recovered, re-ground and the material used again, is uneconomic and non-productive because there is a large amount of money invested in the rejected product and extra energy and labor must then be spent on material recovery. Further consequences from a compromised cable product apart from the economic implications can be seen in the form of electric shocks, electrocution incidence and undisputed difficulty in delivering electrical energy to a load efficiently. In cable manufacturing, product quality is essential and variation in product is a critical issue but in most cases, results from solutions to cable defects identified during process improvement projects are not sustained so is imperative to keep extrusion systems up and running and solutions for eliminating errors and defects from cable extrusion systems are necessary. However, many solutions of integrating Knowledge Management and Six Sigma have been applied into many fields to solve similar problems of sustaining results from projects, but such integrations has not been applied in cable manufacturing industry in Nigeria or developed yet. Many organizations in the past have sought strategies to improve their extrusion process and product quality but none of the approaches were able to tackle the ever challenges of absorptive capacity (not-invented-here syndrome), development and exploration of organizational social capital, best practice replications and co-location creation. This study looked at variation and its causes, and how to improve and control a process using a synergetic support of Six Sigma-DMAIC and Knowledge Management concepts. The proposed Six Sigma-DMAIC-KM integrated solution has been validated in a cable manufacturing company in order to enhance the organizational performance. The improvements of project performance and application impacts of the proposed solution 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. A hierarchy of decision was modeled to prioritize defect judgments on Insulation thickness failures and Insulation Surface flaws. An extrusion model was developed for predicting the appropriate cable dimension. Appropriate engineering specification was designed and tightened from (T±0.185) to (T±0.032) such that a Six sigma process could easily be captured. The completion of the study resulted to peak improvement in the capability performance, for the cable diameter using the newly-designed engineering tolerance, Cp increased from 0.22 to 1.43, Cpk increased from 0.3 to 1.23, CR decreased from 447.43% to 69.96%, ZU improved from -0.88 to 3.68, and ZL now moved from 2.22 to 4.89. DPMO reduced from 810,000 to 10, thus improving the Sigma level from the value of 0.6 to 5.2. On the Insulation thickness using the newly-derived engineering tolerance, Cp value increased from 0.45 to 0.90, Cpk increased from -0.035 to 0.09, ZU increased from -0.11 to 0.28, and ZL from 2.79 to 5.17. CR reduced from 223% to 110%, and total rejection rate was reduced from 54.64% to 38.97%. A significant reduction in DPMO from 570,000 to 420,000 was achieved, thus improving the Sigma level from 1.3 to 1.7.The economic impact assessment for the cable diameter project using quality loss function has shown that the quality loss attributed to every single 1.0s (mm) coil produced has reduced from the initial cost of ₦7.34 to ₦2.08. The percentage decrease in annual loss is estimated at about 72%, an indication that annual loss before the improvement was reduced from ₦ 1,783,620 to ₦505,440 after the process improvement. The quantity of non-conformed 1.0s (mm) cable rejected due to Insulation Surface flaws was reduced by 38.22% from the acceptable defect quantity, and about 5.6% reduction when compared with the entitlement value in the previous years. A generic knowledge-based support tool was developed in a MATLAB graphical user Interface environment that will help cable manufacturing organizations in replicating improvement studies. In general, the proposed improvement solution would serve as practical guide for adoption for cable manufacturing companies and other manufacturing companies in order to improve process performance and in becoming more knowledgeable.

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LIST OF ABBREVIATIONS

Repeatability: This is variation observed when the same operator measures the same part repeatedly with the same device.

Reproducibility: This is variation observed when different operators measure the same part using the same device.

Gage R & R = Gauge Repeatability and Reproducibility

CoP= Community of Practice

DPMO = Defect Per Million Opportunity

DOF = Degree of Freedom

DOE = Design of Experiment

PFD = Process Flow Diagram

MSA = Measurement System Analysis

PCA = Process Capability Analysis

COPQ = Cost of Poor Quality

VOC = Voice of Customer

Baseline: is the actual performance of the process that is to be improved.

Entitlement: is the best possible performance that has been observed recently or was observed in a benchmarking study.

C & E = Cause & Effect

PVC = Polyvinyl Chloride

1.0s (mm) = one millimeter single core wire

ANOVA= Analysis of Variance

Defect: Departure of a quality characteristic from its intended level or state.

Defective: Unit of product or service containing at least one defect, or having several imperfections that in combination cause the unit not to satisfy intended normal usage requirements.

CTQ: Critical –To-Quality Characteristics

ITF: Insulation Thickness Failures

ICD: Inconsistent Cable Dimension

ISF: Insulation Surface Flaws

NL: No Label

WL: Wrong Label

TPs: Torn Poly-sheets

UCL = Upper Control Limit

LCL = Lower Control Limit

USL = Upper Specification Limit

LSL= Lower Specification Limit

σ = Sigma

Cp= Process Capability

Cpk= Process Capability Index

Cpm: This index is referred to as Taguchi Index, and is defined as the ability of the process to be clustered around the target or nominal value.

CR = Capability Ratio

ZU: This index measures the process location relative to its standard deviation and the upper requirement.

ZL: This index, measures the process location relative to its standard deviation and the upper requirement.

Sx = Standard Deviation

$\mathbf{B_T}$= Basic Time

Z:is the distance, measured in standard deviation, from the process mean to the specification limit.

$\boldsymbol{\sigma}^2$= Variance

$\boldsymbol{\sigma}$t = Total Process Standard Deviation;

$\boldsymbol{\sigma}_P$ = Part-to-Part Standard Deviation;

PV = Part-to-Part Variation;

Ndc = Number of Distinct Categories.

%P/T

S*O = Sample * Operator

$\bar{x}$ = Mean

R= Range

$\bar{\bar{X}}$ = Grand Average

QAD = Quality Assurance Department

MD = Manufacturing Department

PCP1 = Power Cable Plant 1

PCP2 = Power Cable Plant 2

CPU: is the position of the total process variation in relation to the upper specification limit.

CPL: is the position of the total process variation in relation to the lower specification limit.

T = Target

S/N = Signal-to-Noise Ratio

$\mathbf{S/N_N}$ = Signal-to-Noise Nominal

r = Measure of Error Precision

CI = Consistency Index

CR = Consistency Ratio

RI: = Random Index

CP = Criteria Priorities

SCp = Sub Criteria Priorities

GP = Global Priorities

CCD = Central Composite Design

$\mathbf{S_T}$ = Standard Time

$\mathbf{R_{TA}}$ = Relaxation Time Allowance

$\mathbf{C_{TA}}$ = Contingency Time Allowance

$\mathbf{t_i}$ = individual observed time

t = Average time for performing the element

SPC = Statistical Process Control

GEMBA = Direct Observation.

SOP = Standard Operating Procedure

MPa = Mega Pascal

RPM = Revolution Per Minute

L16 (4^2) =

$\propto$ = Alpha

λ **=** Lambda

Anderson Darling Test Statistics: Measures how well the data follow a particular distribution.

Box-Cox Transformation: Used to transform data to follow a normal distribution.

Sigma Level

MSD = Mean Square Deviation

∆**o** = deviation

Variable Data: data that can be measured on a continuous basis, example; temperature, weight, height, etc.xxvi

Attribute Data: data that consists of classifications rather than measurement e.g. “good”, “bad”.

QAD = Quality Assurance Department

MD = Manufacturing Department

LIST OF APPENDICES

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

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, and most often after part production. Variations have been a problem since beginning of industrialization and were initially handled by setting specification limits for important production characteristics (Mokhlesi and Azad, 2009). As time passed, focus moved away from the finished products but towards improving the capability of production process (Garvin, 1988). 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).

Cable manufacturing industry is a field with a lot of variations and defects in its processes, the product quality is essential and variation in product is also a critical concern. Use of compromised cable quality in Nigeria is frowned upon and not acceptable across all electrical testing criterions, so the level of commitment to quality required to manufacture cable products in the country is enriching day by day. However, finding the cause of the defect in cables may be a lengthy process since it requires consideration of material, machine, die and process. The origin of extrusion defects is not always understood due to complexities in extrusion coating processes (Sollogoub et. al, 2011), but failures or defects which are normally occurring in cable extrusion process are due to three main causes; mould design, material selection and processing. Most failures that often occur in extrusion line during processing can be seen in the form of Insulation surface flaws, extruder surging, thickness variation, uneven wall thickness, diameter variation and centering problem etc. These defects are more disturbing ones since they affect the homogeneity and the integrity of the polymer film. Insulation Surface flaws occur when the insulation integrity of the conductors is compromised, and are the most common cause of problems in electrical equipment (Reuter-Hanney, 2017). Cable insulation may be considered good when leakage current is negligible but since there is no perfect insulator even good insulation allows some small amount of leakage current. 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 form of electric shocks, high voltage failures, and electrocution, as exposed conductive parts may in some cases also become live due to isolation faults.

Part of the quality problems mostly encountered in cable processing is also seen in form of inconsistency in the dimension of cable extruded. The impact of this quality defects are seen in two forms over-dimensioned cable, and under-dimensioned cable products. These are the two notable production odd consequences attached to inconsistent cable forms. 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. These defects seriously affect the aesthetic aspect, the barrier properties and the mechanical strength of the coated substrate and also cause a big damage to the company’s reputation.

Making defective products in cable manufacturing, even though they can all be recovered, re-ground and the material used again, is uneconomic and non-productive because there is a large amount of money invested in the rejected product and extra energy and labor must then be spent on material recovery. It is best avoided since they are directly reflected in the organization's financial bottom line.

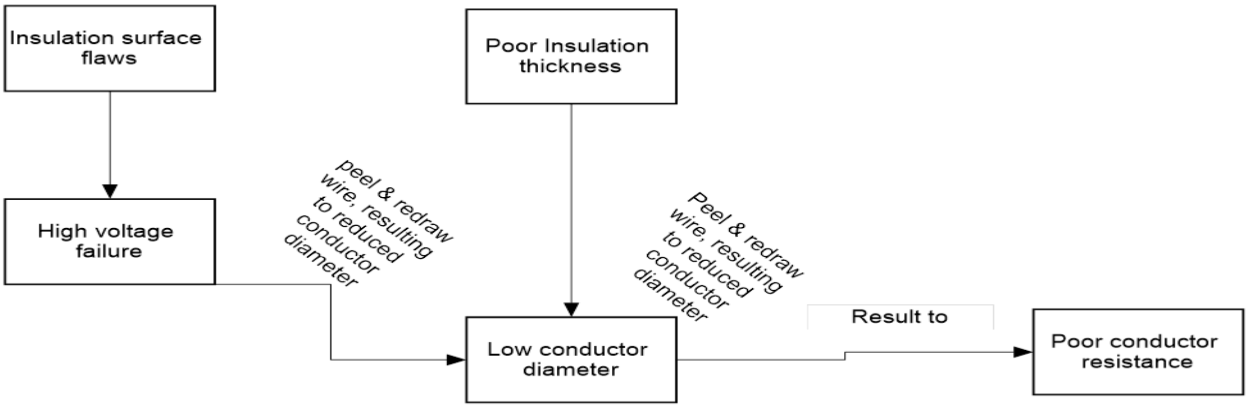


Figure 1. Cable failures and quality implications

Figure 1 describes recovery action that is taken when defect occurs in an extruded cable product. The erroneous products are subjected to a process called "peeling" which is conducted on the peeling machine. The cable insulation is peeled out to recover the copper conductor for other use and the diagram above clearly describes quality consequences associate with this process. The peeling operation leads to wire tensioning which causes reductions in the original conductor diameter (Low conductor diameter). Most of the recovered input conductors have limitations in use, and in some cases, the recovered wires are drawn to a smaller size of wire, and also into a finely drawn dimension depending on the original size of the peeled products. It is imperative to keep extrusion systems up and running and solutions for eliminating errors and defects from cable extrusion systems are necessary.

Many organizations have sought strategies such as Lean manufacturing (Chanarungruengkij, et al. 2017); Lean Six Sigma (Paramech, 2013); QC tools and DMAIC methodologies

(Mondal, et al., 2015); design of experiment (Abdulkareem, et al. 2014), to improve process and product quality. It has been observed through extensive literature review that none of the approaches presently used to solve process-related problems in cable manufacturing processes emphasized on ways to tackle the ever challenges of absorptive capacity (not-invented-here syndrome), development and exploration of organizational social capital, best practice replications and co-location creation.

Since critical knowledge loss occurs through job transfer, retirement, retrenchment, mobility and alternative work arrangements, it is right to deploy logical and systematic solutions/procedures to determine the origin of these defects in a processing line if actually defects are to be eliminated. To this end, one strongly believes that by deploying Six Sigma-DMAIC in agreement with KM principles, organizations can gain an advantage of having both strategies work side-by-side towards an overall goal. Hence, it will be ideal to incorporate Knowledge Management (KM) concept in Six Sigma DMAIC's framework to solve some of the aforementioned quality challenges in cable manufacturing where observational studies are much, and knowledge of the workforce is very vital.

1.1 Statement of Problem

In cable manufacturing, product quality is essential and variation in product is a critical issue, but in most cases results from solutions to cable defects identified during process improvement projects are not sustained. This anomaly is likened to the outsourcing of improvement functions to external professionals most of the time and also due to absence of knowledge-based solution, robust enough to solve most of the real life quality problems that prevails in a dynamic cable manufacturing environment. Hence there exists a need for an efficient deployment strategy applicable in cable manufacturing that will aid organizations in their improvement studies to solve real life problems as well as to become a knowledgeable organization.

1.3 Aim & Objectives

The aim and objectives of the study are as presented below.

1.3.1 Aim of the Study

The aim of this research is to enhance process performance in cable manufacturing using a synergetic support of Six Sigma-DMAIC and Knowledge Management concepts.

1.3.2 Objectives of the Study

The following objectives were pursued in order to achieve the aim stated above.

1. To build up an improvement approach by incorporating Knowledge Management strategies/tools within a Six Sigma-DMAIC's improvement framework.
2. To validate the new approach through practical application in a cable manufacturing industry.
3. To assess the potential contribution and economic implications of the improvement solution.
4. To develop a generic user interface support system for easy replication of the improvement solutions.

1.4 Scope of the Study

The study focused on quality improvement, and defect reduction in a manufacturing system.The validation study was carried out at the Anuka cable Plant of the Cutix cable PLC located at Umuanuka Village Otollo Nnewi, in Anambra State, and was limited to extrusion of 1.0mm Single core house wiring cable from TEKO-50 extrusion line.The Community of

Practice (CoP) used in this study comprises of four heterogeneous mixes of personnel's formed from these departments; Quality Assurance Department (QAD), Manufacturing Department (MD). All the data used in this study were obtained through direct measurements within the eleven (11) month study period, except the historical data that were once used to prioritize the key Projects.

1.4 Significance of the Study

The demand for more synergic supports among process management initiatives has been widely discussed in the literature and there has never been any emphatic statement upholding any of these initiatives over one another. The outcome of this study will proffer efficient technical means of eliminating defects and losses in cable production systems, through careful diagnosis and systematic problem-assessments approach, thus saving the cable manufacturing industry from undue economic losses. The conceptual model should provide an employee capability development atmosphere through careful identification of knowledge domains, retention of already learnt knowledge and building strong social capital within the organization. In a more general dimension, the study would immensely contribute in narrowing the gap between Six Sigma and Knowledge Management studies in Africa and other regions. Lastly, this study could introduce to the existing body of process improvement studies, a form of integration tactics that would benefit process improvement practitioners in cable manufacturing companies, on the matching advantages of these two distinct disciplines "Six-Sigma and Knowledge Management" that have been scarcely reported in the process improvement studies conducted in Nigeria.

CHAPTER TWO

LITERATURE REVIEW

2.0 Six Sigma Developments

The Six Sigma methodology was introduced by Motorola Inc. in the USA in the late 1980s. Companies, such as General Electric, Allied-Signal, Honeywell and many others, followed shortly after and also made it an integral part of their leadership development activities (General Electric, 1997). Since then, this quality concept has been associated with myriads of definitions both in the academic and in the practitioner's literature. Settling on this definition by Linderman et al. (2003), Six Sigma can be defined as an organized and systematic method for strategic process improvement as well as new product/service development that utilizes statistical techniques in causing defect reduction. Although the original focus of Six Sigma was on manufacturing, it has been applied in a non-manufacturing context with minor adaptations (Does et al., 2002). Six Sigma tread the path of rigorous project approach and extensive use of analytic and quality tools. Its structured team approach to solving problem has introduced in its formation a platform that breeds and diffuses knowledge.

Six Sigma 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 customer (Snee, 1999). Its DMAIC method is rather a general method and its original task-domain was variation reduction especially in manufacturing processes (De Mast and Lokkerbol 2012). The method was later used for more general tasks, such as quality improvement, efficiency improvement; cost reduction, etc. Six Sigma's DMAIC is a problem solving method mainly used in manufacturing processes. A problem solving method can be generic or specific for a certain task-domain (Newell, 1969). DMAIC is applied in practice as a generic problem solving improvement approach (McAdam & Lafferty, 2004). The objectives of Six Sigma are to increase the profit margin and improve financial gain through minimizing the defects rate of products. Successful implementation of Six Sigma-DMAIC approach has been widely reported in the literature. Originally, DMAIC concept has provided applicable framework to satisfy requirement for critical to quality characteristics. Its potency in process improvement studies cannot be overemphasized and its integration advantage and applications in various fields, are fast gaining wider recognition. Six Sigma is one of the most important and popular developments in the quality field (Knowles, 2011). However, research on Six Sigma subject irrespective of its impressive track records in practices is still at the low level (Zhang et al., 2009). This is as a result of divergent views and set perceptions on the Six Sigma subject. Some scholars understand Six Sigma simply as the repackaging of the well-known total quality management (TQM) (Beer, 2003), while others view it as a management fad. The concern of Six Sigma being perceived as a management fad, according to Zhang et al (2009), has prevented many scholars from conducting rigorous research on Six Sigma.The research territory to date on Six Sigma subject has been found only within North America region with only a few studies in Europe and Asia (Ahirvar &Verma, 2012; Wang et al., 2004). As a result of this and many more reasons, Six Sigma studies in order parts of the globe become essential to gain further insights and to have a proper generalization into cultural issues that may affect the theory and practice of Six Sigma (Ahirvar &Verma, 2012). On this premise, it now becomes pertinent to have an in-depth understanding of Six Sigma subject, by first reviewing existing literature.

The concept of Six Sigma is based on achieving a quality standard of fewer than 3.4 defects per million opportunities (DPMO) (Bothe, 2002). The special thing about Six Sigma compared to other process improvement methods is the mathematical approach. It is assumed that each business process can be described as a mathematical function.

$$Y = F(x) \tag{2.1}$$

This equation describes the relationship between the three key items, output, Process, and input. Equation (2.1) reads "Y is a function of X". Where "Y" refers to the output, "X" refers to the key measures of the process variables (inputs and/ or the process itself).The Sigma ($\boldsymbol{\sigma}$) is a parameter of distribution function, which expresses the variability of a given quality characteristics compared to the expected value of the mean ($\boldsymbol{\mu}$). The smaller the $\boldsymbol{\sigma}$, the smaller the risk that a portion of measurement variable will fall outside the given limit values. Six Sigma means to produce such small variation around the process mean so that within the tolerance range, there will be exactly 12 units of $\boldsymbol{\sigma}$.This quality improvement programme was developed by Motorola engineers in 1986, and their quality improvement goals were set such that process variability is at ± 6 Standard deviations from the process mean, signifying that customer specifications are met and can only produce 3.4 non-conforming products. These 3.4 DPMO computations assume a 1.5 sigma shift in the process mean, and are based on these two assumptions:

1. That the process output follows a normal distribution, and,
2. That the process means may in the long term shift up to 1.5 standard deviations.

According to Omar et al (2012), a standard deviation is a statistical way to describe how much variation exists in a set of data, a group of items, or a process. Any process that is at Six Standard deviations is highly capable, signifying that customer specifications are met.

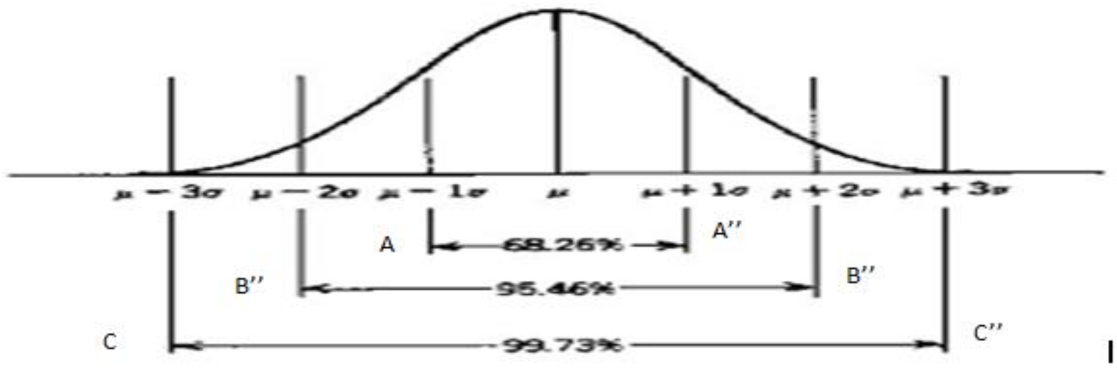


Figure 2.1. The standard normal distribution graph (Source: Midas+ Statist Solutions Group 2018)

Graphically, Figure 2.1, described a standard normal distribution where A: A" distance simply means that 68.26% of values are within 1 standard deviation of the mean; B: B" distance shows that 95.46% of values are within 2 standard deviations of the mean, and C: C' distance also denote that 99.73% of values are within 3 standard deviations of the mean. Under the C-C" scenario, which is at Six Sigma, the process would produce up to 3.4 parts per million (ppm) non-conforming to specifications. As depicted in Fig.2.2, a Six Sigma process has a process mean that is six standard deviations from the nearest specification limit, thus providing enough shields between the process natural variation and the specification limits.

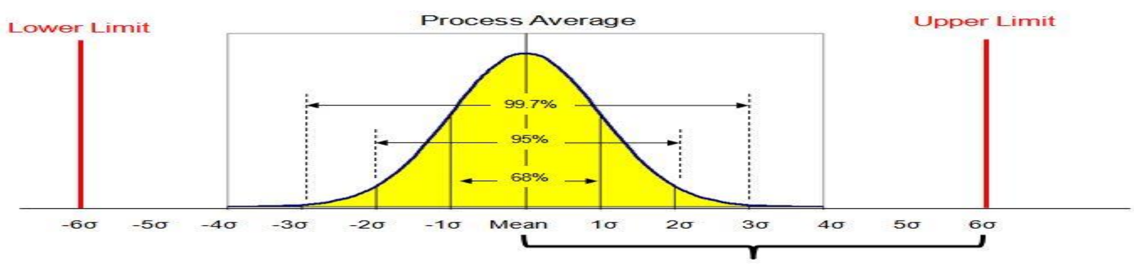


Figure 2.2. Six Sigma definitions (Source: http://leansixsigmadefinition.com/glossary/six-sigma/)

Although in most cases, even stable processes are prone to disturbances that can often lead to shifting in the mean of the process. At 1.5 standard deviation shift of the process mean one way or the other, the most number of defects the process will produce can be calculated as

P(Z>4.5) + P(Z>7.5) (Bothe, 2002). Since P (Z>7.5) is virtually zero, Six Sigma is technically P (Z>4.5), which is 3.4 per million opportunities. However, this drifting mean aspect of Six Sigma metric has been a source of controversy (Montgomery & Woodall, 2008).

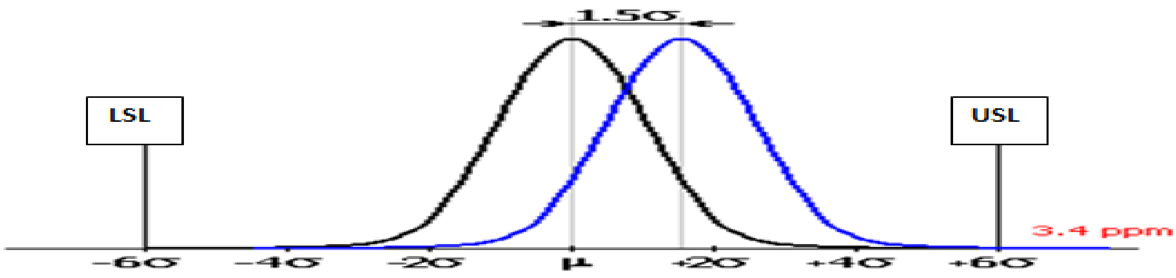


*Figure 2.3.*Normal standard distribution with deviation (Source: Gitlow, 2017 http://www.howardgitlow.com/definitionsofsixsigma.htm).

Some on Six Sigma improvement strategy argued that if the mean is drifting, a prediction of up to 3.4 DPMO may not be very reliable because the mean might shift by more than the allowed 1.5 standard deviations. Fig. 2.2 shows the relationship between DPMO and process sigma assuming the normal distribution. Six Sigma methods have two major perspectives, the statistical and business perspective (Andersson, Eriksson, & Tortensson 2006).

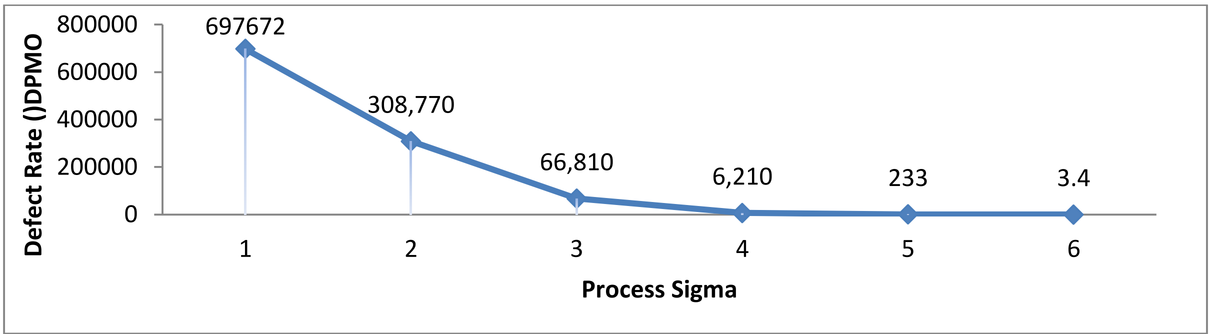


Figure 2.4. Defect rate versus process sigma level (Source: Linderman et al., 2003).

From a statistical point of view, the term Six Sigma is defined as having less than 3.4 defects per million opportunities or a success rate of 99.9997%.

Table 2.1: *Sigma Levels and DPMO*

Sigma Level	**Defects per million**	**Yield**
One	690,000	30.85%
Two	308,000	69.15%

Three	66,800	93.32%
Four	6,210	99.38%
Five	230	99.977%
Six	3.4	99.99966%

Note. Adapted from http://leansixsigmadefinition.com/glossary/six-sigma/)

Similarly, Gilbert (2003) shares in the perspective of viewing Six Sigma as a business strategy along with some Six sigma practitioners by describing it as a way of doing business to meet or exceed customer's needs and expectations. Six Sigma has its origin in quality engineering, which has traditionally had a strong emphasis on statistical methods (Demast & Lobberkol, 2012), and does provide an effective means for deploying and implementing statistical thinking (Snee, 1990). Six Sigma structured improvement procedure we have two known methodology DMAIC and DMADV. These two are the most commonly used Six Sigma methodologies used to attain a single goal under different circumstances and problem areas. DMAIC is an acronym for Define, Measure, Analyze, Improve, and Control, and is a structured problem-solving procedure.

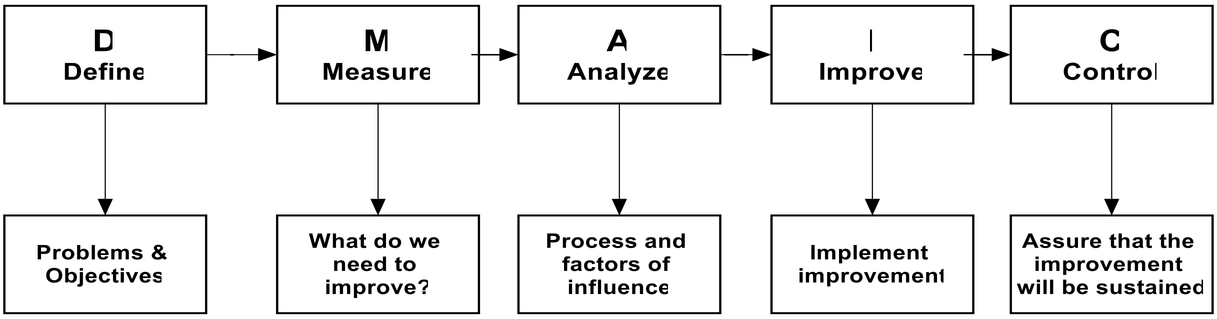


*Figure 2.5.*Lean six sigma green belt certification, 2017 (Adapted from http://www.optiontrain.com/Lean_Six_Sigma_Green_Belt_Certification_Training.php).

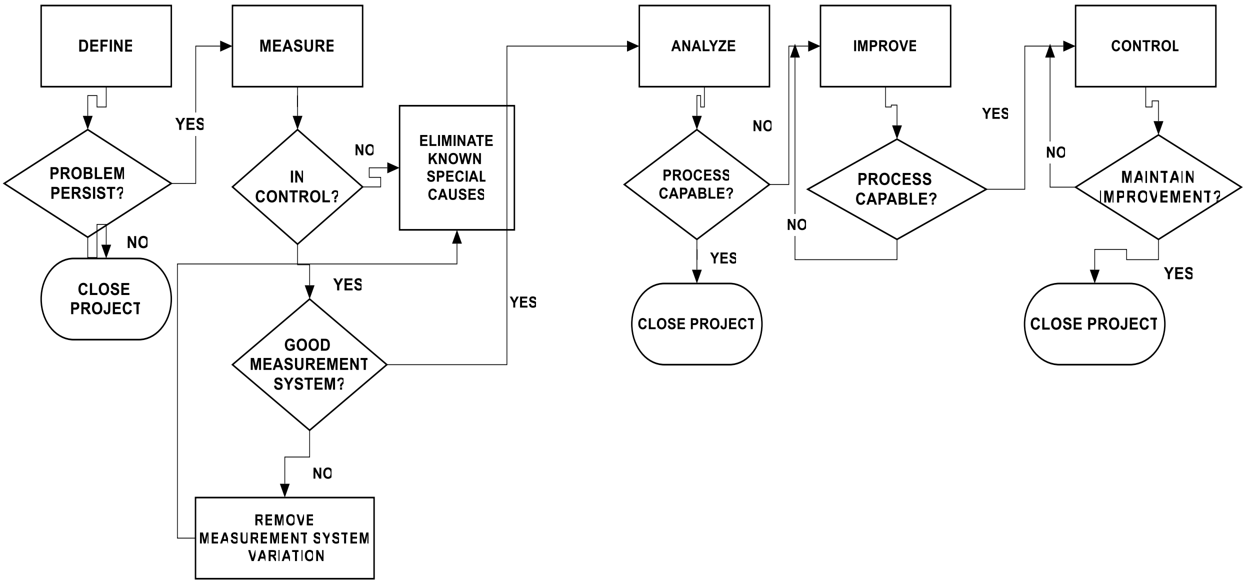


Figure 2.6. High-level DMAIC process flow (Source: cdn.ttgtmedia.com/searchSoftwareQuality/downloads/ect01TreasurechestSixSigma.pdf).

The essence of DMAIC method is to reduce variation in a process, in order to achieve high conformance quality in customer's terms. DMAIC is a revised version of well-known problem-solving methods such as Plan-Do-Check-Action (PDCA) and Plan-Do-Study-Action (PDSA) (Zhang et al., 1999). Six Sigma DMAIC approach of continuous improvement facilitates change on a steady and progressive basis (Banuelas & Antony, 2003), and work within the framework of the existing processes. The DMAIC steps are basically used for any process improvement project. This approach comprises of five steps and each step addressed certain tools and techniques. It offers a structured approach to solving problems and improving results. 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).

However, Demast and Lobberkol (2012), as part of their conclusion in analyzing Six Sigma DMAIC method from the perspective of problem-solving, consider the strategy as a weak guide for less routine projects in which human-dynamics, subjective perceptions, and personal values are important aspects. On the other hand, Chakrabarty and Tan (2007) described DMADV as the incorporation of more innovative tools such as the theory of creative problem solving and axiomatic design which DMAIC does not. According to Eckes (2001) (as cited in Banuelas & Antony, 2003) DMADV is suitable when any of these situations arise; when a new process is required to assist an organization to achieve a strategic objective, and when a current process is irreparably broken.

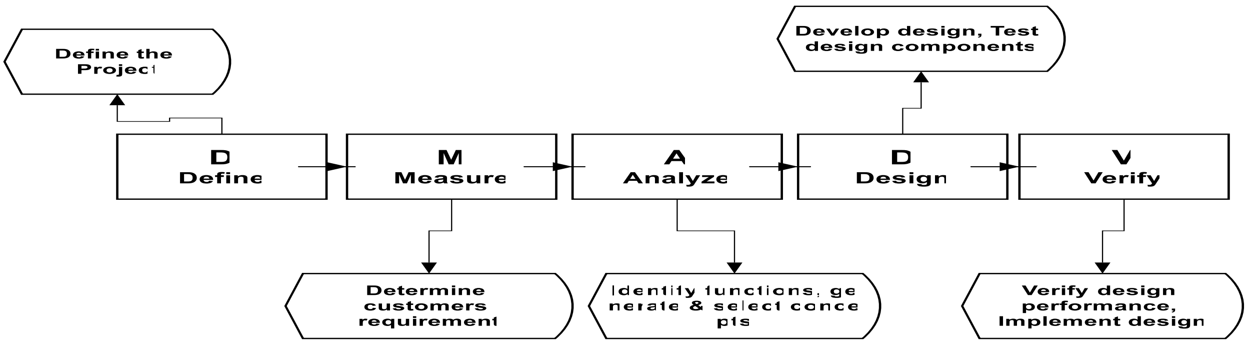


Figure 2.7. Six sigma DMADV methodology (Adapted from https://theblogspotblog.wordpress.com/2014/02/18/six-sigma-methodology/).

2.2 Six Sigma Structure

A well-organized Six Sigma infrastructure is necessary for an organization to carry out the related improvement projects (Hung & Sung, 2011). Six Sigma responsibilities are well defined and in an organizational context cuts across numerous ranks in a well-coordinated formation (Sinha & Van de Ven, 2005). Black belt is a full time Six Sigma practitioner who had rigorous training in the statistical methods used to gather and analyze data in a Six Sigma project. A green belt is a Six Sigma practitioner usually part-time who has been trained in the Six sigma DMAIC problem-solving methodology and basic statistical tools, whereas champions are heads of business divisions or process owners who run the processes.

2.3 Six Sigma Metric

A metric is a specification or attribute against which the outputs of a process are compared and declared acceptable or unacceptable. Six Sigma metrics can be in the form of a number of complaints, percentage scrap, cost of poor quality (COPQ), defect rate, process capability, first-time yield, throughput yield. In general, Six Sigma methodology and process capability analysis (PCA) occupy important places in quality and process improvement initiatives (Senvar & Tozan, 2010). Six Sigma typically monitors the process using control charts, which compares control limits with specification limits to determine process capability (Murugappan & Keeni, 2003).

2.3.1 The Sigma Capability

The Sigma capability is the number of standard deviations from the mean, and is also called "**Z-score**" or "**Standard score**". This metric is also used to standardize a distribution (that is, used to convert a normal distribution to a standard normal distribution).

$$Z = \frac{X-\mu}{\sigma} \tag{2.2}$$

where; x is the specification limit,μ is the mean, and **σ** is the standard deviation.

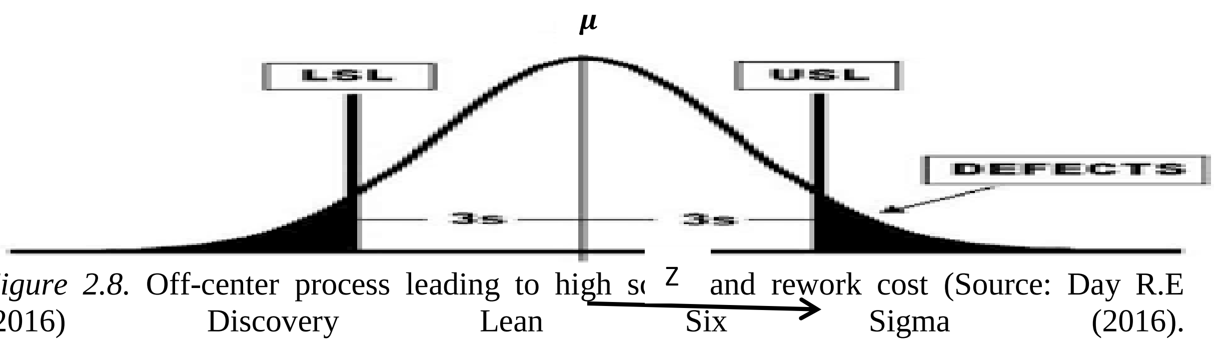


Figure 2.8. Off-center process leading to high sc and rework cost (Source: Day R.E (2016) Discovery Lean Six Sigma (2016). https://leansixsigma.community/blog/view/15352/process-capability-what-it-is-and-how-it-helps)

From the graph, Z capability is the distance, measured in standard deviation, from the process mean to the specification limit, and the shaded area denotes defect probability. For a Six Sigma process, the error probability is 0.0000034 (meaning there are only 3.4 defects per million delivered units). For a three sigma process, the probability of error is 0.0668 (66,800 defects per million units). The sigma or Z capability is the simple metric for measuring a process's capability to produce defect-free products. 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. 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; the concept has been applied 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 some assumptions and mandatory procedural conditions in any PCs so that one does not misrepresent the true capability of a process. These procedural assumptions and conditions are as follows:

1. The process is in statistical control.
2. The distribution of the process considered is normal.
3. As a rule of thumb, a minimum of 50 randomly selected samples must be chosen for process capability studies, a minimum of 20 subgroups, and subgroup size, of at least four.
4. The data chosen for process capability studies should attempt to encompass all natural variations.
5. The process to be studied should be devoid of any special causes of variation.

Process capability indices (PCIs) relate the engineering specification to the behaviour of the process (Bangphan et al., 2014), and can be viewed as effective and excellent means of measuring product quality and performance (Chen et al., 2006). Its numerical value increases when the variability decreases and it is unit less. The greatest value of these indices is that their use encourages efforts to prevent the production of non-conforming products. This capability measures are developed based on various criteria such as process consistency, process departure from a target, process yield, and process loss. Industrial benefits of applying this capability concept are described by (Kane, 1986), as:

1. Prevention of non-conforming product,
2. Continuous improvement,
3. Enhancing communication between the manufacturer and the suppliers by creating a common language.
4. Prioritization of process for improvement.
5. locating / identification of process variability, and
6. Assessment of quality systems.

2.4 Six Sigma Implementation/ Applications

Six Sigma implementation requires resource commitments in terms of money, time, and effort from the entire workforce. A uniform way to implement Six Sigma usually remains a myth as Six Sigma implementation processes and styles differ from company to company, country to country due to the uniqueness of experiences and nature of problems (Moosa & Sajid, 2010). Identification of factors critical to the success of Six Sigma implementation plays a vital role in the development of an adaptive Six Sigma framework (Amar & Davis, 2008; Burton & Sams, 2005). Moosa and Sajid (2010) explored and analyzed the critical success and failure factors of implementing Six Sigma in organizations based on lesson drawn from real life practices, case studies, and available literature. The researcher attributed most failures to the implementation approach to lack of standard model available for Six Sigma implementation and to a number of social factors that prevail in the organization. Antony and Coronado (2002) identified 12 typical critical success factors as:

1. Management involvement and commitment
2. Cultural change
3. Communication
4. Organization infrastructure
5. Training
6. Linking six sigma to business
7. Linking six sigma to customer
8. Linking six sigma to human resource
9. Linking six sigma to suppliers
10. Understanding tools and techniques within six sigma
11. Project management skills
12. Project prioritization and selection

Kwak and Anbari (2004), in their own classification, identified four factors as being more critical for a successful Six Sigma projects implementation:

1. Management involvement and organizational commitment- organizational infrastructure needs to be established with well-trained individuals ready for actions.
2. Project selection, management, and control skills- The project has to be feasible, organizationally and financially beneficial, and customer oriented.
3. Encouraging and accepting cultural change: there should be a clear communication plan, and scheme for motivating individuals facing cultural change in order to overcome resistance.

4. Continuous education and training: - organizations need to continuously learn and adopt the latest trends and techniques that are outside the Six Sigma domain that might be useful to complement the Six Sigma approach.

However, (Llorenz-Montes and Molina, 2006; McAdam and Lafferty, 2004) suggested that the implementation of Six Sigma programme needs successful change management of behavioural and work processes to achieve the desired result as inadequate knowledge sharing capability as one of the factors that inhibit successful change. Successful Six Sigma projects are recorded with some organizations like Seagate, Kodak, Honeywell, Texas Instruments, Boeing, Dupont, Toshiba, Sony, and Ford. Allied-Signal, a technology, and manufacturing company applied Six sigma principles to design recertification of aircraft engines in the 1990s and were able to save more than $600 million in 199l (Raisinghani, 2005). Six Sigma based methodology has been used to optimize the variables of SAW Boom machine operational process to increase the sigma level from 1.8 to 3 and reduction of COPQ from $35,500 to $5,500 per annum (Desai & Shrivastava, 2008).

In automotive designs, Zhan, in 2008, applied Six Sigma methodologies to reduce the average motor speed variation during Pulse-width Modulation (PWM) control using simulation to establish the baseline performance for the existing design. “The DMAIC Six Sigma approaches have been utilized in a food manufacturing company to decrease the defect rate of small custard buns by 70% from the baseline to its entitlement” (Hung & Sung, 2011). In a textile industry, Six Sigma methodologies have been used to improve yarn quality (Gupta, 2013). Similarly, this methodology has also been used to reduce defects in a fine grinding process of an automotive company from 16.6 to 1.19% (Antony, et al., 2011). According to Jirasukprasert et al.(2012), a reduction in the amount of defect was achieved in a rubber gloves manufacturing industry through the application of Six Sigma methodologies. The process improvement according to these researchers has aided the company to earn a savings of approximately $ 2.4 million for the subject year. Although the original focus of Six Sigma was on manufacturing, it has been applied in a non-manufacturing context with minor adaptations (Does et al., 2002).

2.4.1 Six Sigma Applications in Service Sectors

In non-manufacturing, Six Sigma has been applied in the healthcare sector (Wang et al., 2004). Six Sigma applications in healthcare facilities are much vital to minimize medical errors and total eradication of mistakes. In health institutions, poor administrative awareness and absence of administrative systems in hospitals has reflected negatively on the performance of the health service in both public and private sector and this has an indirect effect on customer's satisfaction (Omar et al., 2012). Incessant delays in the provision of hospital beds in Our Lourdes Regional Medical Centre, Louisana was corrected through careful implementation of Six Sigma projects (Sager & Ling, 2007). The Red Cross hospital which is a general hospital based in Netherland has successfully integrated Six Sigma within ISO 9001:200 quality management system to generate annual savings of 1.2 million euro (Heuvel et al., 2005). Allen et al 2010 have also described the application of Six Sigma DMAIC technique in streamlining patient discharge process at a community hospital. The researchers were able to achieve a significant reduction in the average discharge time from 3.3 to 2.8h and missing chart data was also reduced by 62%. A lot of success stories have been recorded by the pioneer Health centers that adopted this approach like Froedtert, Chicago's Northwestern Memorial hospital, mission's heartland health and Kentucky's common wealth health (Lasater, 2006). Common wealth Health Corporation embrace Six Sigma deployment in order to build more effective teamwork around motivated employee under transformed organizational outlook. By working in conjunction with general electric medical systems, common wealth Health Corporation has completed well over 150 Six Sigma projects since the union in 1998. From the vast reviewed works of literature in the health practitioner's domain, financial benefits have not been the most prioritized benefits for Six Sigma deployment unlike in manufacturing & service sectors. Six Sigma practitioners in health sector give more priority to customer satisfaction, quality of care / service, timeliness, speed / convenience over cost. Six Sigma projects has been successfully in finance sector to improve timely reimbursement of claims (Lazarus & Butler,2001), expand cash flow capacity,(Heuvel et al., 2005), streamlining the process of healthcare delivery (Ettinger, 2001), and reducing the inventory of surgical equipment and related costs (Revere & Black 2003). Six Sigma approach optimizes the average and reduces the variance of desired process (Ganti, 2004). Ganti (2004) in her work on Six Sigma and healthcare, enlisted few hospitals that have used Six Sigma as, Long Island Jewish N.Y, standard medical center, CA, Northwestern memorial, IL, M.D Anderson, TX, Virtual health system, NJ, Charleston Area Medical center, CT, Verdugo Hills hospital, CA, John Hopkins hospital, MD, Good Samaritan Hospital, Oh.

At Anderson Cancer Center in the University of Texas, Six Sigma was embraced and improved service operations to a reasonable extent (Benedetto, 2003). Also in the same institution, outpatient's CT exam lab, patient preparation times were reduced from 45minutes to less than five minutes in many cases and there was a 45% increase in examinations with no additional machines or shifts (Elsberry, 2000). Six Sigma program has also been used to enhance performance in a pollution prevention program. According to Calia et al. (2009), implementation of Six Sigma organizational structure and methodology improved significantly the performance of the pollution prevention program, thus the total number of pollution prevention projects increased 6.9 times and the total tonnes of pollution prevented increased by 62% in relation to the period before the Six Sigma implementation. Six Sigma applications have also been extended to supply chain (Tjahjono et al., 2012).

In the US banking industry, Bank of America and Citigroup were considered as organizations that heavily invested in Six Sigma and benefited from it (Rucker, 2000; Roberts, 2007). A good number of financial institutions including Bank of America (BOA) (Roberts, 2004), American Express (Bolt et al., 2000; Doran, 2003) improved their service outlook greatly in terms of accuracy in cash allocation, variation reduction in collector performance, and reduction in documentary credits defects, reducing check collection defects, and reducing variation in collector performance In order words, Six Sigma has penetrated into most sectors such as engineering and construction (Eckhouse, 2003), in telecommunication (Moreton, 2003), and has also inspired a considerable amount of academic literature (Brady & Allen, 2006).

Notwithstanding with the contributions Six Sigma has made in both manufacturing and non-manufacturing sector, Abolemaged (2010) observed an increasing gap between the number of Six Sigma articles that focused in manufacturing than in service sector starting from 2005. Chakrabarty and Tan (2012) also assert that the use of Six Sigma is relatively high among many western organizations, and with a limited spread in service industries. This is as a result of intangible and immeasurable service processes (Chakrabarty & Tan 2007; Wyper & Harrison 2000; Hensley & Dobie (2005)). The authors shared the benefits manufacturing sector has over service sector in terms of Six Sigma implementation; use of statistical tools and techniques, ease of data collection and continuity of the process. “The use of gauge repeatability and reproducibility also is common in manufacturing but not so in services, as a result of non-repeatable nature of service processes” (Does et al., 2002). More so, the nature of services and the way customers tends to evaluate service quality pose important challenges for Six Sigma (Nakhai & Neves, 2009).

2.4.2 Six Sigma Applications in a Small-and-Medium Enterprise (SME)

Six Sigma implementation are associated mainly with large manufacturing organizations which have good resources and technology in place (Amar, & Davis, 2008). Six Sigma improvement strategies were not structured basically to favor big organizations alone (Snee & Hoerl, (2003). Although its propagation through small and medium enterprises has been largely overlooked (He & Goh, 2015). Antony et al., (2005) highlighted common challenges with Six Sigma implementation in a small-and-medium enterprise to inadequate education and training as it is harder for smaller companies to free up top talented people to engage in training. (Davies, 2003) attributed challenges faced by SME with Six sigma strategy to cost of implementation. However, the growing importance of supply chain management issues in global market environment has greatly linked larger firms dependency on small to medium sized enterprises (**SMEs**) for the provision of high-quality products and /services at low costs (Antony et al., 2005). In describing these levels of dependency, some researchers have refuted the wide negative claims with some positive attributes inherent in SME structure.

According to Cazgnazzo, and Taticchi, (2010) small-and-medium enterprise is much more flexible than large ones and hence changes are introduced fairly quickly. Small companies are more agile, and much easier to buy-in management support and commitments, as opposed to large organizations (Antony et al., 2005; Adam et al., 2003). Some of the advantages of small-businesses embarking on Six Sigma initiatives according to Wilson (2004) encompass strong owner influence, fewer layers between the top management hierarchy and frontline workers, rapid and effective internal communication, and a limited number of locations. For a successful implementation of Six Sigma initiative in a small-and-medium enterprise, Spanyi and Wurtzel (2003) identified the following elements as vital:

1. Visible management commitment
2. Clear definition of customer requirements

3. A shared understanding of core business processes and their critical characteristics.
4. Rewarding and recognizing the team members
5. Communicating the success and failure stories, and
6. Selecting the right people and the right projects.

2.4.3 Six Sigma and Quality Management Approaches

Quality management can be described as a new way of thinking about the organizational management in the direction of improvement (Andersson et al., 2006). Six Sigma improvement strategies are the latest and most effective technique in the quality engineering and management spectrum (Desai & Shrivastava, 2008). It incorporates a systematic, scientific, statistical and smarter approach for management innovation, that builds on previous ones like TQC, TQM, and well-suited in the knowledge-based information society (Park, 2003). Six Sigma is not entirely new with respect to prior quality tools or principles, but the deployment approach and emergent structure of Six Sigma are new (Schroeder et al., 2008; Parast, 2011). The Six Sigma method only fully commences a project after establishing adequate monetary justification (Brady & Allen, 2006).

Many proponents of Six Sigma approach claimed that the approach has developed beyond a quality approach into a broader process improvement concept (Nonthaleerak & Hendry, 2008). Six Sigma methodologies is a step further development of the improvement cycle by Shewart and Deming (Anderson et al., 2006).The difference between PDCA/ PDSA and Six Sigma is ultimately on goal setting. While Six Sigma is very specific on goal specification, the other strategies as proposed by Deming's rely on "Do best goals". Six Sigma is known for employing specific challenging process improvement goals (Pande et al., 2000). Six Sigma edge over other quality management concepts is seen in the detailed quality tools, focused attention on financial results, and problem-solving methods, and lastly on the new approaches of sustaining the gains (Kletsjo et al., 2001). Most of the quality management concepts that have been widely promoted in literature and in practice are TQM, Six Sigma, lean manufacturing, business process re-engineering, just-in-time (JIT), Kaizen and Business excellence, Baldrige model, Statistical Quality Control (SQC), and Six Sigma is one of the more recent quality improvement initiatives to gain popularity and acceptance in many industries across the globe (Wang et al., 2009). However, Six Sigma differs from other quality improvement programs due to their measurable and quantifiable goals (Anderson et al., 2006).

Contrary to TQM, Six Sigma allows organizations to measure process capability and improvement efforts internally and externally (Aboelmaged, 2010). An improvement methodology is one of the clear differences between six sigma and TQM. In Six Sigma, there are two major improvement methodologies DMAIC & DMADV, while improvement cycle in TQM is comprised of four stages. The core advantages of Six Sigma over TQM according to Schroeder et al., (2008) is on focused attention on financial and business result, the use of specific metrics such as Critical-to-quality (CTQ), DPMO, use of a structured method for process improvement, and the use of a significant number of full-time improvement specialists. TQM generally focused on organizational result rather than on business result (Quinn, 2003). In Six Sigma programme, all improvements are economically justified (Andersson et al., 2006). However, the use of Total Quality Management (TQM) as an overall quality program is still prevalent in modern industry but many companies are extending this kind of initiative to incorporate strategic and financial issues (Harry, 2000). There are four aspects of Six Sigma strategy that are not emphasized in other business improvement methodologies and total quality management (TQM) (Antony et al., 2005). These aspects are as follows:

1. Six Sigma distinctively emphasis on quantifiable project outcome.

2. Six Sigma has been very successful in integrating both process and organic aspects of continuous improvement.
3. Six Sigma methodologies (define-measure-analyze-improve-control) link the tools and techniques in a sequential manner.
4. Six Sigma creates a powerful infrastructure for training of champions, master black belts, black belts, green belts and yellow belts.

2.4.4 Six Sigma Integration

Sustainable results can only be achieved when an integrated and cohesive approach is adopted with respect to training and learning (Alsagheer & Mohammed, 2011). Snee (2000) calls for research to help practitioners identify a robust set of improvement tools to be used in conjunction with the DMAIC process. Through a proper integration between Six Sigma methodology and other improvement/management initiatives, any process can be improved into infinite position. However, as has been reported in the existing literature, most of these integrations fail to take full advantage of each methodology due to organizational constraints/philosophy. The integration challenge is to create the best process and organizational infrastructure to support each of these methods and to align these infrastructures so that the integrated initiatives are complementary. In recent time, a lot of studies that focused on the shared relationship between Six Sigma and other innovative management and practices were as follows; integrating and comparing principles and characteristic of Six Sigma with Total Quality Management (Revere & Black, 2003; Hammer & Goding, 2001), integrating and comparing principles and characteristics of Six Sigma with human resource functions (Wyper & Harrison, 2001), integrating with the theory of constraints (Ehie & Sheu, 2005), integrating with lean production (Gupta, 2013; Aboelmaged 2010; Andersson et al., 2006; Arnheiter & Maleyeff, 2005; Bendell, 2006; chang & Su, 2007; Pojasek, 2003; Pepper, & Spedding, 2009; Dahlgaard & Dahlgaard-park, 2006; Ferng & Price, 2005; Pickrell et al., 2005; De Koning et al., 2008; Cupryk et al., 2007; Marti 2005; Antony et al., 2003), integrating with Balanced score card SCOR model (Knowles et al., 2005), integrating Six Sigma with IS0 9000 (Catherwood, 2002), Integrating with IS0 9001 (Dalgleish, 2005), and integrating Six Sigma with the capability maturity model (Murugappen & Kenni, 2003) are all part of the quality community's effort to maximize the positive effect of the Six Sigma method. Martin (2006) incorporate an operation research technique in analyze phase.

2.4.5 Six Sigma and Innovation

The premise of Six Sigma is that improving an organization's processes can lead to consistent output that is welcomed by customers (Zhang et al., 2009), but what happens when customers taste changes or competition heighten has not been given wide recognition. Few researchers have proposed theoretical models explaining why process management will impede innovation and empirically tested the relationship in the paint industry. Due to the complexity and dynamism inherent in the management of processes in the operations setting, research on process management remains a challenge in operation management field (Buffa, 1980). Six Sigma mechanistic approaches to improvement are highly prescriptive in mandating how improvement effort should be implemented. The contemporary business environment is most appropriately characterized by versatile customer requirement, complex global supply chains, and fierce global competition. Such mechanistic approach may likely not be appropriate for organizations operating in a dynamic environment, thus organizations need to be adaptive.

Six Sigma initiatives according to some set of researchers are not very effective in environments where the rate of technological change is intense. Process management, in particular, deals with minimizing sources of variability in internal and external activities (Panirselvam et al., 1999; Silver, 2004), which Six Sigma methodology is assumed to be one. Because of the focus of process management programs in variance reduction for improving the operations and continuous improvement of activities in a firm, over-emphasis on these programs affects the balance between exploitation and exploration (Benner & Tushman, 2003). In other words, Garvin (1991) is of the opinion that focusing much on process management will have negative effects on innovation, and may negate long-term performance. In the pursuit of higher operational effectiveness and organizational performance, scholars and practitioners are looking for new approaches to improve operational performance, boost profitability and enhance competitiveness (Parast, 2011). Six Sigma is about overall management strategy, culture, and change, and the organization needs to build all of this into a sound corporate strategy plan (Antony et al., 2005), thus to incorporate all these in an organization is to integrate other innovative approaches like knowledge management (KM). Schroeder at al., (2008) also suggested a specified number of additional research projects using contingency theory, organizational learning, and organization change theories to ensure organizations' innovation processes are not hindered.

2.4.6 Six Sigma and Organizational Sustenance

Some researchers, like Demast and Lobberkol (2012), recommend DMAIC methodology suitable for empirical problems varying from well-structured to semi-structured, but not to ill-structured problems or pluralistic messes of subjective problems (people problem solving). Recently, operations management scholars have recognized that "incorporating" human behavior into operation management models will yield more realistic insights" (Boudreau et al., 2003). According to March (1981), “systems that engage in exploitation to the exclusion of exploration are likely to find themselves trapped in suboptimal condition”. It is vital to find and sustain an appropriate balance between exploration and exploitation for system to survive. Attempt in balancing exploration and exploitation is demonstrated in the differences made between refinement of a prevailing technology and invention of a new one (Winter 1971; Levinthal & March 1981). Operations management should not be understood as a purely technical problem but must be considered simultaneously with behavioral underpinnings (Linderman, et al., 2003). Recent studies have now re-focused research attention to incorporate psychological, and contextual human side of Six Sigma (Buch & Tolentini, 2006), goal setting (Linderman et al., 2006), organizational context, and psychological safety (Choo, Linderman, Schroeder, 2007). Six Sigma benefits can only be sustained by having a mechanism that will address product innovation, the pattern of change in customer base, and environmental uncertainty, while improving organizational processes.

2.3.7 Six Sigma Benefits

Traditionally, between 1989 and early 90s, the aspiration of many quality improvement practitioners/proponents was to improve and maintain a process three(3) sigma (Fursule et al., 2012), and which is half-way to what Six Sigma stands to offer in terms of improvement levels. Six Sigma benefits are numerous as counted in both manufacturing and service industries. The most cited benefit of Six Sigma in the literature is customer satisfaction (Aboelmaged, 2010). In the area of manufacturing, Six Sigma benefits are highlighted in various areas such as reduction in in-process defect levels, reduction of customer's complaint, reduction of the production lead time, improving process capabilities, reduction in the cost of poor quality (COPQ), reduction in unplanned maintenance hours, etc. On the other benefits derived by service organizations for successful Six Sigma includes, reduction in documentary defects, timely and accurate claim reimbursement, improved report accuracy, reduced defect rate in service processes (Kwak & Anbari, 2004). In academics, the three main contributions of Six Sigma to academic according to Brady and Allen (2006) are aligned to increased emphasis on complete case studies, the development of a large market of industrial non-experts that are interested in practically oriented research, and lastly its approaches are core specific with a well formalized structure.

2.4.8 Confrontational Concerns on Six Sigma Improvement Strategies

There is a need to better understand organizational and contextual variables that facilitate or impede effective implementation of Six Sigma. There is a little theoretical support on the effectiveness of Six Sigma projects on organizational achievements, and the existing literature seems to suggest that Six Sigma may hinder an organization's effort to be innovative. Alsagheer and Mohammed (2011) stated that Six Sigma challenges are multidimensional due to many reasons, ranging from a commitment from management, the bottom-up and top-down communication mechanisms, unrealistic expectations, inappropriate resources, inappropriate projects and problem definitions and failure to sustain the results of Six Sigma projects. There is more works on Six Sigma subjects, and this demands academicians in quality improvement tenants to unravel in other to narrow the existing gap between its theories and practical applications (Schroeder et al., 2006). In aerospace companies as documented by Zimmerman and Weiss (2005), less than 50% of the respondents were satisfied with their Six Sigma programmes Similar survey was made on healthcare companies and the revelation showed that 54% of the surveyed subjects do not intend to embrace Six Sigma programs (Feng & Manuel, 2007). On the same vein, Home depot and 3M were also among big enterprise that showed their disdain with the output of the Six Sigma projects (Hindo, 2007).

However, the ability of Six Sigma to achieve both efficiency and innovation has been challenged from different perspectives, which most researchers have argued that the utilization of process management methodologies favours exploitative innovation at the expense of eliminating explorative innovation. With much emphasis on process improvement and variance reduction, Six Sigma would impede product innovation and radical change (Parast, 2011). Many quality management proponents argued that Six Sigma projects focus primarily on understanding and identification of critical characteristics to the existing customers (Harry, 1998; Dasgupta, 2003; Evans & Lindsay, 2005), at the expense of threatening the ability of the firm to identify new customers and introduce new products and/ or services. Thirdly, as a spin-off of quality management, Six Sigma maintains a strong emphasis on setting specific goals (Linderman et al., 2003), and according to Pande et al., (2000) setting a clear goal is central to Six Sigma and as such, cannot address the core principles of quality management such as a culture of learning, continuous improvement of processes, and a system view of the organization.

However, the ability of Six Sigma to achieve both efficiency and innovation has been challenged from different perspectives. Benner and Tushman (2003) are of the opinion that too much dependent on Six Sigma improvement methodology will only encourage only exploitative innovation. With much emphasis on process improvement and variance reduction, Six Sigma would impede product innovation and radical change (Parast, 2011). There are cases of six sigma project failures in literature, amidst their wide promotion in the practitioner's literature (Fursule et al., 2012). Chandra (2008) attributed poor program implementation and poor utilization of expert knowledge, as the reasons why Six Sigma projects fail. Further study by Gopal (2008) has linked Six Sigma implementation failures as a result of the poor commitment from organizational management. Parast (2011) has related most Six Sigma failures to lack of means or structures to address radical innovations. Zimmerman and Weiss, (2005) linked many Six Sigma improvement program failures to wrongfully identified projects. There is also a growing concern that Six Sigma or other process improvement programs fail because they do not consider the human side of implementation (Fursule, et al., 2012).

It is also observed from the literature review that most Six Sigma organizations fail to develop a shared vision of the methodology and expectations from it and often do not have an organized approach towards Six Sigma. To achieve the maximum advantages in the form of removed defects, continuous improvement and sustainability, Six Sigma need to be integrated with other strategic frameworks like knowledge management (KM) that are targeted at achieving corporate sustainability.

2.5 Knowledge Management (KM)

The economic leverage of knowledge has become valued and many organizations have turned their attention to the value created by knowledge workers (Conway, & Sligar (2002). Recent IT platforms and tools along with human-oriented approaches can help greatly in knowledge-sharing processes (Rao, 2005). Contemporary technologies such as the internet, intranet, and wireless media, are transforming the very way knowledge is experienced and transformed (Norris et al. (2003). According to Rao (2005), "KM" can be defined as a systematic discipline and set of approaches to enable information and knowledge to grow, flow, and create value in an organization". This involves human, communication, enabling tools, best practices, and communities of practice. Knowledge management entails vigorous processes and practices that are constantly implied in humans, as well as in groups and in physical structures too (Alavi & Leidner, 2001). Knowledge management is actually aimed at making tacit knowledge explicit in order to be shared and to be reused across an organization (Ghani, 2009). According to Beijerse, (1997) companies on the average only used 20% of the knowledge that was potentially available in the organization, and thus losses huge amounts of money annually reinventing things that already existed. The challenge to manage the knowledge assets of the organization introduces a new business philosophy described as knowledge management, which is about connecting people to people and people to information to create a competitive advantage (Andersen, 1998). Sustainable guarantor to competitive advantage has been aligned with proper knowledge management (Grant, 1996), and organizations are leveraging their knowledge wealth to bring forth organizational expectations.

Knowledge management can be a problematic term and can mean different thing to different people (UNDP, 2007). Another idea according to Basu (1999) is that "**KM** is the process of creating, capturing, and using knowledge to enhance organizational performance". In other words, knowledge management according to Omotayo (2015) is a highly interdisciplinary field that attracts scholars and practitioners from various fields (philosophy, information science, library science, economics, management, sociology, and engineering etc.). The principal reasons for the continued KM are linked to globalization of business, technological advances, workforce dynamism and organizational survival. Primarily, knowledge management emphasize on achieving a well-defined organization specific goal by collectively applying the domain knowledge of the whole workforce (Library, et al., 2005). However, in order to manage knowledge properly, one should carefully learn how to manage effectively key components like people, knowledge, processes and technology (Desouza, 2011). A complete knowledge management system is characterized with four elements; knowledge creation and capture, knowledge sharing and enrichment, information storage and retrieval, and knowledge dissemination (Dalkir, 2005). The purpose of knowledge management according to Depres and Chauvel (2001) "is to enhance organizational performance by explicitly designing and implementing tools, processes, systems, structures, and cultures to improve the creation, sharing, and use of different types of knowledge that are critical for decision-making". Naturally, organizations survives based on their ability to create, and retain already created knowledge and be competitively relevant knowledge creation is primarily a human process, though technology can facilitate knowledge creation but cannot replace people (Omotayo, 2015).

2.5.1 Knowledge Conversion Processes

Knowledge conversion process helps knowledge move from individual knowledge to organizational knowledge through interactions (Linderman et al., 2004). This form of interaction brings about what is called the four modes of knowledge conversion, which according to Nonaka and Takeuchi (1995), occurs through socialization, externalization, combination, and internalization. Knowledge management (**KM**) has been described as a key driver of organizational performance (Bousa & Venkitachalam, (2013). It is beneficial to all sectors such as education banking, telecommunications, production/manufacturing, public sectors etc. (Omotayo, 2015; Teng & Song, 2011). It is important to know that the selection of a suitable KM strategy not only depends on the type of knowledge to be shared but also on the environment the organization operates in. A quite number of challenges present themselves in today's economy causing firms to take an increased interest in knowledge management, probably because of the aging workforce, rapid advance in technology, service retrenchment and retirement (Malone, 2002). Since the organizational knowledge is lost through this conditions, instituting and adapting knowledge-based management system becomes a global sustenance practice.

The hallmark of every new economy is its ability to realize economic value from their collection of knowledge assets as well as their assets of information, production distribution, and affiliation (Gold et al., 2001). Recently, the evolution of global knowledge-based economy has resulted in a shift from the traditional production factors such as land, capital and labour to that of knowledge. At present, most organizations compete on their knowledge-based assets, and their ability to improve processes to bring new products to the market faster and more cheaply (Economic Intelligent Unit, 2007). Uriarte, (2008) characterize knowledge as one that cannot be consumed by the application, or lost during transfer, that which is abundant but the ability to use it is scarce, and that which are easily lost on a daily basis. Searching through so many definitions from various authors, the definition from Leonard (1998) is adopted, which states that knowledge is information that is relevant, actionable, and at least partially based on experience. Commonly, knowledge is known to be in two orders, tacit and explicit knowledge. The tacit form of knowledge is personal and it is accumulated through study and experience. It can be shared and communicated through various activities and mechanisms such as conversations, on-the-job training, workshop, seminars etc. however, due to its subjective nature, it is hard to formalize this form of knowledge (Dinakar, 2016). The management of tacit knowledge is not common and the current technology-based knowledge management has not developed a fully effective means for the extraction of tacit knowledge (Uriarte, 2008). The other knowledge form is known as the explicit. According to (De Tienne & Ann Jackson, 2001, Duffy, 2000), explicit knowledge is that which is already documented: located in files, manuals, databases.

However, both types of knowledge can be produced as a result of interactions & innovations, and complement each other such that without tacit knowledge it will be difficult, if not impossible to understand explicit knowledge. The creation and diffusion of knowledge have become increasingly factors in competitiveness, and understanding of knowledge plays a central role in understanding organizational improvement activities. The SEIC model rightly described the knowledge creation process or mode, which helped in understanding the dynamic nature of knowledge creation and management. Fig.2.9 described the interaction between types of knowledge and knowledge moves from individual knowledge to organizational knowledge through socialization, externalization, combination and internalization.

	TACIT KNOWLEDGE TO	EXPLICIT KNOWLEDGE
TACIT KNOWLEDGE TO EXPLICIT KNOWLEDGE	SOCIALISATION (sharing experiences with others)	EXTERNALISATION (writing down tacit knowledge)
	INTERNALISATION (Learning by doing)	COMBINATION (Systemizing it into a knowledge system)

Figure 2.9. The four knowledge conversion processes (Arendt, 2008)

The socialization process focuses on tacit to tacit knowledge linking to create new knowledge through interaction processes (Dinakar, 2016). This mode of knowledge conversion requires that individuals interact with one another, however, this interaction may occur without the use of language in terms of mentoring, observation, imitation and practice which are ways to share tacit knowledge. The externalization is a process of articulating tacit knowledge into such explicit knowledge as concepts. This stage is known as the knowledge crystallization point, and focuses on linking tacit knowledge to explicit, and is triggered by a dialogue intended to create concepts from tacit knowledge. In the knowledge combination process, new and existing explicit knowledge are assembled into a more systematic knowledge. Internalization is the process of embodying explicit knowledge into tacit knowledge. This often occurs through re-experiencing what was learned, as is often the case in learning-by-doing. The use of operating manuals for various machines or equipment, oral stories, diagrams is quintessential examples of explicit knowledge that are used for internalization.

2.5.2 Knowledge Management Viewpoint

Knowledge management is majorly categorized into people management and information management. These two main paradigms are the computational view of knowledge management and the organic view of knowledge management which are derived from different epistemological positions, positivism and social constructionism (Swan, Newell, Scarbrough & Hislop, 1999), and shares common interest which are to the benefit of the organization (Pan & Scarbrough, 1999). A computational view of knowledge management approaches, view knowledge management as a process of identifying empirically validated facts and the key knowledge management initiatives, and under this include IT infrastructure, data warehouses and virtual centres of expertise, and other technical procedures. The organic view emphasizes the role of people, group dynamics, social and cultural factors, and networks (Argote, 2005). The human or organic side focuses on the sense-making behaviours of individuals, social relations and cultural factors when handling organizational knowledge (Easterby-Smith & Prieto, 2008).

Organizational success is assured when processes and technology are merged together with employee's knowledge assets (Omotayo, 2015). This integrative perspective describes the organization from both the technological and human approaches, suggesting that IT and social factors are independent but interacting components (Easterby-Smith & Prieto, 2008). For instance, where most processes are not routinized or standardized, the human solution becomes preferable. The primary objective of knowledge management research and practices is to facilitate the efficacy of knowledge sharing among organizational members (Desouza, 2003). In relation to the primary objective it enhances both knowledge exploitation and exploration, and also shares the cost of not knowing and shortens learning cycle (Swan et al., 1999).To be precise, inefficiencies are reduced through proper knowledge coordination (Hibbard, 1997). Knowledge management approaches include self-service, networks, and communication of practice (CoP), and the transfer of best practices. Networks and community of practice (CoP) are the most vibrant and powerful KM approach used in quality management initiatives. Impact of other process improvement strategies is enhanced as a result of due cognizance to proper knowledge management (Uriarte, 2008). However, no general approach to managing knowledge has been commonly accepted up till now (Wiig, 1997; Uriarte, 2008), but the success of its implementation is achieved by modifying an organization's culture in ways that encourage and support desired knowledge attitudes and behaviors. Further success of KM program lies with apt alignment with the business goal, for without which is a futile exercise (Dalkir, 2005).

2.5.3 Knowledge Management Critical Success Factors (CSFs)

A suitable KM should be well adjusted to the situation and context of the organization at hand (Liebowitz, 1999; Soliman & Spooner, 2000). Skyme and Amidon (1997) highlighted seven key success factors that would enhance deployment of knowledge management practices in an organization. These include a strong link to a business objective, a compelling vision and structure, knowledge leadership, a well-developed technology infrastructure and systematic organizational knowledge processes, a knowledge creating and sharing culture, and continuous learning. In an exploratory study on 31 KM projects, Davenport et al., (1998) also align KM success to a clear link to economic value, a clear purpose and language, multiple channels for knowledge transfer, a standard and flexible knowledge structure, a knowledge-friendly culture, change in motivational practices and senior management support, and a technical and organizational infrastructure. Liebowitz (1999) proposed six vital **CSFs** to make KM successful in organizations. His suggestions were on; committed senior management leadership, the presence of chief knowledge officer (CKO) and KM infrastructure, knowledge source, incentives, supportive culture, and lastly KM system and tools. However, Wong (2005) posit that solely linking incentives and rewards to individual performance or outcome will result to unhealthy competition and will be detrimental to knowledge sharing culture. Uriarte, (2008) broadly described these KM CSFs as pillars of knowledge management, and categorized them into four: Management and organizations; infrastructure; content management systems, and culture. Reportedly, the commonest impediments to effective knowledge sharing have always been with negligence and lack of commitment (Huber, 1991; Leonard-Barton, 1990). A committed organization is one that ensures availability of an up-to-date knowledge of the entire system of concern without incubating any fear for the loss of supremacy. A certain level of technology and infrastructural support are required for all knowledge management system to be effective. Organizational structure can impede adequate knowledge sharing mainly in cases where there is weaker co-location (Appleyard, 2002; Doz, & Santos, 1997; Kogut & Zander, 1993), knowledge diversity (Pascale, 1999; Lam, 1997), and unfriendly relationships between knowledge source and recipients (Ghoshal, & Bartlett, 1994, Nonaka, 1994). Most of the problems with knowledge management system are basically with the content management. The roles and responsibilities for maintaining and updating content should be clearly delineated to facilitate steady updates for both new and pre-existing events. Culture, on the other hand, may support or undermine discipline in managing and sharing knowledge. Organizational culture can be readjusted by reallocating work assignments, introducing new tools and procedures (De Stricker, 2014). Culture comes into being through constant communication among the members of the organization can be defined as a set of mechanisms such as informal values, norms, and beliefs that guides mode of interaction within and outside the organization (Wenger et al 2002). Incompatibility of culture can pose a serious barrier to effective sharing, and thus to the entire knowledge management system. Many factors such as efficient human resource management, organizational culture are attributed to purposeful knowledge management systems. However, the debate on the most important enabler for knowledge management among knowledge management proponents has always been between technology and people, but a great number of reports consider people to be the most important and argued that knowledge management that focuses mainly on technology often fail.

Table 2.2: *Barriers to Cultural Change and Possible Solutions*

S/N	Cultural barrier	Possible solution
1	Lack of time and meeting places	Hold seminars and e-meetings, re-design physical workspaces.
2	Status and rewards to knowledge owners	Establish incentives and include them in performance evaluations, develop role models.
3	Lack of absorptive capacity (Not-invented-here syndrome)	Hire for openness, educate current workforce, use nonhierarchical approach based on quality of ideas and not status of source.
4	Intolerance of mistakes and need for helps, lack of trust	Accept and reward creativity and collaboration. Ensure there is no loss of status for not knowing everything.
5	Lack of common language	Establish a knowledge taxonomy and knowledge dictionary for knowledge content through the creation of co-location environment.

Source: (Adapted from Dalkir, K., (2005): Knowledge Management in Theory and Practice).

2.5.4 **Knowledge Management Models and Tools**

Most of the management models in literature are basically concern in addressing ways of managing knowledge in a wider perspective. Though in the context of process study, much emphasizes are always laid on the **SEIC** model which is also most widely used model in practice. Tables 2.3 contain the list of knowledge Management models found in the literature.

Table 2.3: *Knowledge Management Application Model*

S/N	KM –Models	Model Description
1	**SECI Model**	This model was developed by Ikujiro Nonaka together with Hirotaka Takeuchi in (1995). A model of a knowledge creating process to understand the dynamic nature of knowledge creation and to manage such a process effectively.
2	**Capability Maturity Model**	An organizational model that describes five evolutionary stages in which processes in an organization are managed. Though this model refers to the management of processes in an organization, it can be easily adapted to manage knowledge.

Table 2.3: *Knowledge Management Application Model*

S/N	KM –Models	Model Description
3	**Business Intelligence model**	BI applications mainly consist of systems and technologies for monitoring, gathering information, reporting, analysis, and profiling.
4	**Johari Window**	Developed by Joseph Luft and Harry Ingham. The model is an information processing model that can be represented in a 2 by 2 matrix form. This model employs the interactions between two sources of information, the Self and the others. It has four quadrants; Arena, Blind spot, Façade, Unknown..
5	**Three worlds of knowledge (Karl Popper)**	Three worlds of knowledge (Karl Popper) This model was developed by Popper to help him solve the mind-body problem and also to understand the interactions between the physical, the mental and the manifestation of human mind.
6	**Bridging Epistemologies**	This model shows that most of the organizational knowledge is based on the understanding of the nature of that knowledge. Developed by S.D.N Cook and J.S Brown..
7	**Pyramid to Wisdom & DIKW Model (RusselAckoff)**	It describes the structural and functional relationships between data, information, knowledge, and wisdom. The knowledge pyramid led to the foundation of DIKW Model. The DIKW model stands for Data, Knowledge, Information, and Wisdom of decision making.
8.	**Knowledge Life cycle (Joseph, M Firestone & McElroy).**	Knowledge is managed in a continuous cycle of production & integration with a focus on innovation.
9	**The knowledge management method (Collison& Geoff Parcell)**	A framework that can be used for learning, capturing, sharing and exploiting knowledge and experience. According to the model proponents, knowledge is something that resides in the minds of individuals and is not something that can be controlled or managed.

Table 2.3: *Knowledge Management Application Model*

S/N	KM –Models	Model Description
10	**Six knows knowledge (Lundvall& Johnson)**	This is the simplest knowledge management, model. The model is quite expressive and similar to DIKW model.
11	**K2BE (Knowledge to Business Excellence)**	The K2BE roadmap is a rough process model for installing professional knowledge management. It consists of four fundamental sections and five phases. .
12	**Choo Sense–Making KM model (1998)**	The Sense-Making KM model is focused on three aspects; Sense making, knowledge creation, and decision-making skills. In general, the model focuses on how informational elements are selected and fed into organizational actions.
13	**Bukowitz& Williams model**	This Knowledge management model plans on how establishments should create and increase knowledge to arrive to an expected worth.
14	**Complex Adaptive system models**	Under this model, an organization is seen as an adaptive complex system. Its principles are based on cybernetics, which uses communications and control mechanisms in order to understand, describe and predict what a viable organization should do.
15	**Zack Knowledge Management model**	The model is extracted from work on the design and development of information products, in Meyer and Zack's approach
16	**Boisot I-space model**	The model considers organizations as living organisms and requires a dynamic knowledge management strategy. This model can be seen as a three-dimensional cube with the following dimensions: from uncodified to codified, from concrete to abstract.

Table 2.3: *Knowledge Management Application Model*

S/N	KM –Models	Model Description
17	**Von Krogh &Roos Model (1995)**	This model precisely differentiates between individual knowledge and social knowledge. It analyses : 1. Why and how knowledge gets to the workers of a company. 2. Why and how knowledge arrives at the organization 3. What does knowledge mean for the workers as well as the organization, and 4. What are the barriers to Organizational Knowledge Management?
18	**WIIG KM model (1993)**	This model is marked with the basic principle which states that, for knowledge to be useful and valuable, it must be organized and synchronized. Some of the essential dimensions in the WIIGS KM model are; completeness, connectedness, congruency, perspective, and purpose.

Note. Adapted from (Dalkir, (2005); Frost, (2012)

Knowledge Management tools and methods are classified into two, the non-information Technology (IT) methods and tools, and the Information Technology (**IT**). Young (2010) compiled twenty Knowledge Management tools and methods as agreed by the Asian Productivity Organization (**APO**), and are tabulated in the Table 2.4.

Table 2.4: *Knowledge Management Tools and Methods*

S/N	Non-IT tools and methods	S/N	IT tools and methods
1	Brainstorming	12	Document libraries
2	Learning and Idea curve	13	Knowledge bases (Wikis etc.)
3	Peer Assist	14	Blogs
4	Learning Reviews	15	Social Network Services
5	After Action Review	16	Voice and voice-over-Internet Protocol (VOIP)
6	Storytelling	17	Advanced Search tools
7	Collaborative physical work pace	18	Building knowledge clusters

Table 2.4: *Knowledge Management Tools and Methods*

S/N	Non-IT tools and methods	S/N	IT tools and methods
1	APO knowledge management Assessment tool	19	Expert Locator
2	Knowledge café	20	Collaborative Virtual Spaces
3	Community of practice		
4	Taxonomy		

Source: (Young, 2010).

2.5.5 Community of Practice (CoP)

Regardless of what business one is doing, the ability to compete is based on the knowledge of its employees. Many companies already know that the knowledge of their employees is their most valuable asset (squierer, 2006). According to the CEO of the American Productivity & Quality Centre (**APQC**) Carla O'Dell, networks and communities of practice (**CoP**) are probably the most vibrant and powerful knowledge management approaches. CoP provides an easy entry point in knowledge management with enormous benefits and readily overcome cultural barriers to knowledge sharing (Asoh, Belardo, & Neilson, 2002). The primary goal of any organization is to integrate the specialized knowledge of many individuals to maximize efficiency (Grant, 1996). As knowledge resides within each organization both explicitly and implicitly, organizations must find ways in which to manage the processes by which knowledge is created and applied (Quintas, et al., 1997; Davenport & Klahr, 1998). Organizational knowledge and ideas are adequately maintained through a social process other than the sum of the individual cognitions (Gheradi & Yanow, 2003). Critical knowledge loss occurs by a job transfer, retirement, mobility and alternative work arrangements. According to Omotayo, (2015) "when an employee leaves an organization, his idea, information, experience, contacts, relationships and insights leave with him if no attempts are made to identify, capture and share this knowledge in the organization". To capture knowledge for further use in any organization certainly entails workers should be working in groups (Hislop, 2013; Dul et al., 2011). The Phrase community of practice was introduced by Wenger & Leave in the 90's and is the most interesting informal network from a knowledge management point of view.

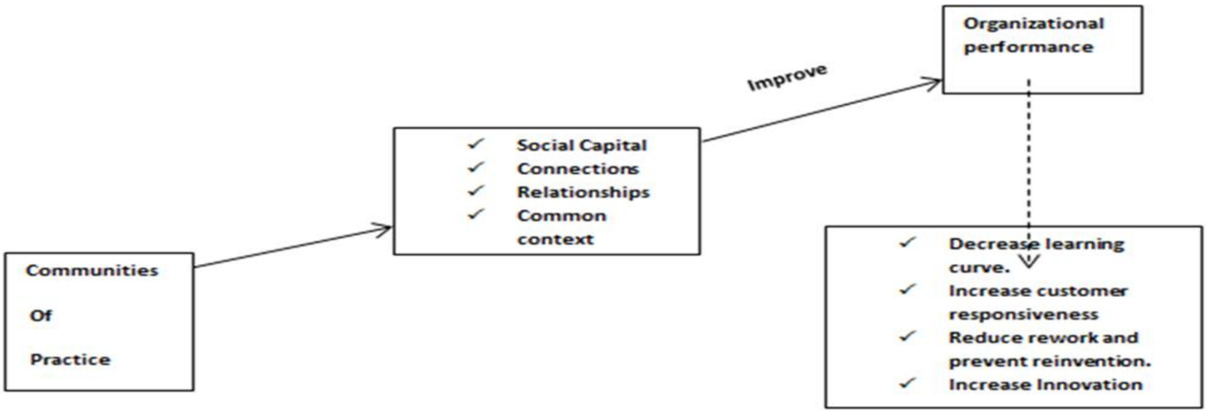


Figure 2.10. Communities of practice and organization performance (Adapted from Lesser, & Stock (2001)).

The community of practice is a knowledge-based social structure where a group of people with a common interest are united about a topic or set of problems; thereby deepen their knowledge and expertise by interacting on an ongoing basis (Wenger, McDermott & Snyder, 2002). This environment supports faster problem solving, cuts down on duplication of effort, and provides potentially unlimited access to expertise (Leask et al., 2008). In the context of knowledge management (KM), community of practices is formed intentionally or spontaneously to share and create common skills, knowledge, and expertise among employee. Malone, 2002) described as a step formed toward developing a learning organization. The community of practice model allows for the exploration of the implicit knowledge (Skalicky & West, 2014), and further leads participants towards the greater attainment of social capital (Bourdieu, 1997), connections, relationships, and expression of a common understanding and context of problems (Wenger et al., 2002). The size of CoP varies from 2-3 people to thousands of people, and members of expertise could be either homogeneous or heterogeneous (Young, 2010), meaning it could be a group of people in a specialized field or group of people from different specialty, depending on the nature of the assignment to be carried out. In anticipation of the expected organizational outcome, the goals of a community of practices should be aligned with the goals of the organization (Brown & Gray, 1995).

2.5.6 Practical Concerns on KM Functions

The common challenge concerning knowledge management is that the actual situation is unique in every organization (Mittelmann, 2004), and there is still no absolute method for measuring KM organization (Gupta et al., 2000). Other problems faced by knowledge management functions are attributed to culture, organizational structure, trust, job security. The willingness of individuals to share their knowledge in an organization heavily depends on the organizational culture (Kucza, 2001). Cultural issues are the largest obstacles to implementing successful knowledge management strategies (Hibbard & Carrillo, 1998; Wong, 2005). One cultural aspect which is key for KM is a collaboration (Goh, 2002), thus knowledge transfer requires individual to come together to interact, exchange ideas and share knowledge with one another. The second challenge is in identifying those knowledge domains possessing potential value for the firm and ways of converting them into actual value (Malone, 2002) because most individuals that possess unique knowledge hold a monopolistic power and are reluctant to relinquish that power (Davenport & Prusack, 2000).

Another most internal barrier to the flow of knowledge is lack of communication between functions in the company. Lastly is security; as most of the employees hide valuable knowledge that can equip them as better entrepreneurs, if their job is threatened. In order words, most organizations are reluctant to engage in knowledge management program because they are afraid that some vital organizational information will be compromised. By accessing, sharing, and implementing both explicit and tacit knowledge, organizations can influence behaviour and achieve improved performance both individually and organizationally, and the more effective organizations are at learning, the more likely they will be at being innovative (Argyris, 1992).

2.5.7 KM Metrics

Measurement is undoubtedly the least developed aspect of knowledge management and without measurable success, enthusiasm and support for knowledge management are unlikely to continue" (De Brun, 2005). Knowledge measurement is developing into a new research field in the area of knowledge management (Jennex & Smolnk, 2009). While there are many empirical based metric systems available online, many knowledge management practitioners believe that because knowledge is intangible, knowledge management cannot be measured (Milton, 2009). Metrics are essential for the advancement of research and practice in an area (Kankanhalli & Tan, 2005). The development of KM metrics has begun in recent years and these metrics are being applied by some organizations in measuring organizational knowledge management capabilities (Ranjit, 2004). The measurement metrics is necessary to determine the extent to which an organization utilizes its knowledge assets. However, Tiwana (2002) warns against choosing too many metrics that will tip people off from business goals. According to Rao, (2005) organizational success depends on the performance maximization across these five dimensions of KM metrics; technology, process, knowledge, employee, and business. These KM metrics and their scope are enlisted in Table 2.5.

Table 2.5: ***Knowledge Management (KM) Metrics and Scope***

Scope of KM Metrics	Sample parameter
Technology metrics	Number of e-mails, usage of online forums, number of database queries, Web site traffic, duration of portal sessions, number of search queries, number of blogs, number of alerts
Process metrics	Faster response times to queries, meeting international certification standards, more real-time interactions with clients, tighter collaboration with suppliers and distributors, more direct channels to customers, more accurate content taxonomies, more secure communications
Knowledge Metrics	Number of employee ideas submitted, number of knowledge asset queries, number of knowledge assets reused, best practices created, rate of innovation, active CoPs, knowledge retention, quicker access to knowledge assets. knowledge ("flow" and "stock" measures)
Employee metrics	Degree of bonding with colleagues, improved performance in CoPs, peer validation, feeling of empowerment, growth in trust, satisfaction with reward/recognition, retention in company, decrease in time to competency, more accountability, responsible risk-taking, increased motivation
Employee metrics	Degree of bonding with colleagues, improved performance in CoPs, peer validation, feeling of empowerment, growth in trust, satisfaction with reward/recognition, retention in company, decrease in time to competency, more accountability, responsible risk-taking, increased motivation

Source: Rao, (2005).

2.5.8 Knowledge Creation within Six Sigma Quality Management

Learning and knowledge creation in quality improvement relate to how an organization manages the cognitive processes of its members (MacDuffie, 1997). The relationship with organizational cognition is critical because how a quality program successfully changes practices in an organization depends on how the cognitive processes of its organizational members are managed (Reger et al., 1994). It is of utmost benefit that Six Sigma Projects are understood from a knowledge management perspective. Choo et al., (2007) developed a knowledge-based framework for Six Sigma projects by focusing on two complementary sources of knowledge creation in Six Sigma projects; prescribed methodology and organizational context.

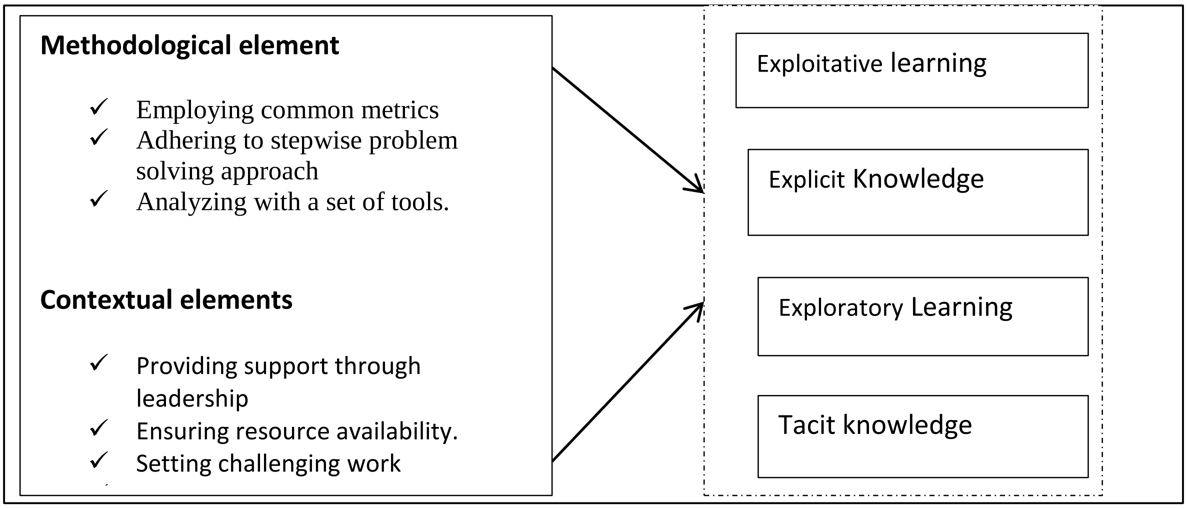


Figure 2.11. A framework for learning and Knowledge creation in quality improvement. Source: (Choo et al 2007)

These two perspectives reflect the dual emphasis of technical (prescribed methodology) and social (organizational context). Technical dimension (e.g tools and techniques) requires having a method built on the efficient process and cumulative experience acquired through a repetitive structured process. The social dimension (leadership, organizational culture, etc.) puts more emphasis on the social environment in knowledge creation, by designing a creative environment for organizational members. Before Choo et al., 2007 study, there has been a little insight into how a quality advantage can become more sustainable as a result of insufficient understanding on how the technical and social components of quality practices lead to learning and knowledge creation.

The researchers examine how learning and knowledge creation can be facilitated in a Six Sigma projects by effectively implementing both perspectives in order to generate a higher level of knowledge such that a sustainable quality advantage will be sustained. KM theories enrich our understanding of quality management (Linderman et al., 2004). Arendt, (2008) succinctly add that the knowledge of the individuals and the explicit knowledge of the organization are the bedrock of the successful application of Six Sigma projects. In Six Sigma projects, for example, the team members comprising of experts and regular workers are closely connected with the affected process. In this team collaboration, these experts now share tacit knowledge with the rest of the group, so a common understanding of the entire process is gained. Linderman in 2004 with his co-researchers made some propositions in relation to quality management and knowledge creation as vital integrations for an improved firm performance, and further advocates for deploying quality practices that support the knowledge creation processes (socialization, externalization, combination, and internalization). This organizational knowledge creation process is continuous and ideally creates a "knowledge spiral" as it moves from an individual to a group to the organization.

Most of the quality improvements attained in most organizations are always not well sustained mainly because of the outsourcing of improvement functions to external process improvement practitioners. It is more effective to have members of an organization as an integral part of the improvement project than handing off or turning over a project (Leavitt, 2002). According to Arendt, (2008) employees being exposed to Six Sigma projects through their participation as team members not only share their knowledge but also gain new knowledge. On the other hand, Six Sigma practitioners need to learn from KM strategies that sustain change, by leveraging Six Sigma achievements over a long term. This process improvement innovation of incorporating KM in Six Sigma strategy in an organization will create a systematic problem-solving culture among members, thereby making members of the organization direct members of the given functional group. The idea will be to move people from a departmental thinking in which they are least inclined to share information all the way up to an ideal where knowledge is shared intuitively. Currently, knowledge management has stood out a foundation for competitive advantage and has contributed in the successful implementation of Six Sigma. (Gowen et al., 2008). Barton and Byard, (2008) assent to the early arguments, that Six Sigma's positive improvement results can only be well sustained if implemented in a knowledge-based environment.

Table 2.6: ***Description of Practices that Link Knowledge and Quality Management***

Knowledge / **Quality**	**Socialization** (Tacit to Tacit)	**Externalization** (Tacit to Explicit)	**Combination** (Explicit to Explicit)	**Internalization** (Explicit to Tacit)
Customer satisfaction	The extent of interactions between organizational members and customers.	The extent that customer needs are articulated or conceptualized.	The extent of information analysis conducted on customer data.	The extent of monitoring and providing feedback on customer information.
Continuous improvement	The extent of interactions between organizational members in improvement activities.	The extent that improvement ideas are articulated in the form of theories, concepts, or cause-and-effect reasoning.	The extent of information analysis conducted on problem understanding and diagnosis.	The extent of on-going process monitoring and control.
System View	The extent of interactions between heterogeneous organizational members.	The extent that organization conceptualize the purpose and aim of system	The extent that organization synthesizes information from heterogeneous sources.	The extent that organization consistently acts in conformance with its purpose, aim and strategy.

Source: Linder man et al., (2004)

Table 2.6 describes practices that link knowledge and quality management considering knowledge conversion processes and few quality measurement parameters. Arendt, (2008) succinctly added that the knowledge of the individuals and the explicit knowledge of the organization are the bedrock of a successful application of Six Sigma projects. Recently, operations management scholars have recognized that "incorporating" human behavior into operation management models will yield more realistic insights (Boudreau et al., 2003). However, Antony (2004), had earlier argued that improvement in decision-making, communication, and learning processes cannot be achieved with Six Sigma projects since they are designed to deal with specific quantifiable and measurable improvement goals. Six Sigma integrations with other management models and methods have become the focal and contentious subject of debate among the circles of quality/ process improvement proponents.
Recent un-impressive records on failed Six Sigma projects globally has awakened most quality improvement proponents to engage in concerted research efforts to unravel answers to poor Six Sigma project executions. (Kwak & Anbari, (2004); Antony (2004b); Parast, (2011); Alsagheer & Mohammed, (2011)), through their concerted research efforts aligned Six Sigma failures to organizations inability to retain knowledge and sustain learning environment. Based on the experiences in the literature concerning many manufacturing companies that have implemented Six Sigma technique without creating the underlying culture of learning, and incessant loss of control to the newly improved process begot the era of shared relationship between Six Sigma and knowledge management (KM) integration. The quest for establishing corporate and sustainable management models start to gain wider recognition in the last decade, hence era of propositions in Six Sigma-KM integration subjects swoops more ground in quality improvement palace.

However, some of recently reported Six Sigma and Knowledge Management integrations from the available literature are basically on organizations that already have Six Sigma certified experts, thus a discouraging factor for organizations that would want to adopt the strategy newly due to the responsibilities of acquiring Six Sigma experts. The available integration efforts have failed to consider prevailing realities among organizations that are at their teething quality management level to solve domain-specific problems. Some of the recently proposed Six Sigma and KM integrations, as well as their individual shortcomings, are as highlighted below:

1. Proposed integrated knowledge representation (**IKR**) model (Yeung, 2004). The proposed model has very little interaction with the basic Six Sigma steps. Its complex-IT platform and budgetary set-up requirements made it more conducive to only large organizations.
2. Proposed Process-based knowledge creation and opportunities model (Wu & Lin, 2009). In this proposed model, the KM process is vague and not clearly described. A proposed integrated PRAND MODEL (Alsagheer & Mohammed, 2011). The idea of the model is to have a specialized process research development team in the company. This idea of having a specialized team may deter organizations at a teething quality management level from adopting due to the presumed high resource requirements.
3. Proposed SEIC/SIPOC Continuous Loop model (Nold III, 2011). KM process was not distinctively highlighted, except the knowledge conversion processes.
4. Proposed Knowledge flow in Chinese s] Six Sigma teams model (Zou & Lee, 2010). Only Chinese cultural environment was considered.

In summary, most of the Knowledge gained in Six Sigma-DMAIC is difficult to sustain over time especially when competent staffs that were involved in improvement projects are retired, retrenched or through job rotations. Recently, Six Sigma and Knowledge Management (**KM**) integration approaches have been recognized as part of the ongoing process improvement initiatives to make Six Sigma-DMAIC approach a more viable solution in tackling similar quality related problems in manufacturing firms. Although many solutions of integrating Knowledge Management and Six Sigma have been applied into a number of fields such as hospital (Gowen et al 2008), textile industry (Baral, 2014), IT system management (Nguyen, 2017), such integration has not been applied in cable manufacturing industry in Nigeria. In cable manufacturing where observational studies are much, knowledge of workforce is very vital in every improvement studies and most experienced staffs leave with their individual knowledge of the process due to retirement, retrenchments, and during job rotations without transferring them. Most cable industries have over the years tried a good number of improvement strategies to help save on the cost of not knowing, but are still faced with some real life problems in their manufacturing processes due to process knowledge loss, and lack of knowledgeable workers. Hence a solution to the aforementioned challenges becomes imminent and requires a robust methodology that can be used as a model for transfer of best practices and contains Silos effect.

Furthermore, most cable making organizations are more engrossed in instituting a quality management system, and often pay less attention to selection of appropriate tools that will guide them to success. Although most cable manufacturing organizations are ISO certified, it is pertinent for these organisations to be conscious of the fact that ISO does not suggest any tools, methods or solutions on how to improve, but mainly on following standardized procedures. Hence, there is utmost need to always develop improvement strategies that can be utilized as a tool within a quality management system to meet ISO requirements.

2.6 Knowledge Gap

The quest for efficient and sustainable strategy for tackling process and product variability especially in cable manufacturing companies is yet to be satisfied. The efficacy of Incorporating Knowledge Management within Six Sigma-DMAIC in tackling such manufacturing process challenges has not been explored. Moreover, Six Sigma implementation processes and styles differ from company to company, country to country due to the uniqueness of experiences, nature of problems and maturity level of quality management. Thus there is need for indigenous study and adaptation of the improvement strategy in industrial settings, with particular reference to the Anuka cable plant of the Cutic Cable Plc.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Research Design

A uniform way to implement Six Sigma-DMAIC usually remains a myth (Moosa & Sajid, 2010) and its application, according to Tennant (2002), is still novel. In this study, power of generality trade-off was explored by augmenting the Six Sigma methodology with domain-specific adaptations which includes the introduction of additional Knowledge Management techniques in the existing method to make it more powerful for application. Figure 3.1 describe the entire improvement cycle, starting at the conceptual level of the improvement solution, where the essential tools and procedures are integrated for improvement functions. The second phase in the research design is an empirical research, saddled with the responsibility of validating the conceptualized solution in an industrial setting. The third phase of the research design is concerned with the economic evaluation of the proposed solution. The last phase on the research design flow chart is concerned with the development of Knowledge based tool for easy replication of the improvement solution.

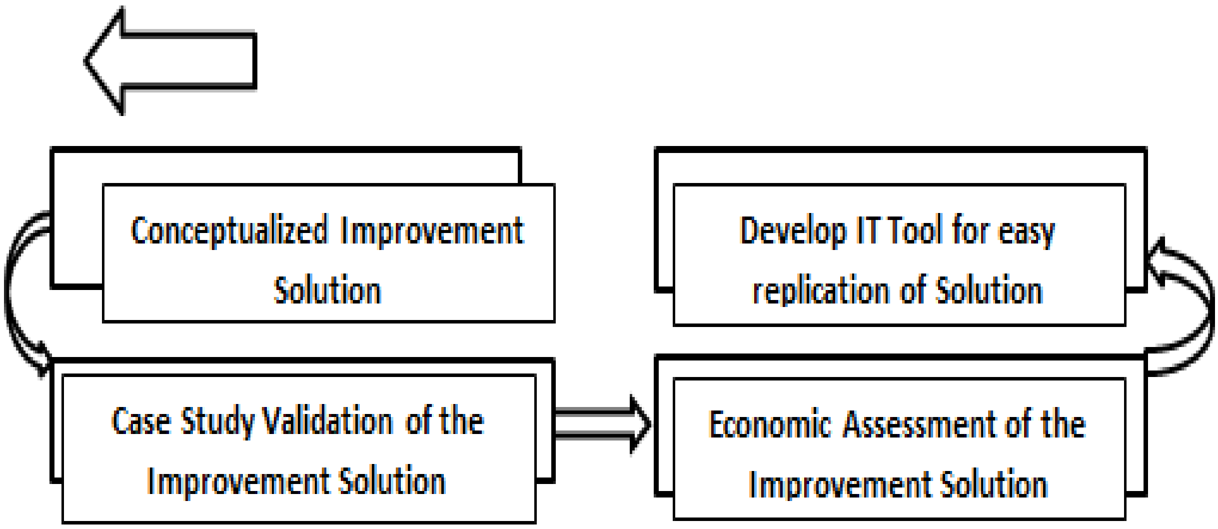


Fig. 3.1. Flowchart of the Research Design representing the Entire Improvement cycle

3.1 The Underlying Philosophy for the Development of the Improvement Strategy.

In the development of the improvement strategy, the matching advantage of these two distinct disciplines Six Sigma and knowledge management were explored. The knowledge management concept that was explored laid emphasis on the social environment through the use of Cop and other non-IT techniques.The Knowledge management ideas in the conceptual development was based on the informal knowledge in tacit order, and the need to move people from a departmental thinking in which they are least inclined to share information all the way up to an ideal where knowledge is shared intuitively. Figures 3.2 & 3.3 aid in the proper understanding of the underlying Knowledge management idea that precipitate to the model development.

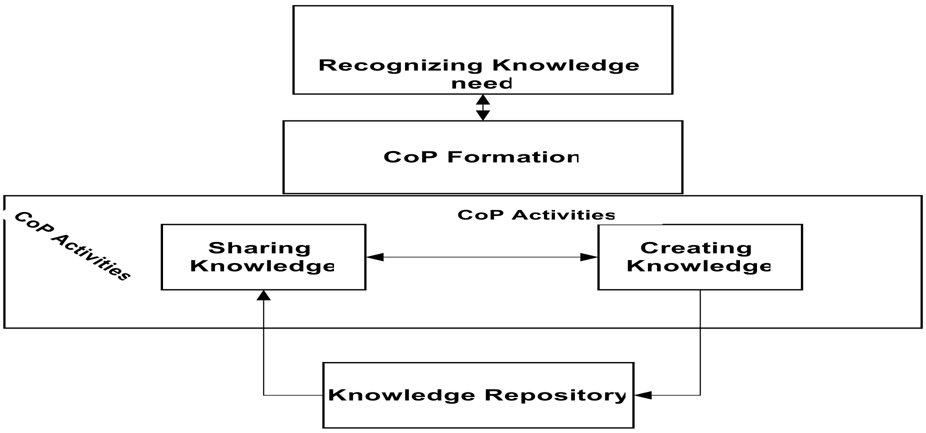


Fig. 3.2: Knowledge Management Process Model

The knowledge process model as described in Figure 3.2 how organizational knowledge are enriched as each member of the unified group of Cop becomes more knowledgeable on chosen projects through the knowledge dynamics processes in a Cop environment. The modeled processes are distinctively in three separate parts, knowledge need identification, knowledge creation/sharing and knowledge coordination. This organizational knowledge creation process is continuous and ideally creates a "knowledge spiral" as it moves from an individual to a group and to the organization which is the eventual goal through active documentations.

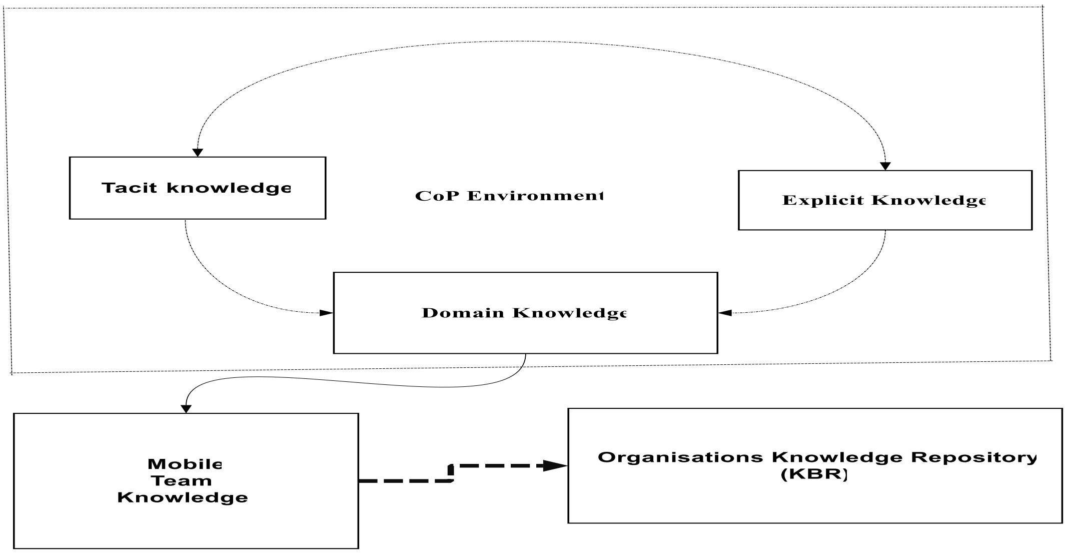


Figure 3.3: Knowledge dynamics in CoP environment.

The Cop interaction as described in Figure 3.3 would create knowledge spiral whereby tacit knowledge of member group involved in the improvement studies are made explicit. During the improvement studies, knowledge are created, shared and are often located within the cognitive domain of the members involved in the improvement function. Knowledge at this stage is seen as mobile team knowledge which is still transitory and can be lost due to a number of factors such as retrenchment, retirement etc. The mobile team knowledge order are transferred to organizational knowledge through proper documentation and update on the standard operating procedure (SOP) of the organization. On the other hand , Six Sigma DMAIC is a rigorous and systematic approach to improvement, capable of providing platform for knowledge creation across its phases and is an ideal improvement framework for incorporation of knowledge management techniques. However, attempts on the matching advantage of these two disciplines, Knowledge Management and Six Sigma-DMAIC, has been made in a number of fields but such integration has not been applied in cable manufacturing, where observational studies are much and knowledge of workforce is very vital in every improvement studies. The research examined how learning and knowledge can be facilitated in a Six Sigma projects by effectively implementing both perspectives, KM and

Six Sigma-DMAIC, in order to generate a higher level of knowledge such that a sustainable quality advantage would be sustained in cable manufacturing at the study object. The conceptualized approach was of a typical five phased DMAIC structure, with some adaptive modifications. In the proposed hybrid structure shown in figure 3.4 , Knowledge Management techniques were incorporated in the typical DMAIC framework to make the methodology more engaging and resourceful for improvement functions. The conceptual approach considered all these DMAIC phases in its implementation and in a chronological order.

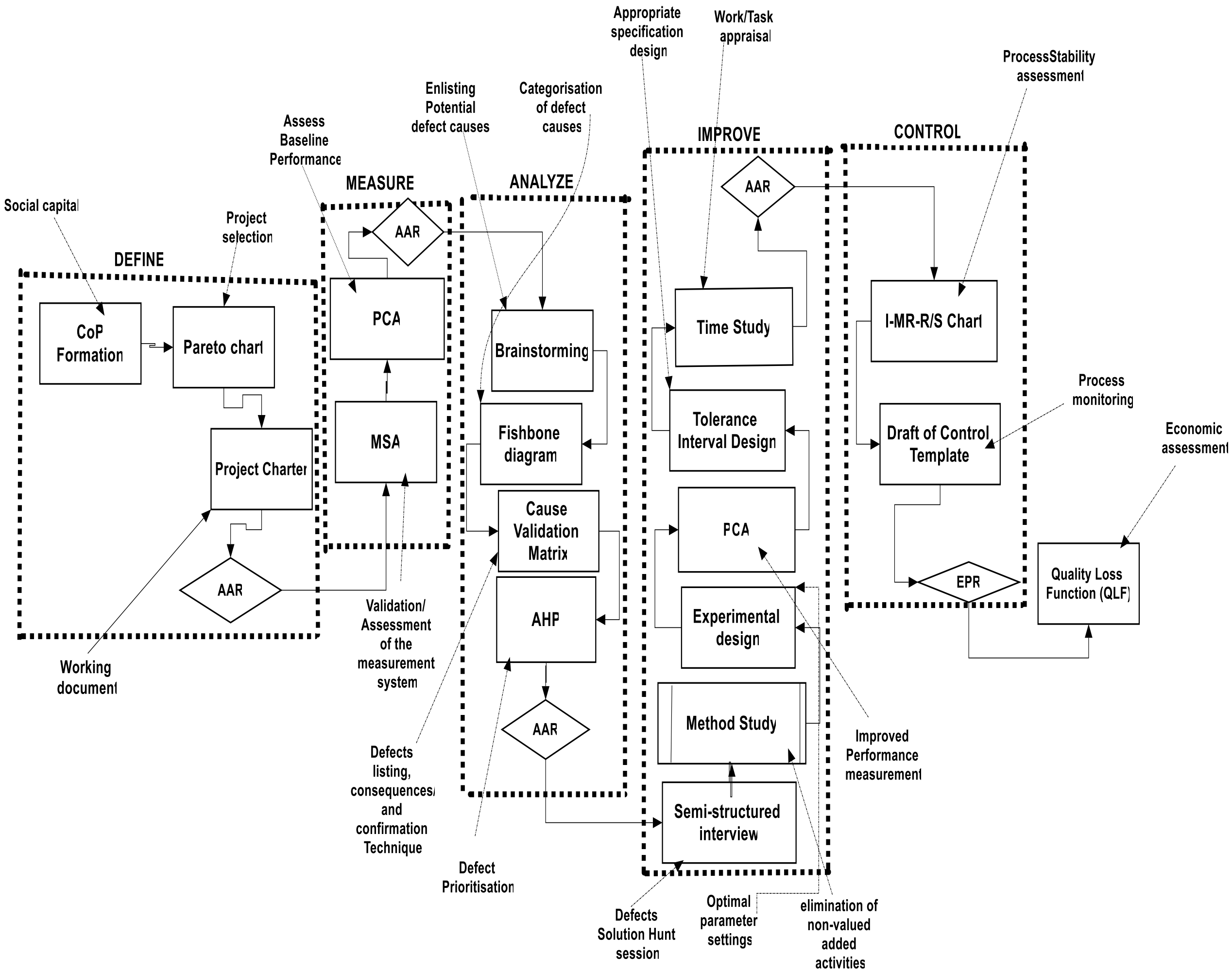


Figure 3..4. The Proposed conceptualized Improvement strategy.

The aim of each stage is briefly described as follows:

- Phase 1: Phase one was the "Define Phase" and the research aim at this phase was centered on the identification of real life problems. The Define phase of the Six Sigma-DMAIC provides the socialization environment, just like a reflection of the Nonaka SEIC model, where sharing experiences with other members aid in transfer of tacit knowledge. The idea of initiating the Cop in this phase was as a result of informal knowledge representation in tacit order and core knowledge creation takes place at the group level as the team engages in improvement studies. Important task and techniques were incorporated like the Project charter and After action review session. These two tools would provide the externalization experience as tacit knowledge were made explicit through writing down tacit knowledge
- Phase 2: This second phase, The Measure phase, was aimed at understanding the baseline performance of the system/process though the use of important tools and execution of tasks such as Measurement System Analysis (MSA), Process Capability Analysis (PCA) and eventual After action review (AAR). Three knowledge interactions are likely observed at this stage, socialization, Internalisation and externalization.
- Phase 3: This third phase, The Analyze phase, was aimed at investigating reasons for the identified problems. During this team participation, the individual members of the team made explicit their innate tacit potentials. Three knowledge creation modes socialization, externalization and internalisation were found in the third phase of DMAIC . Knowledge moved from tacit to tacit, tacit to explicit and from explicit to tacit. Some of the important tasks and tools incorporated at this phase included brainstorming, cause and effect diagram, Cause Validation matrix, Analytic Hierarchial Process (AHP) and eventual after action review (AAR).

- Phase 4: The fourth phase was the “Improve phase” and was aimed at setting up probable solutions to eliminate the identified problems. Some of the important techniques incorporated at this phase include, semi-structured interview, method study, experimental design, process capability studies, engineering tolerance design, time study and eventual after action review (AAR).
- Phase 5: The fifth phase, The Control phase, was to ensure that all the implemented solutions were maintained and controlled consistently. This phase is incorporated for systemizing knowledge created in the process into a knowledge system through the updating of the standard operating processure (SOP) of the system. Documented explicit knowledge of the Cop memebers were converted to organizational knowledge after the entire phase review. The prototypical of the envisaged knowledge management process is mapped in Figure 3.2, The improvement projects would provide the knowledge-based resources that it will benefit internal operations of the organization, outside the participants' cognitive domain.

3.1.1 Data collection

Most of the qualitative data used in this study come from interviews, and discussions with involved personnel. Quantitative data have also been collected mostly in the Define, Measure, Analyze and Improve phases of the DMAIC’s framework.

3.1.2 Software Packages used in this Study

The following software packages were used for data analysis in this study:

1. Minitab-17 Software was used for statistical analysis and graphical representation.
2. Free web based AHP Software by Goepel (2018) was used to prioritize the criticality of defects.
3. Design Expert-11 was used for the experimental design

4. MATLAB Software was used to develop the Knowledge-based support tool.

3.2 Validation Case Study

In this study we looked at variation and its causes, and how to improve and control a process using the synergetic support of Six Sigma-DMAIC and Knowledge Management concepts. The Integrated solution was validated in a cable manufacturing company "Cutix cable Plc." located in Umuannuka, Otollo Nnewi in Anambra State of Nigeria. Figure 3.5 is the flow diagram for the validation.

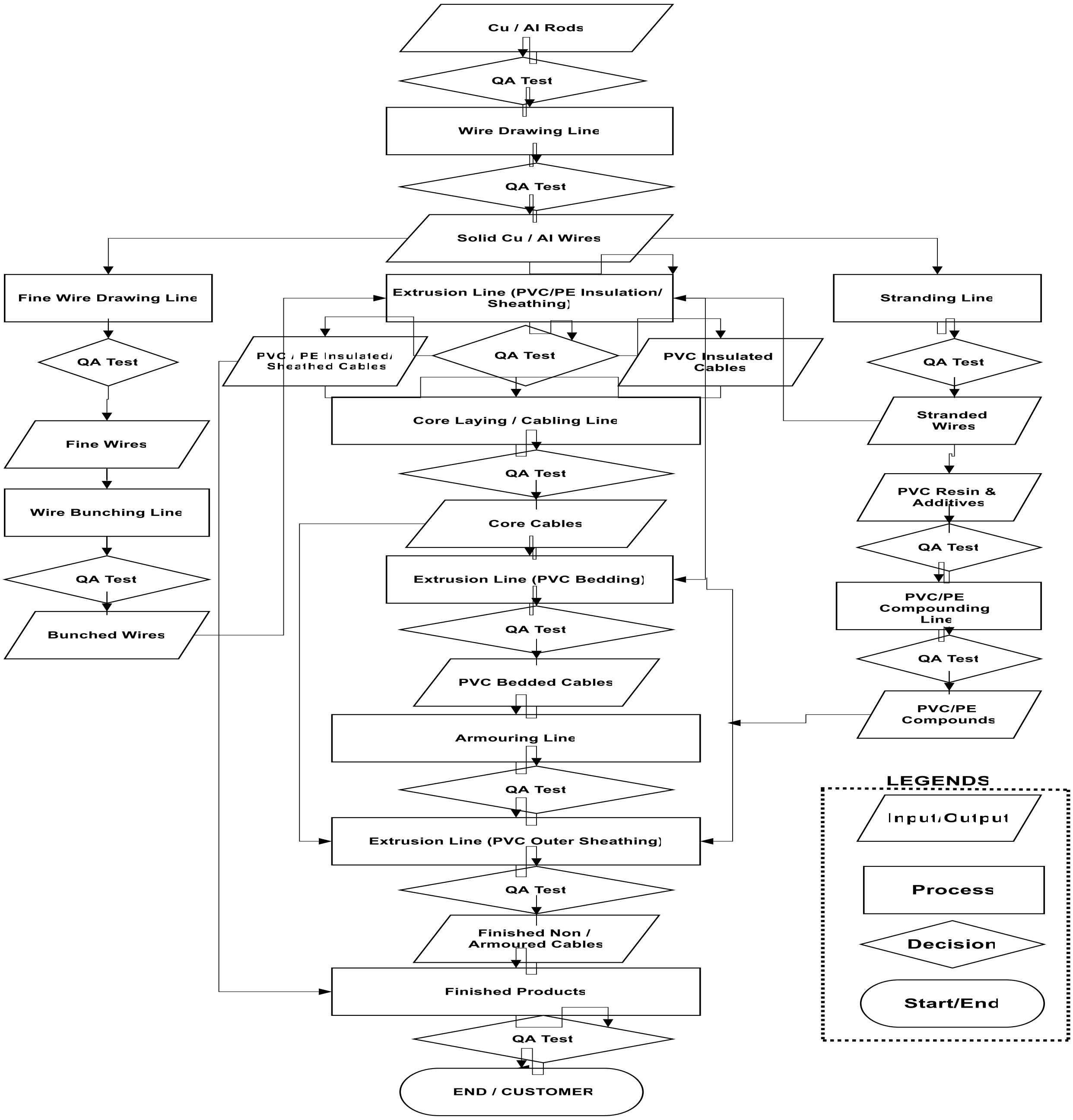


*Figure 3.5***.** Process Flow Diagram of Anuka Cable Production line of Cutix Cable Plc.

The company is mainly involved in the production of different types of cables. Anuka cable plant station is basically for the production of primary house wiring cables, while Power cable plants (PCP I & II) station are mainly for the production of 'Armored' cables and compounding of PVC materials used for insulation. The company has earned a good reputation in the whole of Africa for production of high quality cables, and their quality management system is ISO 9001 certified.

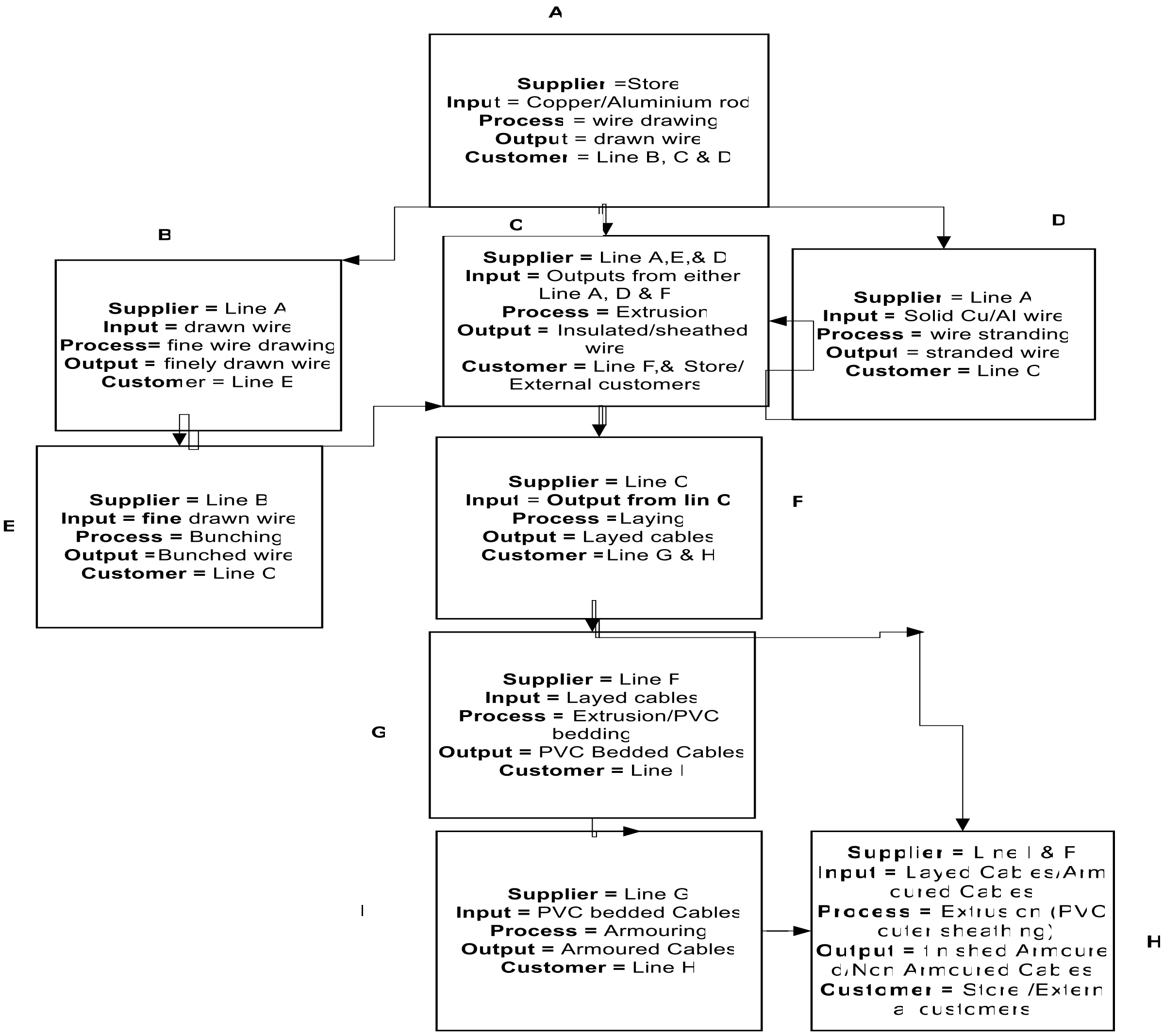


Figure 3.6. .SIPOC diagram of Anuka Cable Production line of Cutix Cable Plc

Supplier-Input-Process-Output-Customer (SIPOC) as shown in Figure 3.6 is drawn for more clarifications on the process elements and aids in troubleshooting and formulation of hypothesis that would be tested during the Analyze Phase.

3.2.1 Overview of Cable Extrusion System

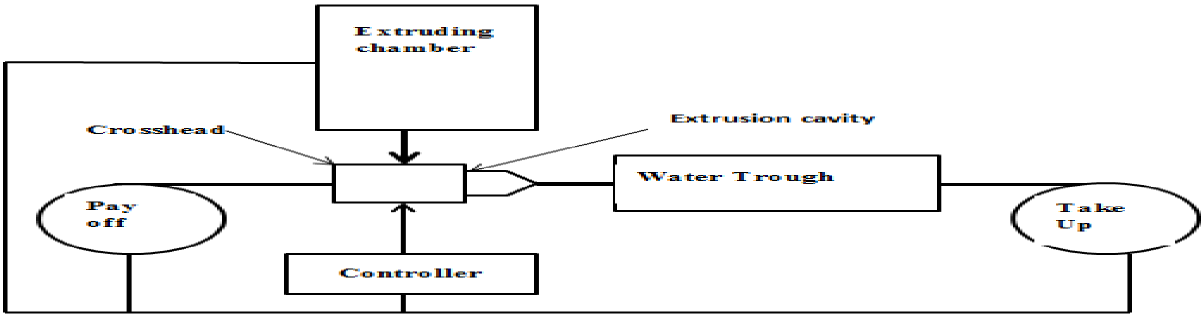


Figure 3.7. Wire extrusion system

An extrusion system includes a crosshead designed to receive and distribute material for extrusion and a die and tip defining an extrusion cavity in mechanical communication with the crosshead. The crosshead is designed to vibrate at an ultrasonic frequency and transfer vibration to the die and tip during wire. Payoff section is configured to hold and supply wire to the crosshead. The payoff is coupled to a rotating mechanism configured to facilitate unwind and supply wire from reels. A water trough designed to receive and cool coated wire; Take-up section designed to receive and store cooled cable.

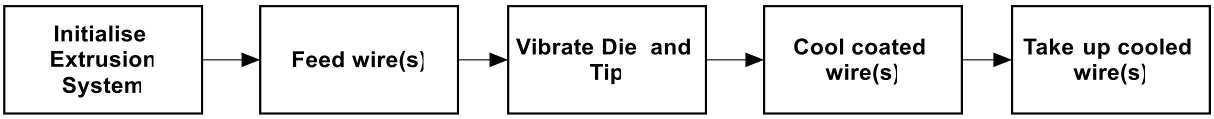


Figure.3.8: Flow chart of wire extrusion method

Experimental adjustments to the extrusion process may allow some reduction of some undesirable attributes under certain conditions but may lack repeatability of a desirable set of physical attributes, thus making it difficult to implement any experimental adjustments to real world manufacturing scenarios (Briskey, 2014).

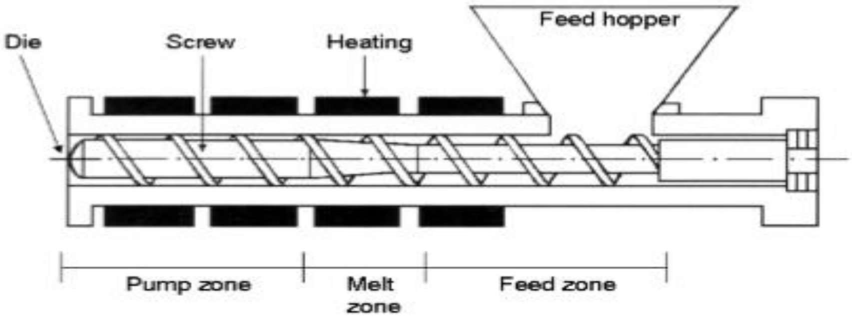


Figure 3.9. Components of Extruder chamber

The process of cable extrusion is a continuous transportation and transformation of poly vinyl chloride (**PVC**) pellets into a molten paste. A rotating screw does the transportation, where the pellets are fed into the extruder from a feed hopper. The extruder ends up in a die that applies the melt on to the copper wire. There are three zones in the extruder, feed zone, melting zone, and pump zone. In the feed zone, the **PVC** pellets are compressed between the barrel and the screw. The melting zone, also called the compression zone does most of the melting. Next zone, the pump zone, does the final transportation of the homogenous polymer material with constant temperature and pressure to the die. The research was conducted with the help of the initiated project team from the case company following the conceptualized DMAIC approach in executing the projects towards a logical solution of the problems.

3.3 The Define Phase

This phase of the DMAIC methodology aimed to define the goals and scope of the improvement projects in terms of customer requirements and to develop a process that delivers these requirements. The first step towards solving any problem in Six Sigma methodology is by formulating a team associated with the process. In this study, the team build-up session was formulated through series of meetings with departmental heads in the organization to help select individuals with recognized skills, passion and knowledge of the process. Afterwards, an introductory meeting was held with the selected members that made up the target group/ community to share ideas and need for establishing a learning community within the process cycle. The objective of the formulated team was to develop common skills on Six Sigma-DMAIC improvement strategies, as well as to harness knowledge and shared expertise among the participants. A moderator was appointed based on his knowledge about a wide range of topics that were discussed during the meetings. Member meetings were made flexible enough such that sometimes members meet every day during break hours to discuss selected projects and most times once every week. Mode of member interaction was through face-to-face interactions, mobile communication and electronic messages mainly through WhatSapp.

A project charter was developed by this team, containing all the necessary details of the project like the project objectives, project duration, resources available, project scope and boundaries, and also the expected results from the projects. In this phase, Graphical tool like Pareto chart was used also to prioritize the key projects. The end of each Six Sigma-DMAIC phase was concluded with a phase review session to assess the group's achievements towards the overall organizational goals. The extracted explicit knowledge from the Define phase after the action review session, were documented to the knowledge repository system for easy retrieval and cross-referencing.

3.4 The Measure Phase

The objective of the measure phase was to understand and establish the baseline performance of the process in terms of process capability and also to quantify the measurement error on the total variation of a unit operation. The Measurement System Analysis (MSA) was conducted in the measure phase of a Six Sigma-DMAIC project (attribute and gage repeatability and reproducibility (Gage R & R) study) to validate the measurement system. The critical-to-quality (CTQ) measurements considered in the case organization are the cable insulation smoothness, and uniformity of cable diameter, excluding cable concentricity due to measurement difficulties. The critical to quality characteristics considered in the MSA are shown in Table 3.1.

Table 3.1: ***Critical to Quality Characteristics Considered in the MSA***

S/N	Critical to Quality Characteristics	Data type	Instrument for Inspection
1	Insulation Surface Flaws	Attribute data	Visual Inspection
2	Core Cable diameter	Variable data	Profile enlarger

3.4.1 Materials and Equipment for Measuring the Cable Diameter and Thickness

1. Insulating outer wall thickness projector cable tester (Profile Enlarger): This equipment enlarges the sample test and projects it in x, y, z plane. It gives the insulation thickness measurements starting from the inner to outer thickness of a core sample.
2. Digital Caliper: This instrument is used for a wide range of measurements. It can be used to measure outside dimension, inside dimension, and depths. Digital calipers are much easier to read than the dial calipers.
3. Micrometer screw gauge: Micrometer screw gauge is a handheld gauge used in the study to measure the diameter of the copper conductor used for extrusion.
4. Insulation Cutter: This is a handheld cutting tool used to cut the cable so that the conductor can easily be detached from the cable.
5. Paper Tape: This is used to label the collected sample, as numerical inscription is inscribed on the entire sample collected for easy identification.
6. Cellophane Bag: This is used to house the samples obtained for easy identification and reuse.
7. Marker: This is used to mark numbers on the paper tape for ease of identification.

8. Razor Blade: This is used to cut the insulation materials into sample slice to be measured.

3.4.2. Attribute Gage Measurements Study and Collection of Data

Attribute MSA was set up as an experiment to assess the agreement of nominal or ordinary ratings by multiple appraisers. An experiment was designed to determine the number of samples, operators and trials to be used for the study. Ordinarily, larger numbers of parts and repeat readings give results with a higher confidence level, but the numbers has to be balanced against the time, and cost. From the study design, ten (**10**) samples were used with three (**3**) operators for two (**2**) replicates. The cable samples that were used for the attribute testing was gotten from different extrusion lines, since they only had to undergo visual inspection, and they were also not size-bound. The samples were of ratio 50:50 mix of good/bad (defective) parts. Each of the three operators randomly inspects each of the ten samples twice and records of the results were taken by a member of the team. With the same sample set, similar test was conducted with the most experienced quality personnel and outcome of her assessment was used as a reference value in the attribute measurement. In this attribute measurement, intra-inspector agreement measures repeatability (within inspector) while inter inspector agreement measures the combination of repeatability and reproducibility (**between inspectors**). The non-chance agreement between the three inspectors, denoted by Kappa was computed, using the formula:

$$K = \frac{Po-Pe}{1-Pe} \tag{3.1}$$

$$Po = \frac{1}{Nn(n-1)}\left(\sum_{i=1}^{N}\sum_{j=1}^{k} n_{ij}^2 - Nn\right) \tag{3.2}$$

$$Pe = \sum_{j=1}^{k} p_j^2 \tag{3.3}$$

where, Po = number of observed agreements, Pe = number of expected agreements, 1= total number of observations, P^2_j = the expected proportion agreement for each category, N = the number of subjects, n = the number of raters, K = the number of categories of the scale, X_{ij} = the number of raters who assigned the i^{th} subject to the j^{th} category.

3.4.3. **Gage Repeatability and Reproducibility (R & R)**

Crossed gage R & R study compares measurement system variation to total process variation or tolerance. With crossed gage R & R study, one can ascertain how much of the variability in the measured diameter of a cable is caused by the equipment/measurement device or how much of the variability in the measured diameter of a cable is caused by the operator. In other words, Gage R & R study (**Crossed**) are used to assess how well the measuring system can distinguish between parts, and also assess whether the operators measured consistently.

Measurement system variation consists of;

1. Repeatability: This is variation due to the measuring device or the variation observed when the same operator measures the same part repeatedly with the same device.
2. Reproducibility: Basically, this variation is as a result of measurement system errors, and are noticed when a particular part is being measured by different operators using same equipment.

3.4.4. Sample Selection in Gage Repeatability and Reproducibility (R & R) Study

The number of operator/appraisers used in the study is three and the number of samples used is five (5) while the number of replicates is three. This design selection is according to Automotive Industry Action Group (AIAG) recommendations as described in the 4th edition manual. The cable samples used for variable studies were gotten from the extrusion lines while the sample sizes were all 1.0mm single core cables. These samples were all randomly gotten at the coiling section during cable coiling process. Mathematically, the total variance in a quality characteristic of a process is described by Eqns. (3.4) & (3.5), while the percentage contribution of the measurement system to the total variance is calculated using Eqn. (3.7) and other useful Gage R & R metrics used in the study are also represented mathematically.

$$\sigma^2_{total} = \sigma^2_{product} + \sigma^2_{measurement} \tag{3.4}$$

$$\sigma^2_{measurement} = \sigma^2_{Repeatability} + \sigma^2_{Reproducibility} \tag{3.5}$$

where; σ^2_{total} = total variance; $\sigma^2_{product}$ = variance due to product; $\sigma^2_{measurement}$ = variance due to measurement system; $\sigma^2_{Repeatability}$ = variance within operator/device; $\sigma^2_{Reproducibility}$ = variance between operators.

$$\sigma^2_{Reproducibility} = \sigma^2_{Operator} + \sigma^2_{Part*Operator} \tag{3.6}$$

$$\text{\% contribution} = \frac{\sigma^2 \text{ Repeatability} + \sigma^2 \text{ Reproducibility}}{\sigma^2 Total} \text{ x } 100 \tag{3.7}$$

$$\text{\% Study variation} = \frac{\sigma\ measurement}{\sigma\ total} \text{ X } 100 \tag{3.8}$$

$$\sigma t = \sqrt{\sigma^2_m + \sigma^2_P} \tag{3.9}$$

$$\sigma p = \frac{R_p}{d_2*} \tag{3.10}$$

$$\text{Two-sided Spec \% P/T} = \frac{6\sigma\ measurement}{USL-LSL} \text{ X } 100 \tag{3.11}$$

$$\text{NDC} = 1.41\left[\frac{PV}{\sigma^2 \text{ Repeatability} + \sigma^2 \text{ Reproducibility}}\right] \tag{3.12}$$

where; σt = total process standard deviation; σ_P = part-to-part standard deviation; PV = part-to-part variation; NDC = the number of distinct data categories that can be created with this measurement.

$$\text{UCL} = D_4\bar{R} \tag{3.13}$$

$$\text{LCL} = \bar{\bar{X}} - A_2\bar{R} \tag{3.14}$$

$$\text{UCL} = \bar{\bar{X}} + A_2\bar{R} \tag{3.15}$$

where $\mathbf{A_2}$, $\mathbf{D_3}$, and $\mathbf{D_4}$ are factors obtained from tables of constants used in constructing control charts.

Table 3.2: ***Measurement System Analysis Design***

S/N	Sample * Operator	Trials
1	S*O ≥15	3
2	8≤ S*O < 15	4
3	5 ≤ S*O < 8	5
4	S*O < 5	6

3.4.5 Process Capability Studies

Process capability refers to the evaluation of how well a process meets specifications or the ability of the process to produce parts that conform to engineering specifications. The basic capability indices commonly used in manufacturing industries are Cp, Cpk, Cpm, CR, ZU, and ZL. These indices help to change the focus from only meeting requirements to a continuous improvement of the process. However, before evaluating the process capability of any process according to Wooluru, *et al,* (2014), the process must be under statistical control. Average charts (X-bar) and range charts (R- chart) are commonly used to investigate when a process is under statistical control. These aforementioned indices were evaluated in the present study before the improvement process and after the improvement processes. The flow chart of Process capability studies is shown in Fig. 3.8.

3.4.6. Sample Size Selection

Choosing an appropriate sample size is crucial to have a study that will provide statistical results significantly. The stability of estimates of the standard deviation increases with sample size (**n**), and sample size of five (**5**) provides a very stable estimate of process capability (Bangphan, Bangphan, & Bookang, 2014).

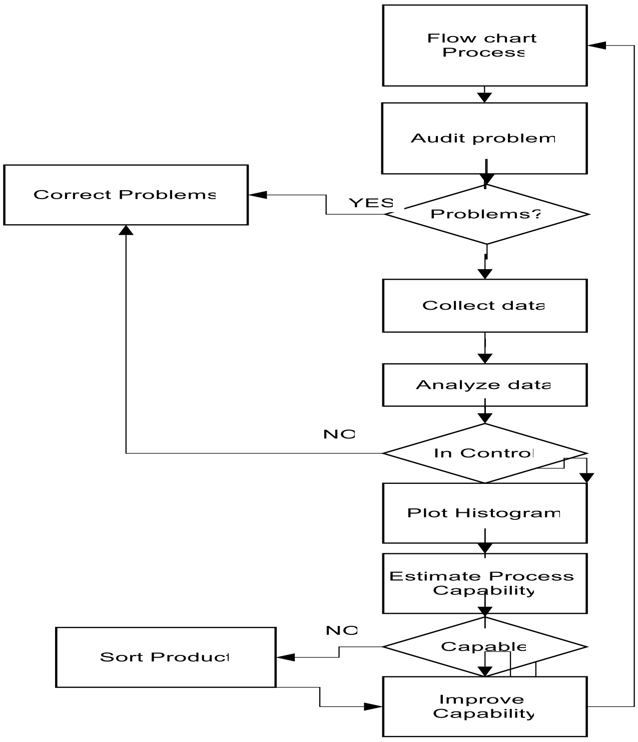


Figure 3.10. Flow chart of Process Capability Analysis (Source: Pyzdek, 2003)

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 were classified into 20 subgroups of five observations and were randomly collected at the coiling section. The collections of the samples were spaced out within each subgroup over time, in recognition of the fact that the number of sources of variation increases as the time interval between samples within a subgroup increases. Spreading out the samples within a subgroup over time increase $\overline{R}$, widening the control limits, and thus makes achieving statistical control more likely (Kane 1989). The samples were accordingly labeled in order of collection. The samples were taken to Quality Assurance Department (QAD) laboratories where the samples were cut in slices for measurements. With the aid of the Cable cutter, the samples insulation surfaces were cut-open to detach the insulation from the conductor. With the use of sharp razor blade, a slice concentric dimension of the insulator was made from each of the insulation sample lengths. Each of these slice parts was marked at opposing sides with the use of marker pen for ease identification of measurement points. Each of the sliced samples is placed on the glass plate of the Insulating outer wall thickness projector cable tester commonly referred in the case organization as “Profile Enlarger”. With this equipment, insulation thickness measurement of four points was taken on the sliced samples. The readings for the cable diameter measurements and insulation thickness measurements were concurrently taken. The readings were all in “mm” and were recorded accordingly. With the measured data, process capability studies were conducted based on the values gotten from the sample measurements. Mathematical computations of common indices used in the process capability studies are as follows:

3.4.6.1. **Process Standard Deviation ($\hat{\sigma}$)**

$$\hat{\sigma} = \frac{\bar{R}}{d2} \tag{3.16}$$

where d2 is the factor obtained from tables of constant used in constructing control charts.

3.4.6.2. **Process Capability (Cp)**

This index is also called potential index or process capability ratio, and is two-sided PCI for two-sided specifications having both lower and upper specification limits. Cp is frequently used in an industrial environment in order to express process capability in a simple quantitative way. When the parameters are known, i.e. when the process standard deviation is known, Cp is computed as follows:

$$Cp = \frac{USL-LSL}{6\sigma} \tag{3.17}$$

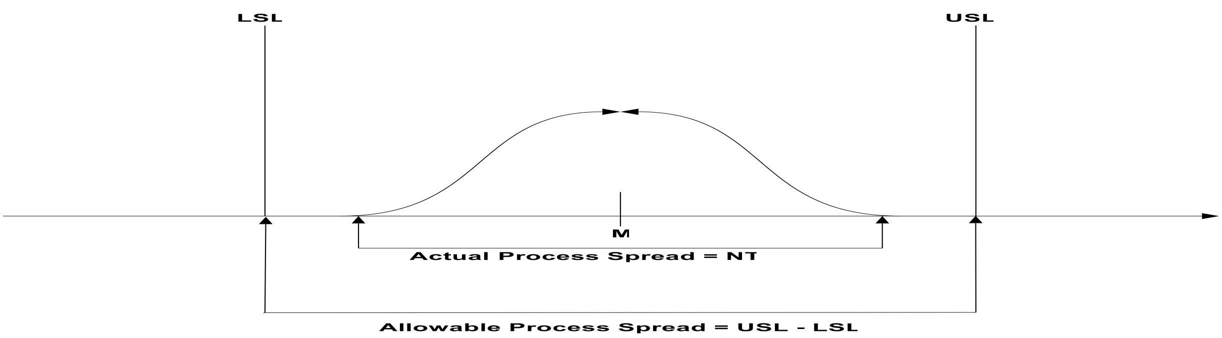


Figure 3.11. Relationship of Cp parameters

Where LSL and USL are lower and upper specification limits, NT = natural tolerance. In practice, it is often impossible to know parameters, therefore it is suitable to use sample standard deviation 's' to estimate process standard deviation σ. Thus, when the parameters are unknown, i.e. when process standard deviation σ is unknown, by replacing sample standard deviations to estimate process standard deviation σ, the formula used for estimating Cp is given below as:

$$\widehat{Cp} = \frac{USL - LSL}{6s} \qquad (3.18)$$

3.4.6.3 Process Capability Index (Cpk)

This index is defined as the position of the total process variation (**σ**) in relation to the specification mean. The Cpk associated with a process or a group of items is either the value for Cpu or Cpl. Cpu is the position of the total process variation (**σ**) in relation to the upper specification limit, while Cpl is the position of the total process variation in relation to the lower specification limit. When the parameters are known, that is when process mean μ and the process standard deviation σ are known, Cpk is computed as follows:

$$\text{Cpk} = \frac{1}{3\sigma} min[USL - \mu, \mu - LSL] = \min[Cpu, Cpl] \qquad (3.19)$$

In practice, it is often impossible to know parameters, generally it is suitable to use sample mean **s** to estimate process mean $\boldsymbol{\mu}$ and sample standard deviation S to estimate process standard deviation σ. When the process mean $\boldsymbol{\mu}$ and process standard deviation σ are unknown, by replacing sample mean x and sample standard deviation s to estimate process mean $\boldsymbol{\mu}$ and process standard deviation σ, the formula for estimating Cpk is computed as follows:

$$\widehat{Cpk} = \frac{1}{3s}\min[USL - \mu,\ \mu - LSL] = min[Cpu, Cpl] \qquad (3.20)$$

$\widehat{Cpk}$= Cp (1-k) (3.21)

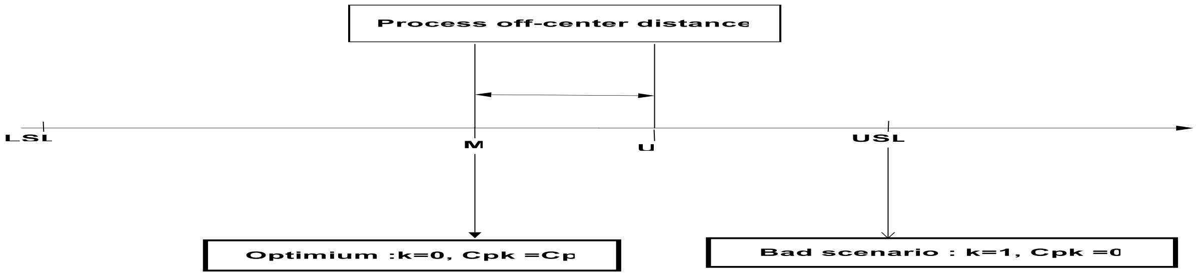


Figure 3.12. Relationship of Cpk parameters, (Adapted from Kane, 1989)

Where k = is an index that explains the amount the process mean is off-center (bias factor) and computed as follows:

$$K = \frac{|m-\mu|}{\frac{USL-LSL}{2}} \quad (3.22)$$

$$C_{pk}= \frac{ZMIN}{3} \quad (3.23)$$

Montgomery (2009) examined several cases, which can explain the relationship between Cp and Cpk, as follow:

1. When Cp = Cpk, the process is centered at the midpoint of the specification limits. The process capability related to use of target values is shown in Fig. 3.11.

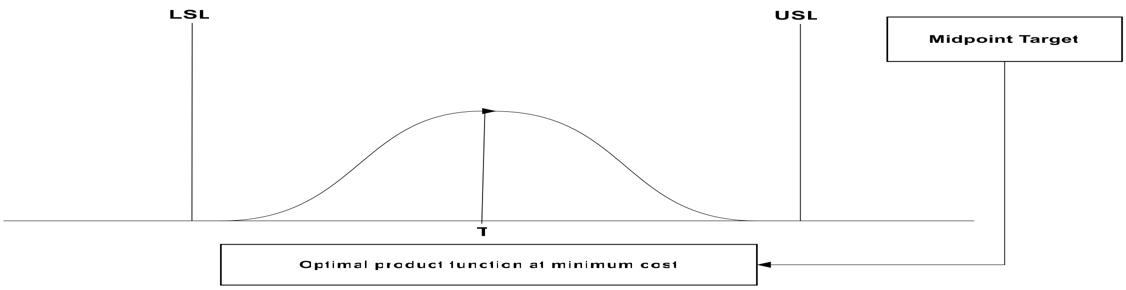


Figure 3.13. Process capability related to use of target values

2. When Cpk<Cp, then the process is off-centered. The off- centered process is shown in Fig. 3. 12.

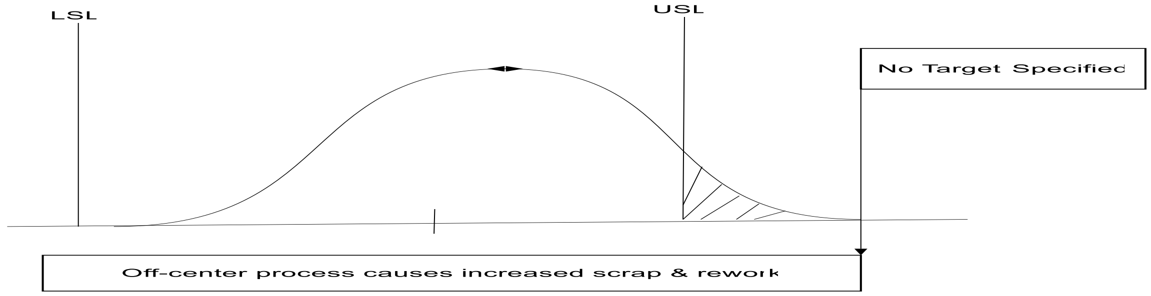


Figure 3.14. Off-centered process

3. When Cp<0, then the process mean lies outside the specification limits.
4. When Cpk = 0, then the process mean is exactly equal to one of the specification limits.

3.4.6.4 Process Capability Index (Cpm)

This index is referred to as Taguchi Index, and is defined as the ability of the process to be clustered around the target or nominal value. Cpm index is useful in process centering, and when the parameters are known, Cpm index is computed as follows:

$$\text{Cpm}= \frac{USL-LSL}{6t} \qquad (3.24)$$

The target value T, is known to be the midpoint of the specification interval

$$\text{T}= {}^{1}\!/_{2}\, [LSL + USL] \qquad (3.25)$$

The formula for process variation around desired process target is given below:

$$\tau^2 = \text{E}[X - T]\; E[X - \mu]^2 + [\mu - T]^2 = \boldsymbol{\sigma}^2 + [\mu - T]^2 \qquad (3.26)$$

Computation of Cpm can also be done the following way:

$$\text{Cpm} = \frac{USL-LSL}{\sqrt[6]{\sigma 2+[\mu-T]}} = \frac{Cp}{\sqrt{1+\left[\frac{\mu-T}{\sigma}\right]2}} \qquad (3.27)$$

3.4.6.5 Capability Ratio (CR) Index

This index simply makes a direct comparison of the process to the engineering requirement, and is computed with the formula

$$\text{CR}= 100 \text{ X } \frac{6\hat{\sigma}}{Engineering\ tolerance} \qquad (3.28)$$

3.4.6.6 The ZU Index

This index measures the process location (central) relative to its standard deviation and the upper requirement. If the distribution is normal, the value of ZU can be used to determine the percentage above the upper requirement by using standard table for area under the standard normal curve. ZU is computed with the formula

$$ZU = \frac{Upper\ specification - \bar{\bar{X}}}{\hat{\sigma}} \tag{3.29}$$

3.4.6.7 The ZL Index

This index, measures the process location (central) relative to its standard deviation and the upper requirement. For a normal distribution, the value of ZL will as well be used to determine the percentage above the lower requirement by using standard table for area under the standard normal curve. ZL is computed with the formula

$$ZL = \frac{\bar{\bar{X}} - Lower\ specification}{\hat{\sigma}} \tag{3.30}$$

In this phase, like the **Define phase**, after completing the “After Action Review” session, the extracted explicit knowledge from the “Measure Phase” are launched to the knowledge base system.

3.4.6.8 Precautions

The following precautions were observed:

1. We ensured that the personnel used for the measurement system analysis (MSA) do not compare notes.
2. The digital calipers used were always set at zero reading before taking measurements.
3. The caliper jaws were placed in a parallel position to the length of the cable during experimental measurements.
4. Only well-sliced samples were used during measurement of Insulation thickness.

5. The battery conditions of the digital calipers used were regularly checked before measurements were taken.
6. The measurement accuracy of the digital calipers used for the study was always checked at the start of the experiment to ensure they give accurate readings.

3.5. The Analyze Phase

At the analyze Phase, a brainstorming session was conducted with the CoP to identify and analyze the potential causes of these defects. The brainstorming results was arranged in rational categories and, Fish Bone or Cause and Effect Diagram that accurately displays the relationships of all the data in each category was prepared at the course of the session. To analyze the decision of eliminating defects in extrusion of primary cable, a judgmental model, known as the Analytical Hierarchy Process (AHP) was applied to prioritize the criticality of the different causes of these defects in the extrusion process. Based on the CoP's interaction, a cause validation plan was prepared detailing the type of data to be collected and the type of analysis possible for each of these causes. An overview on the improvement approach, tools and order of deployment at this phase is described as follows, starting with:

3.5.1 Brainstorming and Creation of Fish Bone (Cause-and-Effect) Diagram

Brainstorming is a method for generating ideas to solve a design problem. It usually involves a group under the direction of a facilitator. It involves harnessing synergy through collective thinking towards a variety of potential solutions. Brainstorming offers the advantage of the full experience and creativity of all the team members. Since the Community of Practice (CoP) was of heterogeneous-mix, their cross-section of experience would make the session more creative. Through brain writing, many ideas were generated in a very short amount of time. In this brainstorming approach, CoP members were empowered to suggest solutions that they, otherwise, might have thought were too unusual or would not be well received. Thus, the brainstorming approach created more freedom among the participants to be truly creative. After the brainstorming session, a fishbone diagram which is a visualization tool was used to categorize the potential causes. This fishbone diagram is particularly useful in a brainstorming session and for situations in which little quantitative data was available for analysis. After the fishbone diagram, a cause validation template was created to aid gather possible data on defect causes.

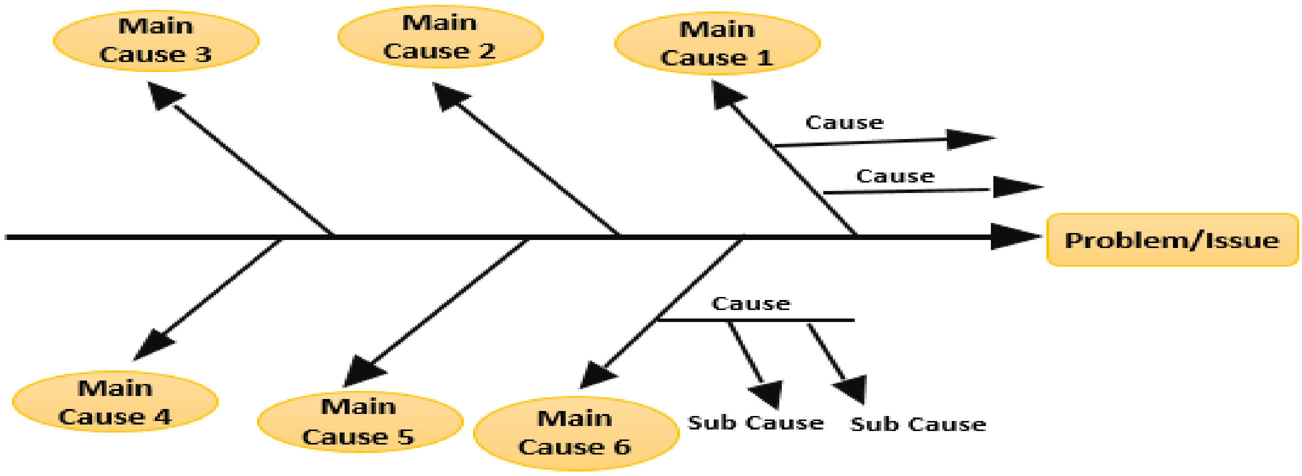


Figure. 3.15: Fishbone Diagram (https://www.wallstreetmojo.com/fishbone-diagram/)

3.5.2 Cause Validation Matrix

This template is in a tabular format, consisting of three sections, causes; error description/ associated quality implications, and then the confirmation section. At the cause(**s**) section, all the defect causes were all listed and were described in detail based on the group understanding and experiences.

3.5.3 The Analytic Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is one of well-known techniques in Multiple Criteria Decision Making (MCDM). In this approach, a model was built to represent hierarchy of levels with respect to objectives, criteria, defect categories, defect details, etc. The Analytic Hierarchy Process (AHP), introduced by Saaty (1980), is an effective tool for dealing with complex decision making and aids the decision maker to set priorities and make the best decision. AHP considers a set of evaluation criteria and a set of alternative options among which the best decision is made. The AHP generates a weight for each evaluation criterion according to the decision maker's pairwise comparisons of the criteria. The higher the weight, the more important is the corresponding criterion. The procedures for using the AHP are summarized in Appendix F.

3.6 The Improve Phase

The first responsibility at this phase is to explore solutions for all of the identified defect causes. Solution exploration mechanism that was followed is based on qualitative method of investigation, which allowed unlimited expression from the respondents. An open-ended question format was designed and administered to the member group and some of the experienced workers in the organization were interviewed to elicit wider information based on practical knowledge of the processes considering the history of the chosen projects. After the solution harvesting session, the next act which goes as a sub process to prior action of solution hunts was to remove non-value added activities through "Method Study".

3.6.1 Method Study

Method study was conducted to eliminate non-value added activities and examine human work, basically extrusion process in all its contexts. Its systematic approach of investigation has led to the identification of key factors that affects the efficiency and the economy of the extrusion activities. The mnemonic SREDIM which is a common-sense heuristic that followed a six stage procedure was employed in the method study and are as follow:

1. SELECT work to be studied and define its boundaries.
2. RECORD the relevant facts about the job by direct observation and collect additional data as may be needed from appropriate sources.
3. EXAMINE the way the job is being performed and challenge its purpose, place sequence and method of performance.

4. DEVELOP the most practical, economic and effective method, drawing on the contributions of those concerned.
5. INSTALL the new method as a standard practice and train the persons involved in applying it.
6. MAINTAIN the new method and introduce control procedures to prevent a drifting back to the previous method of work.

Right after the method study, when all the non-value added activities are eliminated and improved method has been established. The next research action is to design experimentally for optimal control settings.

3.6.1. Design of Experiment (DOE)

Taguchi method was first deployed in this study to create a fractional design of the experiment considering time, cost, and mathematical simplicity over a full factorial design that will require a large number of extrusion experiments to be performed and analyzed which will be very costly in terms of time and materials. The assumption for design of experiment is that there is no interaction between any two factors for orthogonal array and this is due to the reduced number of experiments. The guidelines for designing experiments are as follows:

1. Recognition and statement of the problem
2. Choice of factors and levels
3. Selection of the response variable
4. Choice of experimental design
5. Performing the experiment
6. Data analysis
7. Conclusion and recommendations

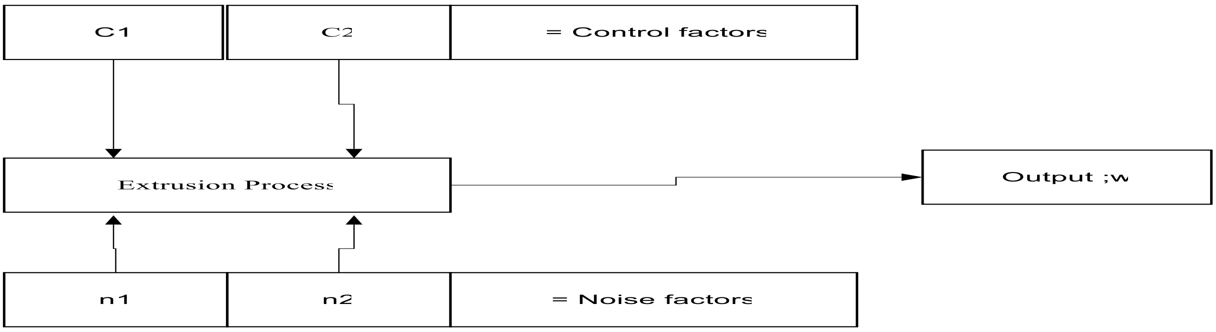


Figure 3.16. General model of the process (Adapted from D.C Montgomery, 1991)

Generally, the process to be optimized should have several control factors which directly decide the target or desired value of the output. The optimization then involves determining the best levels of the control factors so that the output is at the target value, and such is referred to as "static problem". The primary aim of the Taguchi experiments is to minimize the variations in output even though noise is present in the process. From figure 3.15, the process parameters c1, and c2, are controllable, whereas n1 and n2 are uncontrollable and commonly known as the noise factor. The term W refers to the output variable. The objectives of the experiment are stated as

1. Ascertaining and establishing the controllable factors that affect the output response, w.
2. Determining where to set the dominant control factors so that the output is at or close to the nominal value.
3. Determining where to set the influential c's so that variability in w is small.
4. Determining where to set the influential c's so that the effects of the noise factors n1 and n2 are minimized.

3.6.2. Counting Degree of Freedom (df)

The number of factors to study is two, each at four different levels. The degree of freedom (df) rule would be followed in other to determine the number of experimental runs required. The Degree of Freedom (df) rules are as follows:

1. The overall mean always uses 1 degree of freedom.

2. For each factor, C, D…., if the number of levels is n_c, n_d... for each factor, the degree of freedom equals the number of levels minus 1.Degree of freedom for factor C = n_c-1, and for factor D, degree of freedom = n_d-1.
3. For two factor interaction, for example CD interaction, the degree of freedom = (n_c-1) (n_d-1).
4. Sum all the degrees of freedom to determine the required number of experimental runs.

Taguchi Orthogonal array design was selected for the study after counting the degree of freedom. The signal-to- noise (**S/N**) considered in this study is nominal-is-best, and is calculated for each factor level combination. This S/N ratio assumes that the given target is best and is appropriate when there is a target value with both upper and lower tolerance limits. The goal of an experiment for nominal-value-is-best situations is to reduce variability around a specific target. It is worthy to note also that when the variability of the response is reduced relative to the average response, S/N_N will increase. According to Kong (1996), there are three steps in the Taguchi analysis:

1. Find the factors that affect the signal-to-noise ratio and set the levels of these factors to satisfy our objective.
2. find the factors that affect the average response and set the levels of these factors toward to the target value, and
3. Find the factors and set their levels to best satisfy both step1 and step 2 and other practical issues.

In other words, collected data was actually analyzed twice; first to analyze the effect of standard signal-to-noise ratio, and next was to ascertain the effect of average response. The formula for nominal is-best signal-to- noise ratio using base 10log is computed as follows:

$$S/N_N = 10*\log((Y^2) / s^2) \quad (3.31)$$

$$\text{Loss} = k\,[s^2 + (\bar{x} - n)^2] \tag{3.32}$$

$$\text{Mean response } (\bar{x}) = \frac{1}{n}\sum_{i=1}^{n} xi \tag{3.33}$$

$$\text{Standard deviation (s)} = \sqrt{\sum_{i=1}^{n}\frac{(x-\bar{x})^2}{n-1}} \tag{3.34}$$

Where; k is a constant, $\bar{x}$ and s^2 are the mean and variance of the measurements of quality characteristics respectively, and n is the nominal value of the process.

3.6.3 Collection of Data

The digital calipers were used to take cable diameter measurements during the experiment. For each of the parameter settings, the extruding machine was allowed to run a maximum of two-three minute, after which the machine is halted and measurements were taken at different points in the cable lengths, and the average of the readings was taken. These procedures were repeated severally for all the parameter settings for the number of experimental runs. All the readings were recorded. Although the Taguchi method can be used to determine an optimum from the preset factor level, such values are not necessarily the global optimum (Su and Chou, 2008). For this reason, a parameter optimization study such as Response Surface Design technique was employed to determine the global optimum.

3.6.4 **Response Surface Methodology** (RSM)

In most RSM problems, the form of the relationship between the response and the independent variables is unknown. Thus, the first step in RSM is to find a suitable approximation for the true relationship between y and the independent variables. Usually, a low-order polynomial in some region of the independent variables is employed. If the response is well modeled by a linear function of the independent variables, then the approximating function is the first-order model. In other words, RSM tends to focus on the relationships between multiple factors (x_1, x_2, x_3, x_4 …x_k) and the response (quality) y. consequently, the functional relationship between the responses and the independent variables should first be determined to produce a proper approximating function, and then the factor setting levels (x_i) needed to obtain the optimal response is identified. The relationship between the response variables and the independent variables (factors) can be represented as;

$$Y = f\left(x_1, x_2, x_3, x_4 \cdots x_n\right) \tag{3.35}$$

where f is a multivariate function, the items represent the factors (independent variables), and the relationship describes a curved surface y = $f\left(x_1, x_2, x_3, x_4 \cdots x_n\right)$ that is known as a response surface.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon \tag{3.36}$$

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \varepsilon \tag{3.37}$$

Equation (3.51) and (3.52) are first-Order and Second-Order Response Surfaces respectively. Generally, Response Surface Methodology utilizes First-Order and Second-Order models. The second-Order model is used in cases when the First-Order model is not suitable (Montgomery, 2009). When selecting fitting experiments requiring Second-Order RSM, Central Composite Design (CCD) experiments are normally performed, because Second-Order fitting with CCD provides favorable predictions, and the fitting model shows consistent and stable variance for the prediction of any input point (Yung-Tsan et al, 2014). In the beginning of the solving procedure, a starting point is selected as the experimental center for the CCD factorial fitting experiments. Regression Analysis was applied to the experimental results to find a suitable model. A desirability function is further applied to acquire the optimal processing parameter composition and operating window. In this study, design expert (version 11) was used as optimization software. The steps that was followed for the Central Composite Design (CCD) are presented in Fig. 3.17

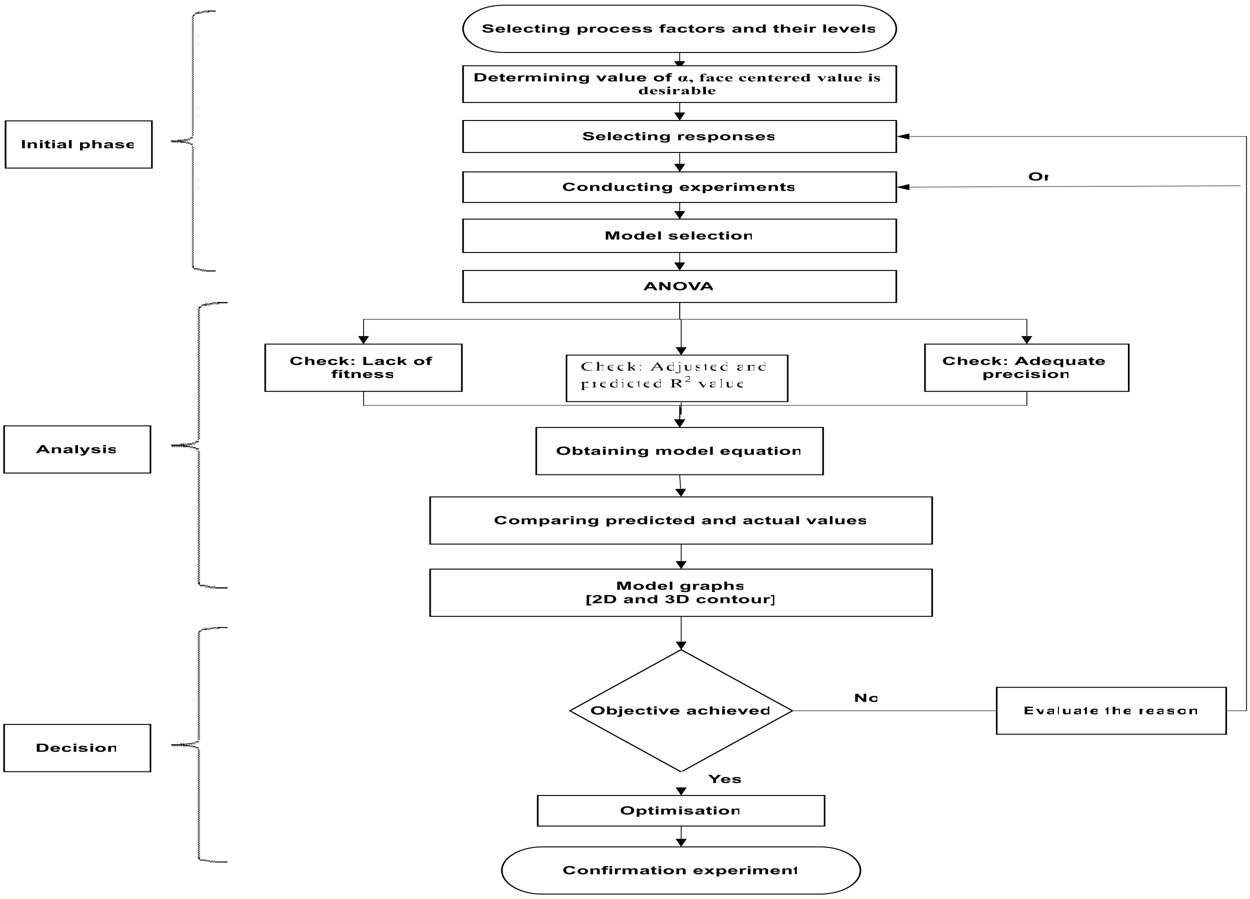


Figure 3.17. Central Composite Design flow diagram (adapted from Asghar, et al., 2014)

Next step after the experimental design was to conduct a capability studies to ascertain the level of improvement attained at the end of the experimental design. In cases where the Sigma level cannot be gotten, a new engineering tolerance would be designed around the nominal settings identified by parameter design to clearly capture a Six Sigma process.

3.7 Tolerance Interval Design

Tolerance design is a method for determining tolerances that minimise the sum of product manufacturing and lifetime costs. It is still a common practice in industry to assign tolerances by convention rather than scientifically. Tolerances that are too wide increase performance variation and the lifetime cost of the product, and tolerances that are narrow increase manufacturing costs. In Six Sigma, the tolerance intervals according to Pyzdek (2003) are typically of the form:

$$\overline{X} \pm Ks \tag{3.38}$$

$$s = \sqrt{\frac{\sum(x - \overline{x})^2}{N - 1}} \tag{3.39}$$

where K is a constant, and is determined so that the interval will cover a proportion P of the population with confidence ϒ, s is the sample standard deviation, x = each value in the sample, $\bar{x}$= the mean of the values and N = the sample size. After the tolerance design interval then the time study in order to determine the standard time of operation at the determined optimal parameter settings.

3.8 Time Study

The time study involves a direct, continuous observation of a task using a time measurement instrument to record the time taken to complete the task (Groover, 2007). The collection of data sample is an iterative process in which data were collected and out-of-range data were discarded, and the existing data sample were augmented through additional data collection until the desired sample size is achieved. The extrusion "Start–up" tasks were studied, and the data collection process is shown in Fig. 3.18.

3.8.1 Data Collection Steps:

1. Collect the first data sample
2. Discard any out-of-range data
3. Based on the resulting sample size, determine the achievable confidence and degree of precision.
4. Decide whether a larger data sample is needed to achieve desired confidence level and degree of precision.
5. If a larger data sample is needed, collect additional data, and repeat the entire process.

Mathematical computations for sample size selections, and other time study variables are as follows:

$$Sx = [\sum [((t1-t) 2)]/ n] 0.5 \quad (3.40)$$

$$\text{Lower limit} = t- 2Sx \quad (3.41)$$

$$\text{Upper limit} = t +2Sx \quad (3.42)$$

$$n = [(k * Sx) / (r * t)] 2 \quad (3.43)$$

Where; t = Average time for performing the element, Sx = Sample variance for the element; n = number of data points in the data sample; k = number of standard deviations at the confidence level; r = measure of error precision; and t_i = individual observed time.

$$\text{Basic Time } (B_T) = \frac{Observed\ Performance\ rating}{Normal\ Rating} \quad (3.44)$$

$$\text{Standard Time } (S_T) = B_T + R_{TA} + C_{TA} \quad (3.45)$$

Where R_{TA} = Relaxation Time Allowance; C_{TA} = Contingency Time Allowance (contingency time allowance are allowances due to unanticipated official disturbance to one at work).

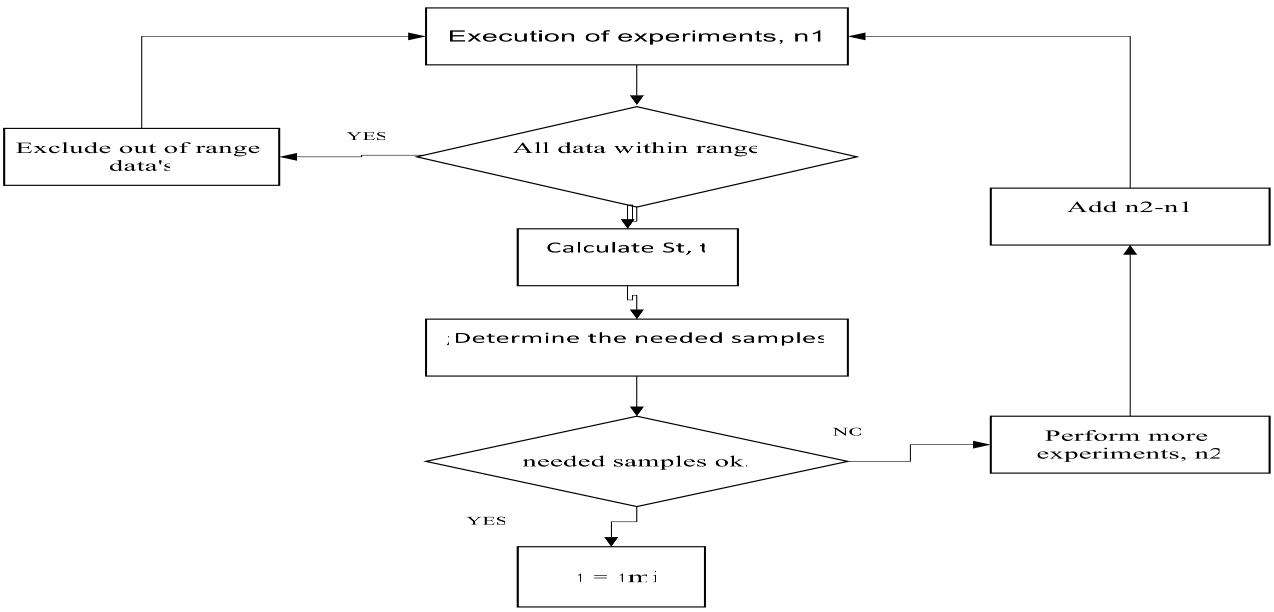


Figure 3.18. Data collection process (Adapted from Wigdor, T.(n.d.)http://www.werc.org/assets/1/workflow_staging/Publications/660.PDF.).

3.9 The Control Phase

Control phase is concerned with establishing procedures to sustain improvements made. Since a process is referred to as the combination of machines, tools, methods, and personnel engaged in adding value by providing either product or services, a control plan template would be drafted, and emphasize should be on the voice of the customer. In addition, as part of the control plan, there should be stratification of within and between subgroup variations. The improvement should be verified and control charts would be presented with control limit, which are statistically calculated and located 3$\boldsymbol{\sigma}$ from the center line. The control charts are very useful when finding unusual sources of variation. Samples that are found outside the control limits are indications for unusual sources of variations, and require an investigation to find the cause(s) behind it.

3.10 Assessing the Economic Implication of the Improvement Solution

Economic impact assessment of the improvement solution was achieved following quality loss function procedures. The derivation of Taguchi's loss function equations expressed in this study is given in parts in Fowlkes and Creveling, (1995), and explicitly in Taguchi et al.,1989; Venkateswaren, (2003). From the experimental design, the quality characteristic is of the type Nominal–the best, and the quality loss function is derived as:

$$L(y) = L\,(T) + \frac{L'(T)}{1!}\,(y\text{-}T) + \frac{L''(T)}{2!}\,(y\text{-}T)^{2} + \ldots \frac{Ln}{n!}\quad (y\text{-}T)^{n} \qquad (3.46)$$

Assuming the cost incurred by the company when the product does not meet the target value is A, and the Loss function denoted by L(y) is expanded in Taylor's series about the target value T. Since L(y) = 0, when y = T, its first and second derivative with respect to m is zero. Neglecting terms with powers higher than 2, the equation now reduces to;

$$L(y) = k\ (y\text{-}T)\ 2 \qquad (3.47)$$

$$k = \frac{A}{\Delta^2}\ \text{(At specification)} \qquad (3.48)$$

Let y be the measured value of the characteristics, and note that the adjustment of the process is not needed when y = T; However, if y≠T, then an amount of adjustment needed equal to y-

T. The quantity (y-T) is usually estimated based on available data, and the usual estimate of mean square deviation (MSD) is denoted as follows:

$$\text{MSD} = \frac{1}{n}\left[(y_1 - T)^2 + (y_2 - T)^2 + \ldots + (y_n - T)^2\right] \qquad (3.49)$$

where n is the number of measurements available, and yi is the value of the ith measurements. Equation (4.9) & (4.11) are used to determine the quality level of the quality core diameter characteristics.

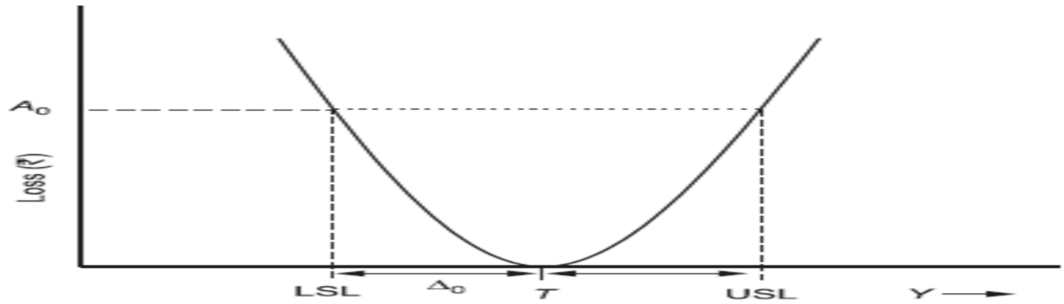


Figure 3.19. Graphical representation for quality loss function for nominal is the best. (Adapted from Sharma et al., 2007).

L(y) is the loss associated with producing a part at "y" value, K = Cost coefficient which depends on the cost at the specification limits and the width of the specification; y is the measured value of the characteristics; T is the target of the characteristics; A = cost incurred by the manufacturer when the product does not meet the target value, Δ = tolerance limit; (y-T) = mean squared deviation of the produced value (y's) from the target value (T).

3.11 Development of the Generic Graphical User Interface Tool

To accomplish the demands of the fourth objective, a generic user interface support system was developed for easy replication of the improvement studies in cable manufacturing. Figure 3.20 is the architecture of the software development.

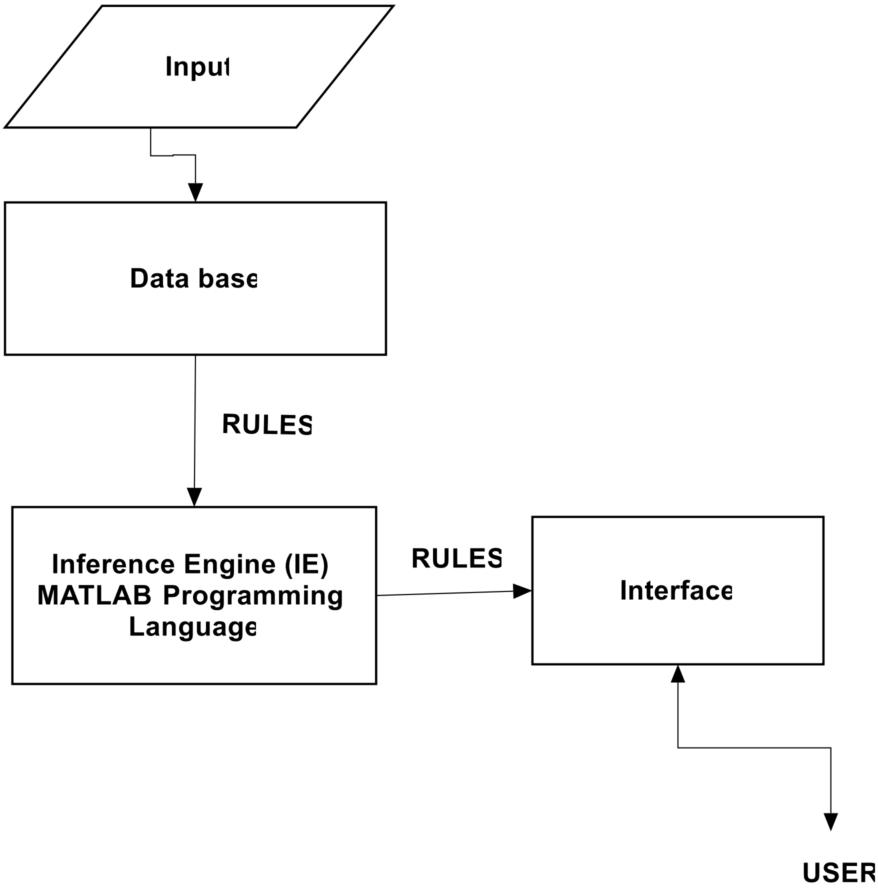


Figure 3.20: Flowchart for the Generic Graphical User Interface Support System Development.

3.12 Ethical Consideration

The following considerations were upheld during the study:

1. The participating manufacturing firm was informed of the purpose and expected benefits of this research study.
2. The participating manufacturing firm was offered the choice to indicate whether they would like to receive a report about this research study upon conclusion. A contact detail was provided.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

The analysis on the validation results followed the same Six Sigma DMAIC's five-phase sequential order. Each of the phases in the methodology was analyzed in detail and the outcomes of every one of the phases were highlighted in an ordered manner since each of the phases is characterized with a unique responsibility.

4.1.1 The 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. Historical data were provided from Manufacturing Department (MD) and Quality Assurance Department (QAD). Table 4.1 contains the records of 1.0 (mm) single core house wiring cables produced from 2013 to February 2017 and Table 4.2 contains quantity of cable products rejected from 2013-Feb.2017. Seven different types of defects were identified to be related with the product, as shown in Table 4.2. The asterisks found in Table 4.1 and Table4.2 connote periods when there is no production, and when there is absence of particular defect type/ no rejections of defect type(s) in the subject year.

Table 4.1: *Records on 1.0mm Single Core House Wiring Cables Produced from 2013-Feb.2017***Source:** Cutix Cable PLC Umuannuka PCP1 Plant

Monthly production	*Quantity produced* (*m*) (2013)	*Quantity produced* (*m*) (2014)	*Quantity produced* (*m*) (2015)	*Quantity produced* (*m*) (2016)	*Quantity produced* (*m*) (2017)
Jan	459,245	579,927	722,558	410,631	1,174,004
Feb.	572,724	115,666	465,009	600,637	*
March	573,393	*	895,685	749,572	*
April	547,612	*	838,339	1,026,326	*
May	550,454	*	334,866	841,004	*
June	656,202	*	878,437	732,712	*
July	225,191	*	893,041	589,568	*
Aug.	649,335	689,840	818,403	*	*
Sept.	451,158	605,923	406,139	*	*
Oct.	706,199	564,649	900,909	*	*
Nov.	615,612	689,882	369,894	*	*
Dec	466,573	481,130	771,873	*	*
$\sum$	6,473,678	3,727,017	8,295,153	4,950,450	1,174,004

Table 4.2: *Quantity of 1.0mm Single House Wiring Cables Rejected from 2013-Feb.2017*

S / N	*Defects* (*m*)	2013	2014	2015	2016	2017	*Total*
1	*ITF*	5,672.44	3,995.092	9,025.110	8,743.098	1,125.231	28,560.971
2	*ISF*	4,697.44	4,877.495	5,460.999	10,710.054	1,209.009	26,954.997
3	*LCD*	*	*	1,680.111	*	*	1,680.111
4	*WL*	*	*	*	*	105.000	105.000
5	*NL*	*	*	945.000	*	525.000	1,470.000
6	*TPs*	420.000	*	*	210.000	735.000	1,365.000
7	*ICD*	*	882.403	*	*	420.000	1,302.403
	Total (*m*)	10,789.88	9,754.99	17,111.22	19,663.35	4,119.240	61,438.482

Source: Cutix Cable PLC Anuka Cable Plant

The identified defects are, Insulation Surface flaws (ISF), Insulation Thickness Failures (ITF), Low Conductor Diameter (LCD, Wrong Label (WL), No Label (NL), Torn Poly-Sheet (TPs), Inconsistent Cable Dimension (ICD).

Table 4.3: *Financial Cost (₦) of 1.0mm Single Wires Rejected as a Result of Defects from (2013-Feb.2017) at Anuka Cable Plant*

S / N	*Defects*	2013	2014	2015	2016	2017	*Total*
1	*ITF*	115,150.532	81,100.318	183,209.773	177,484.889	22,573.6	579,519.072
2	*ISF*	*	99,013.149	110,858.280	217,414.096	24,545.449	547,186.44
3	*LCD*	*	*	34,106.253	*	*	34,106.253
4	*WL*	*	*	*	*	2,131.5	2,131.5
5	*NL*	*	*	19,183.50	*	6,394.5	25,578
6	*TPs*	8,526	*	*	4,263	14,920.5	27,709.5
7	*ICD*	*	17,912.781	*	*	8,526	26,438.781
	Total	219,034.564	198,026	347,357	399,161.666	79,088.98	1,242,669.546

Source: Cutix Cable PLC Anuka Cable Plant

The associated financial costs of these defects were also tabulated in Table 4.3. The gross financial loss incurred by the company due to these defects amount to ₦ 1, 242, 669.546. In a descending order from Table 4.3, the defect types with the highest accrued financial loss are defects due to Insulation thickness failures, followed by Insulation Surface Flaws, Low conductor diameter (**LCD**), to inconsistent cable dimension (**ICD**). Pareto chart were used to streamline the selected project among the seven most common defects as shown in figure 4.1, and 4.2.

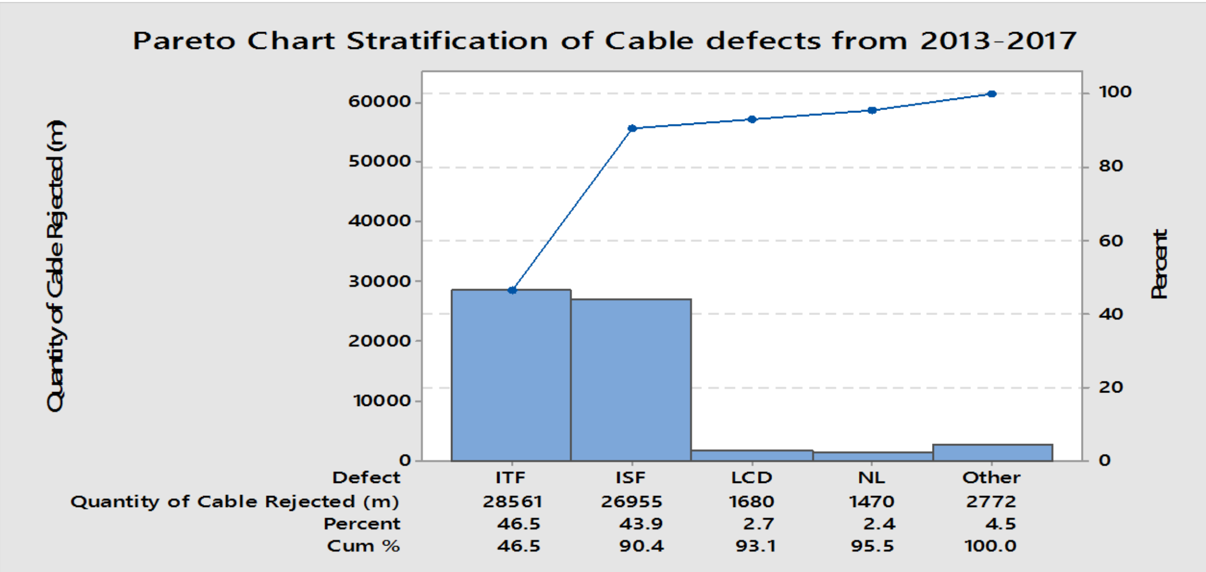


Figure 4.1. Pareto chart of defects (Cutix Cable Plc, Anuka CablePlant)

The most prevalent and most cost daring quality defects in the case organization are failures in the required cable Insulation thickness and Insulation smoothness. These quality defects cascade further to webs of trivial problems that require further attention and resources. Poor cable concentricity and cable surface flaws have become a very big challenge to the organization, and these quality defects have a big toll on the financial report as shown in fig. 4.2.

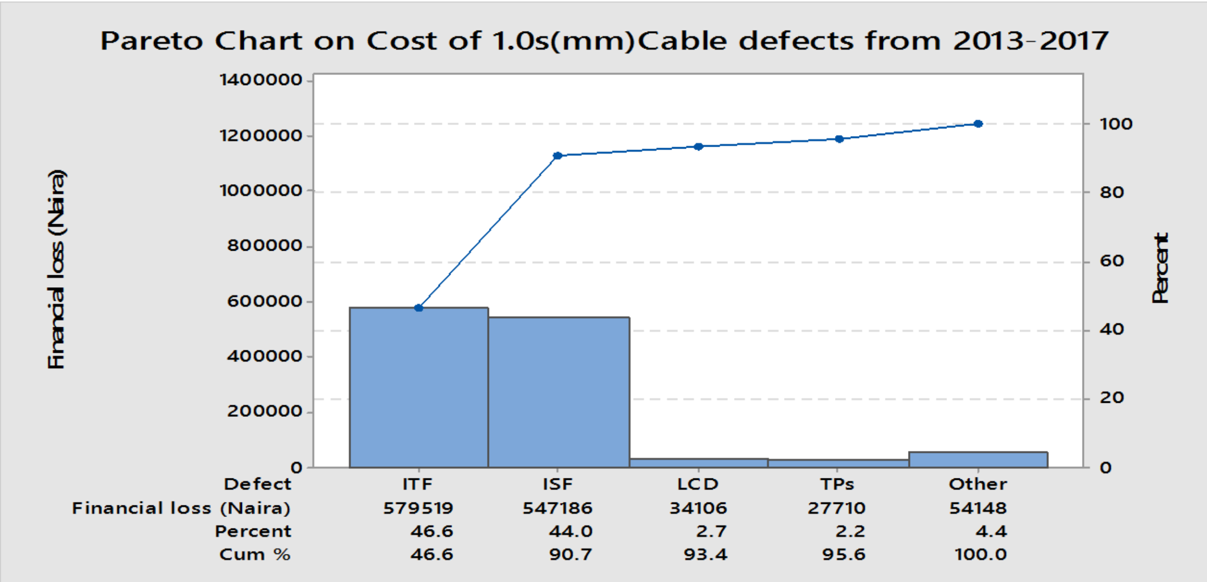


Figure 4.2. Pareto chart of defects (Cutix Cable Plc, Anuka Cable Plant)

The quantity of 1.0s (mm) cables rejected due to Insulation thickness failures (Poor concentricity) in the extrusion process from Jan. 2013 to Feb. 2017 was as high as 46.5%, with an associated cost of 46.5% of the total cost of poor quality (COPQ) in the observed production period. More so, the percentage of cable rejected in the same period due to Insulation Surface flaws was as high as 43.9%, with an accrued cost of 44% of the total cost. Both defects cumulatively contributed to 90.7% of Cost of Poor Quality (COPQ) and have always occurred in every one of the quarters. The goal statement was to improve the extrusion process capability of 1.0mm single cable and increase its existing sigma level by at least one more level, which should result in large cost saving for the company in terms of reduction in rework and scrap cost. The main objective of our Six Sigma projects was to reduce variations in cable concentricity, reduce the rate at which insulation surface flaws occurs, and minimize waste of Insulation materials as well. A project charter was drafted as shown in Table 4.4, containing necessary information pertaining to the projects selected.

Table 4.4: *Project Charter*

<table>
<tr><td colspan="2">Project Title:
Project I: Reduce the rate at which cables with poor cable concentricity are extruded.
Project II: Reduce the rate of extruding cables with insulation surface flaws.
Project III: Reduce rate of extruding inconsistent dimensioned cables.</td></tr>
<tr><td colspan="2">Background and reasons for selecting the projects
The length of 1.0s (mm) cables rejected due to poor concentricity in the extrusion process from Jan. 2013 to Feb. 2017 was as high as 46.5%, with an associated cost of 46.5% of the total cost of poor quality (COPQ) in the observed production period. More so, the percentage of cable rejection in the same period due to rough insulation surface was as high as 43.9, with an accrued cost of 44% of the total cost. Both defects cumulatively contributed to 90.7% of COPQ, and has always occurred in every of the quarters. In addition to this, inconsistency in the cable dimensioned requires a design attention to cut the anomalies of having over dimensioned and under dimensioned cables. Over dimensioned cable is an indication that the process is using more polyvinylchloride (PVC) material than required for production, while low dimensioned cables often fail the insulation thickness test.</td></tr>
<tr><td colspan="2">Aim of the Project
The aim of this research is to enhance process performance in cable manufacturing through incorporation of Knowledge Management and Six Sigma DMAIC’s improvement concepts</td></tr>
<tr><td>Voice of the Customer (VOC)</td><td>Product quality</td></tr>
</table>

Table 4.4: *Project Charter*

Critical to Quality Characteristics	1. Insulation thickness of the cable 2. Surface smoothness of the cable 3. Uniform cable diameter
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 TEKO-50 extrusion line.
Community of practice (CoP)	The researcher, two Personnel from QAD, and two personnel from Manufacturing department (MD).
Expected Financial benefits	A considerable cost saving due to the defect reduction.
Expected Customer benefit	Receiving the product with the expected quality according to requirements.

The end of the Define Phase was concluded with after action review, during which an opportunity and technical guidance was given on the use of specific tools and exchange of information about the selected problems.

4.2 The Measure Phase

4.2.1 **Measurement System Analysis (MSA)**

The objective of the measure phase is to understand and establish the baseline performance of the process in terms of process capability. Before assessing the capability of the process, measurement system analysis (**MSA**) was first conducted to validate that the measurement system is good enough to be used in the study. The purpose of MSA is to statistically verify that the current measurement system provides representative values of the characteristics being measured, with minimal variability. For the attribute data, there was no instrument involved in the inspection process and only visual inspection was performed. Master samples were provided for identifying each of these defects and the selected team members did the inspection. Table 4.5 and Fig.4.3 depicts the outcome of the attribute measurements.

Table 4.5: *Measurement System Analysis- Attribute Data (Cable Insulation smoothness)*

Sample	Reference	Operator 1		Operator 2		Operator 3	
		Trial 1	Trial 2	Trial1	Trial 2	Trial 1	Trial 2
1	B	B	B	B	B	B	B
2	G	G	G	G	G	G	G
3	G	G	G	G	G	G	G
4	G	G	G	G	G	G	G
5	G	G	G	G	G	G	G
6	B	B	B	B	G	B	B
7	B	B	B	B	B	B	B
8	G	G	G	G	G	G	G
9	B	B	G	B	B	G	B
10	B	B	B	B	B	B	B

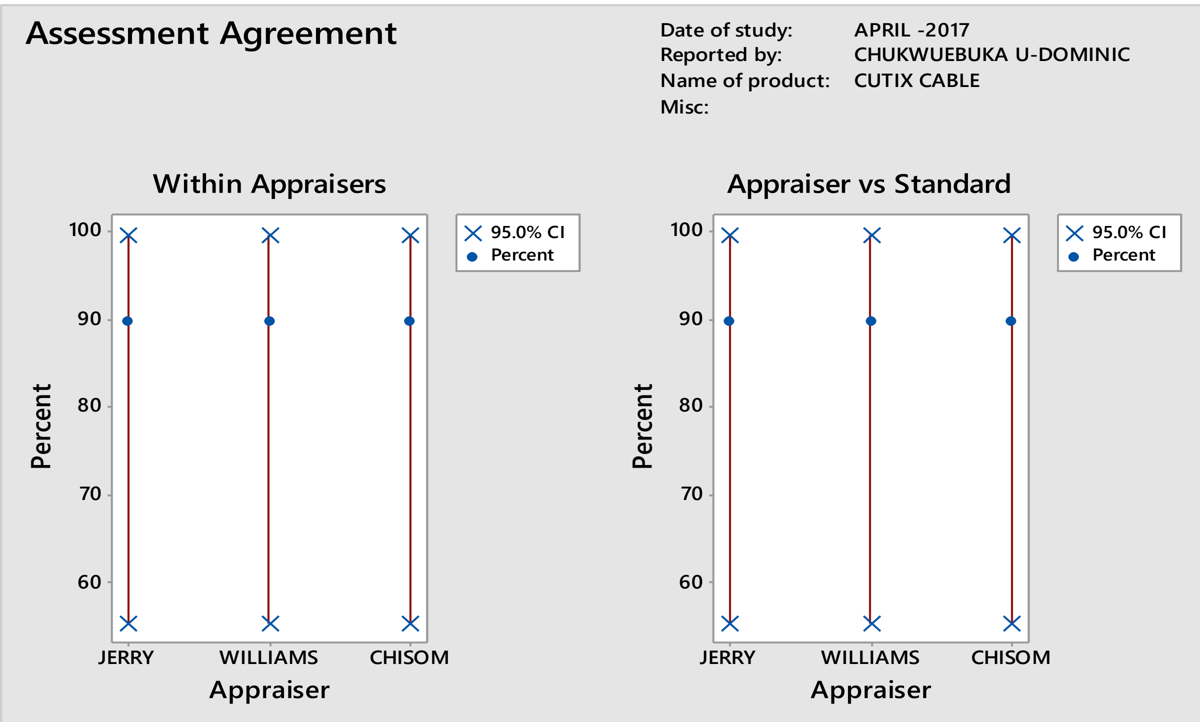


Figure 4.3. Measurement System Analysis results for the attribute data

From the graphical results, we can see that the operators were in agreement with each other 90% of the time and were in agreement with the expected (**Standard**) result 90% of the time. The analytical output of the window session as shown in Appendix A, we can see that the agreement between appraisers was 80% and the overall agreement versus the standard values was 80%. Looking at Fig. 4.3 also the Kappa Value for all appraisers versus the standard values was 0.90, indicative of excellent agreement between the appraised values and reference values.

Table: 4.6: *The Benchmark Interpretation for kappa Value*

Kappa	**0.0**	**0.01-0.20**	**0.21-0.40**	**0.41-0.60**	**0.61-0.80**	**0.81-0.99**	**1.0**
Agreement	Poor agreement	Slight agreement	Fair agreement	Moderate agreement	Substantial agreement	Almost perfect agreement	Perfect agreement

(Source: Viera, et al., (2005).

4.2.1.1 **Gage Repeatability and Reproducibility Analysis on the Cable Core Diameter**

Table 4.7: ***Measurement System Analysis- Variable Data (Core diameter)***

Sample	Operator 1			Operator 2			Operator 3		
	Trial 1	**Trial 2**	**Trial 3**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 1**	**Trial 2**	**Trial 3**
1	2.900	2.900	2.900	2.900	2.900	2.900	2.907	2.906	2.906
2	2.840	2.842	2.842	2.840	2.842	2.842	2.843	2.842	2.842
3	2.778	2.778	2.778	2.779	2.779	2.778	2.778	2.779	2.778
4	2.691	2.690	2.692	2.693	2.693	2.692	2.692	2.692	2.692
5	2.787	2.787	2.788	2.786	2.786	2.787	2.786	2.787	2.878

A slice cut of the cable insulation for the test was gotten from the sample lengths with the aid of cable cutter and sharp razor blade. The assigned first sample was placed on the glass plate of the Profile enlarger, and the entire operators for the MSA took their first trial measurements and recorded their average readings. The order of taking the measurements by the operator was not in sequence, but in random formation. Without altering the position of the sample on the plate, second and third trial measurements of the sample were taken by these operators in a random order, and readings were recorded accordingly. The same measurement procedure was followed for the remaining samples.

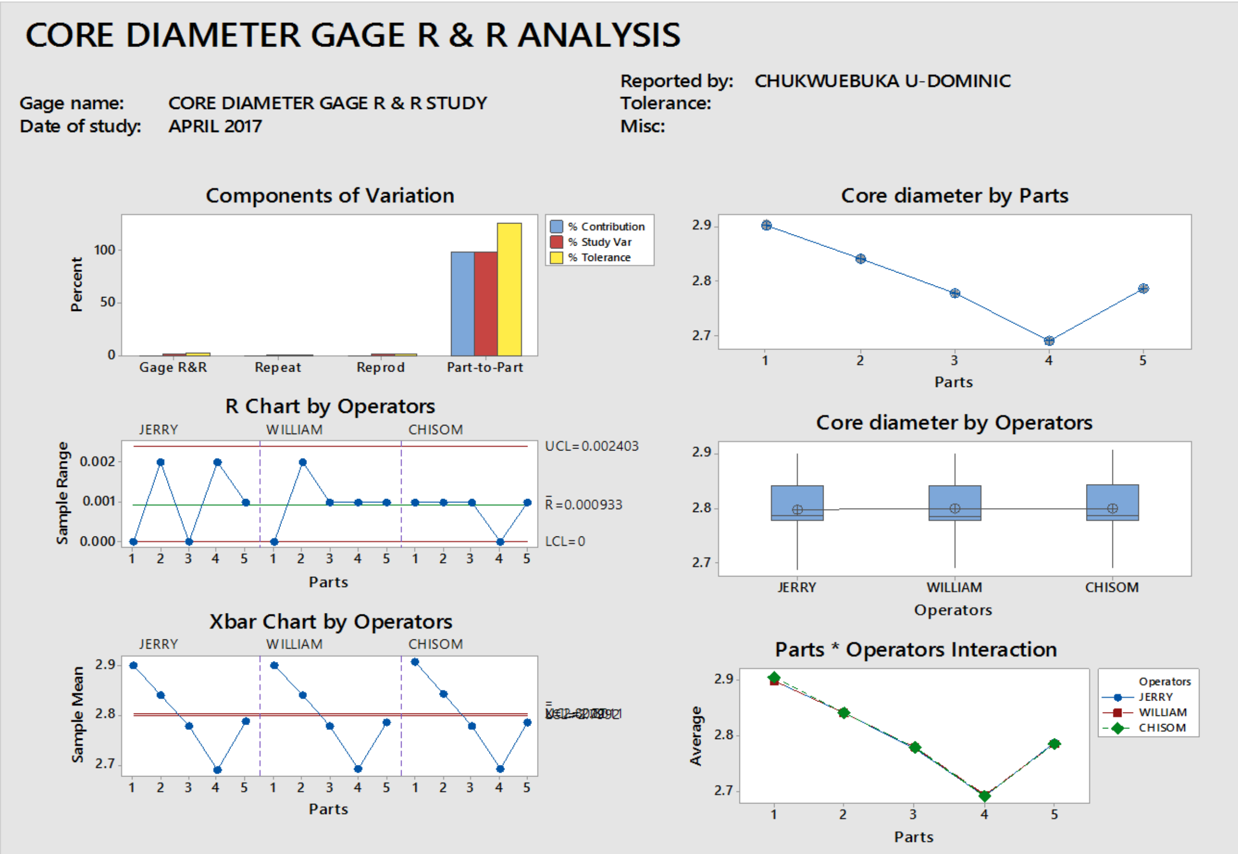


*Figure 4.4.*Measurement Analysis results for the variable data

Analytic output of the session window is captured in Figure 4.4. From Fig. 4.4, the bars for repeatability and reproducibility are very small relative to part-to-part variation, which is a good indication that the measurement system has a small margin of variation. The percent contribution (99.95%) from part-to-part is larger than that of total gage R & R (0.05%) indicating that most of the variation is due to differences between parts and little is due to the measurement system. For the parts, there are large differences between parts as shown by the non-level line. The range chart is in control, while the X-bar SPC chart is out of control, and according to MSA 4th edition manual, is an indication that the variability present is due to part to part differences rather than operator to operator differences. On the other hand, most of the points in the $\bar{X}$ chart will be within the control limits when the observed variation is mainly due to the measurement system. Also in the figure 4.4 is a box plot of the cable diameter measurement by operator, and the nearly level line showed that the differences between operators are small. Last diagram in figure 4.4 is an individual value plot used to check for operator–sample interactions. From Appendix B, 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%, while the number of distinct categories NDC = 61.Comparing these with the benchmark values in Table 4.8, it denotes that the measurement system was good enough.

Table 4.8: *Gage R & R Metrics Guidelines*

Gage R & R Metric	**Unacceptable**	**Acceptable**	**Recommended**
% Contribution	>9%	1% to 9%	<1%
% Study Variation	>30%	10-30%	<10%
% P/T ratio	>30%	10-30%	<10%
Number of Distinct category	<5	5-10	>10

(Source: AIAG: Measurement System Analysis Manual, 4th Edition, 2010)

4.2.2 Process Capability Analysis (PCA)

4.2.2.1 Process Capability Assumptions

It is a prerequisite step and mandatory procedure in any process capability studies to lay cognizance of some critical assumptions, so that one do not misrepresent the true capability of a process. According to Bower, (2000) there are two critical assumptions to consider when performing process capability analysis:

1. The process is in statistical control.
2. The distribution of the process considered is normal.

Table 4.9: *Product Description for cable diameter measurement specifications*

Cable Size: 1.0s (mm)	CTQ: Core cable diameter
Operation : Extrusion	Specifications: USL= 2.90; LSL = 2.53
Instrument used: Profile enlarger	All dimensions are in millimeter

Table 4.10: *The Baseline Measurements for the Cable Core Diameter*

Subgroup	*Sample* (1)	*Sample* (2)	*Sample* (3)	*Sample* (4)	*Sample* (5)	$\overline{X}$	*R*
1	2.719	2.896	2.769	2.773	2.693	2.770	0.203
2	2.732	2.894	2.725	2.716	2.782	2.769	0.178
3	2.864	2.887	2.824	2.826	2.796	2.839	0.091
4	2.907	2.846	2.878	2.755	2.787	2.835	0.152
5	2.792	2.778	2.823	2.798	2.801	2.798	0.045
6	2.864	2.756	2.785	2.840	2.871	2.823	0.115
7	2.734	2.747	2.726	2.770	2.709	2.737	0.061
8	2.761	2.746	2.713	2.786	2.792	2.760	0.079
9	2.691	2.743	2.821	2.790	2.705	2.750	0.130
10	2.899	2.787	2.747	2.864	2.822	2.824	0.152
11	2.761	2.697	2.826	2.765	2.790	2.768	0.129
12	2.820	2.699	2.745	2.789	2.788	2.768	0.121
13	2.891	2.800	2.721	2.795	2.700	2.781	0.191
14	2.866	2.784	2.756	2.718	2.758	2.776	0.148
15	2.857	2.844	2.767	2.884	2.810	2.832	0.117
16	2.708	2.772	2.770	2.795	2.758	2.761	0.087
17	2.854	2.792	2.812	2.855	2.775	2.818	0.080
18	2.769	2.725	2.730	2.740	2.725	2.738	0.044
19	2.771	2.696	2.661	2.708	2.849	2.737	0.188
20	2.857	2.844	2.767	2.884	2.810	2.832	0.117

4.2.2.2 Test validation of first Assumption for the Baseline Cable diameter Measurement

Construction of $\bar{X}$ and R- chart to assess the statistical stability of the extrusion operation

Control limits for $\bar{X}$ –chart:

$$UCL = \bar{\bar{X}} + A_2\bar{R} = 2.7858 + 0.577(0.1214) = 2.7859 + 0.07005 = 2.8559$$

$$LCL = \bar{\bar{X}} - A_2\bar{R} = 2.7858 - 0.577(0.1214) = 2.7859-0.07005 = 2.71585$$

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 in Appendix C, n= 5, $A_2 = 0.577$, $d_2 = 2.326$, $D_3 = 0$, $D_4 = 2.114$

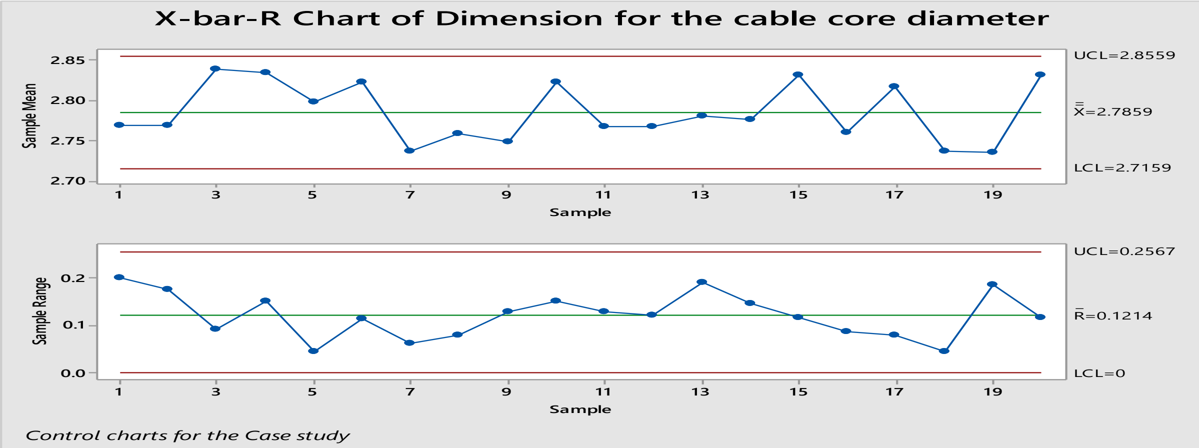


Figure 4.5. X-Bar-R chart of the Cable diameter data

From figure 4.5, the center line on the $\bar{X}$ chart is at 2.7859, implying that the process falls within the specification limits, and is a stable process. The center line on the R chart is 0.1214, is also within the maximum allowable variation of ± 0.185.

4.2.2.3 **Test Validation of the Second Assumption for the Baseline Cable diameter Measurement**

Graphical methods including the histogram and normal probability plot are used to check the normality of the data used for the case study. Figure 4.6 displays the histogram and the sample data appears to be normal.

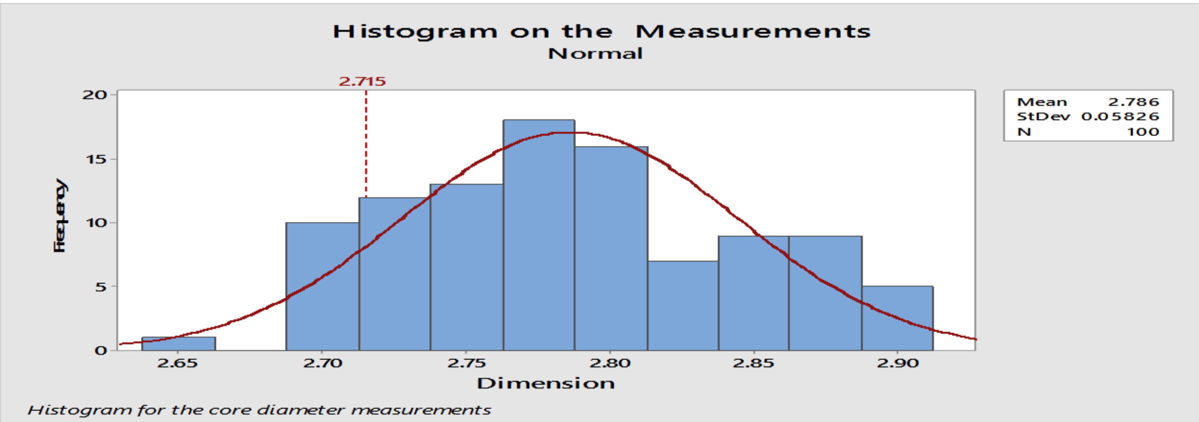


Figure 4.6. Histogram of the cable diameter baseline measurements

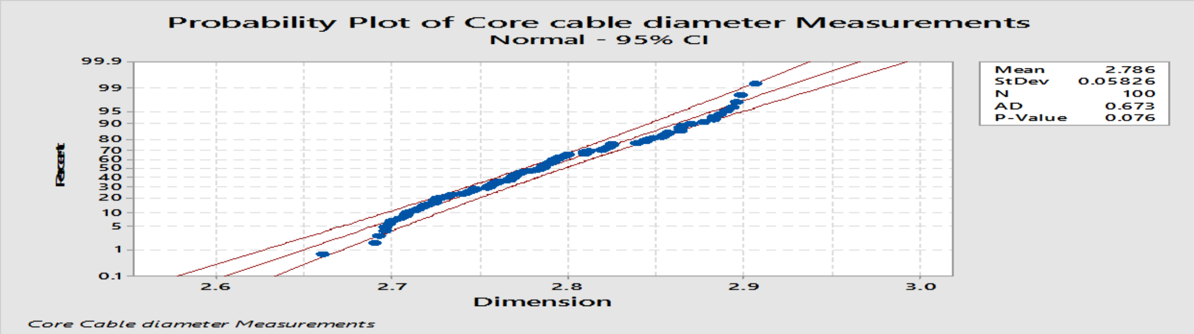


Figure 4.7. Normal Probability plot of the cable diameter baseline measurements

The test results for normal probability plot are as follows; Mean: 2.786, Standard deviation: 0.05826, Anderson Darling test statistic value: 0.673 and P-value: 0.076 which is greater than the significance level (**α = 0.05**), and this implies that the data is distributed normally.

4.2.2.4 Process Capability Index Estimations for the Baseline Process Conditions

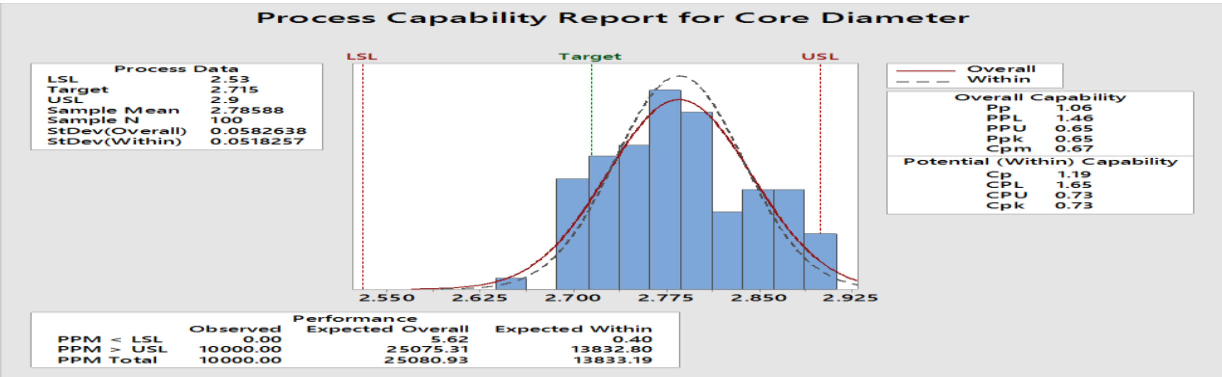


Figure 4.8. Graphical illustration of the cable diameter baseline measurements

From figure 4.8, both the tails of the distribution fall outside the specification limits, an indication that some of the thickness points are less than the lower specification of 2.53, while some are greater than the upper specification of 2.90. CP is equal to 1.181, and since the minimum acceptable value for this index is 1, the 1.181 result indicates that this process can meet the requirements. The CR is 84.67%. With this value, it means that the "natural tolerance" of the process uses 84.67% of the engineering requirement, which is, of course, unacceptable. The Cpk = 0.73, the value of Cpk is smaller than that of Cp by 0.451, and with this difference, much improvement can still be gained through centering the process. The calculated Z_U for the process is 2.18, and checking from the table in Appendix D we have ZU

= 1-0.9854 which is 1.46%. By this estimation, approximately 1.46% of the production will exceed the upper specification. The calculated Z_L for the process is 4.98, and since Z_L value of at least +3, so 4.98 is acceptable.

4.2.3 Baseline Process Capability Analysis for the Cable Insulation Thickness

Table 4.11: *Product Description for cable Insulation Thickness measurement specifications*

Cable Size : 1.0 (mm) single core	**CTQ : Insulation thickness**
Operation: Extrusion	Specifications: USL = 0.89; LSL = 0.53
Instrument used : Profile enlarger	All dimensions are in millimeter

The existing company's insulation thickness evaluation technique was based on one sided specification, thus the lower specification limit (LSL). By this evaluation technique, it means that the quality check is only to ensure that the insulation thickness of extruded cables do not go beyond the specified 0.53mm. However, without creating an upper specification limit (USL) for the process, it will be difficult to conduct the process capability studies for the insulation thickness measurements. The upper specification limit was derived as follows;

For 1.0s (mm) cable; USL = 2.90 LSL = 2.53, and the input conductor diameter = 1.13(mm).

Derivations:

$$USL = \frac{USL - Input\ conductor}{2} = \frac{2.90 - 1.13}{2} = 0.885$$

Table 4.12: *The Baseline Measurements for Cable Insulation Thickness*

Sample	Point (1)	Point (2)	Point (3)	Point (4)	$\bar{X}$	$\bar{R}$
1	0.7490	0.9055	0.8315	0.6920	0.7945	0.2135
2	0.8775	0.8710	0.8485	0.9355	0.8831	0.0870
3	0.7535	0.9295	0.7400	0.8615	0.8211	0.1895
4	0.7070	0.7900	0.8335	0.7155	0.7615	0.1265
5	0.7230	0.8700	0.7090	0.8305	0.7831	0.1610
6	0.6935	0.8890	0.7460	0.8810	0.8024	0.1955
7	0.6835	1.0120	0.8565	0.9810	0.8832	0.3285
8	0.7680	0.8340	0.6970	0.8960	0.7987	0.1990
9	0.8085	0.7900	0.9130	0.6595	0.7927	0.2535
10	0.6990	0.9500	0.7510	0.9045	0.8261	0.2510
11	0.8985	0.8770	0.9725	0.7250	0.8683	0.2475
12	1.0035	0.7390	0.7885	0.9885	0.8799	0.2645
13	0.9965	0.7085	0.9050	0.7825	0.8481	0.2880
14	0.9475	0.7550	0.7205	0.9750	0.8495	0.2545
15	0.8565	0.8485	0.9655	0.6680	0.8346	0.2075
16	0.8470	0.9750	0.9045	0.8325	0.8898	0.1425
17	0.7235	0.8265	0.8515	1.0360	0.8594	0.3125
18	0.7725	0.8665	1.0510	0.8100	0.8750	0.2785
19	0.8530	0.7475	0.9260	0.7215	0.8120	0.2045
20	0.9850	0.6395	0.8445	0.8345	0.8259	0.3455
21	0.7625	0.9615	0.8860	0.7135	0.8309	0.2480
22	0.7560	0.8160	0.8505	0.8630	0.8214	0.1070
23	0.9595	0.8250	0.7955	0.7950	0.8438	0.1645
24	0.7710	0.8905	0.8945	0.7800	0.8340	0.1235
25	0.7970	0.8215	0.8320	0.8905	0.8352	0.0935
26	0.7655	0.9365	0.9315	0.8280	0.8654	0.1710
27	0.8665	0.7560	0.8480	0.7745	0.8113	0.1105
28	0.8865	0.7645	0.7455	0.9075	0.8260	0.1620
29	0.7790	0.7300	0.7200	0.8365	0.7664	0.1165
30	0.7935	0.8935	0.7915	0.7585	0.8093	0.1350
31	0.9350	0.6755	0.8315	0.7645	0.8016	0.2595
32	0.6920	0.9170	0.8085	0.8150	0.8081	0.2250
33	0.8875	0.6670	0.8560	0.7805	0.7977	0.2205
34	0.7380	0.9560	0.8010	0.7850	0.8200	0.2180
35	0.6600	0.8795	0.8050	0.8115	0.7890	0.2195
36	0.7615	0.8260	0.8765	0.7975	0.8154	0.1150
37	0.8145	0.8090	0.8380	0.7700	0.8079	0.0680
38	0.8055	0.7830	0.8150	0.7615	0.7913	0.0535
39	0.8240	0.78555	0.8575	0.8440	0.8277	0.0720
40	0.7860	0.8570	0.8570	0.8230	0.8307	0.0710

Table 4.12: *The Baseline Measurements for Cable Insulation Thickness*

Sample	Point (1)	Point (2)	Point (3)	Point (4)	$\bar{X}$	$\bar{R}$
41	0.5115	0.9935	0.7645	0.8525	0.7805	0.4820
42	0.7410	0.8745	0.8845	0.7350	0.8087	0.1495
43	0.8280	0.9580	0.7660	0.7710	0.8307	0.1920
44	0.7955	0.7955	0.8545	0.8700	0.8289	0.0745
45	0.7565	0.8405	0.8150	0.7370	0.7873	0.1035
46	0.9385	0.8360	1.0050	0.7575	0.8842	0.2475
47	0.7015	0.9460	0.7120	0.9540	0.8284	0.2525
48	0.8925	0.8400	0.9865	0.7140	0.8582	0.2725
49	1.1065	0.6940	0.9050	0.7610	0.8666	0.4125
50	0.7910	0.8495	1.0560	0.7170	0.8459	0.3390
51	0.7955	0.8250	0.7055	0.9355	0.8154	0.2300
52	0.6415	0.9345	0.7140	0.8425	0.7831	0.2930
53	0.6780	0.9385	0.7450	1.0294	0.8477	0.3514
54	0.8600	0.6855	0.8855	0.8370	0.8270	0.2000
55	0.9455	0.7340	0.9280	0.7115	0.8297	0.2340
56	0.6335	1.0590	0.7470	0.9465	0.8465	0.4255
57	0.8225	0.7085	0.8375	0.8375	0.7861	0.1290
58	0.5875	1.0005	0.8955	0.7525	0.8090	0.4130
59	0.7195	0.8035	0.7245	1.0700	0.8294	0.3505
60	0.6550	0.9100	0.9935	0.7575	0.8290	0.3385
61	0.6995	0.9800	0.8635	0.9800	0.8808	0.2805
62	0.6775	0.9325	0.8565	0.8740	0.8351	0.2550
63	0.6460	0.8600	0.7740	0.9020	0.7955	0.2560
64	0.8235	0.8620	0.7105	0.9330	0.8322	0.2225
65	0.7949	0.7674	0.9325	0.6455	0.7851	0.2870
66	0.9300	0.8250	0.8140	0.8590	0.8269	0.1160
67	0.8155	0.7980	0.8745	0.8195	0.8570	0.0765
68	0.8385	0.8060	0.7870	0.8490	0.8269	0.0620
69	0.7930	0.8055	0.7570	0.8185	0.8201	0.0615
70	0.8095	0.8730	0.7550	0.8175	0.7935	0.1180
71	0.7880	0.9495	0.9270	0.7885	0.8137	0.1615
72	1.0730	0.6965	0.7260	0.9310	0.8633	0.3765
73	0.9235	0.7355	0.6740	0.9405	0.8566	0.2665
74	1.0515	0.7455	0.7380	0.9715	0.8184	0.3135
75	0.7945	0.8615	0.9510	0.7522	0.8398	0.1988
76	0.8410	0.7470	0.7200	0.8480	0.7890	0.128
77	0.9490	0.5045	0.8785	0.8720	0.8010	0.4445
78	0.7110	0.8935	0.8720	0.8040	0.8201	0.1825
79	0.8723	0.6715	0.8971	0.8896	0.8326	0.2256
80	0.6474	0.8799	0.8499	0.8784	0.8139	0.2325

Table 4.12: *The Baseline Measurements for Cable Insulation Thickness*

Sample	Point (1)	Point (2)	Point (3)	Point (4)	$\bar{X}$	$\bar{R}$
81	0.7130	1.0710	0.7980	0.8645	0.8616	0.3580
82	0.8490	0.7625	0.7600	0.9515	0.8308	0.1915
83	0.7450	1.0100	0.7785	0.8290	0.8406	0.2650
84	0.6865	1.0095	0.9090	0.8447	0.8624	0.3230
85	0.6865	0.9310	0.8975	0.7745	0.8224	0.2445
86	0.8460	0.8125	0.8200	0.8000	0.8196	0.0460
87	0.8320	0.7615	0.7760	0.7895	0.7897	0.0705
88	0.8280	0.7775	0.8555	0.7395	0.7996	0.1160
89	0.8225	0.8370	0.7800	0.7700	0.8024	0.0670
90	0.7570	0.8085	0.8445	0.7780	0.7970	0.0875
91	0.7990	0.8000	0.8220	0.8605	0.8204	0.0615
92	0.7460	0.7935	0.7705	0.8205	0.7826	0.0745
93	0.6435	0.8325	0.7645	0.8215	0.7655	0.1890
94	0.7785	0.8045	0.7775	0.7940	0.7886	0.0270
95	0.8965	0.7985	0.8675	0.8745	0.8593	0.0980
96	1.0065	0.7771	0.5210	0.6889	0.7484	0.4855
97	0.4479	0.7992	0.7816	0.7313	0.6900	0.3513
98	0.8916	0.5110	0.9290	0.7317	0.7658	0.4180
99	0.8912	0.8714	0.6347	0.8880	0.8213	0.2565
100	0.9211	0.7480	0.5910	0.7116	0.7429	0.3301

4.2.3.1 Test validation of the first Assumption for Insulation Thickness Measurements

Construction of $\bar{X}$ and R-chart to assess the statistical stability of the Insulation Thickness measurements.

Control limits for $\bar{X}$ –chart:

$$UCL = \bar{\bar{X}} + A_2\bar{R} = 0.8210 + 0.729(0.2141) = 0.8210 + 0.1561 = 0.9771$$

$$LCL = \bar{\bar{X}} - A_2\bar{R} = 0.8210 - 0.729(0.2141) = 0.8210 - 0.1561 = 0.6649$$

Control limits for R-chart:

$$UCL = D_4\bar{R} = 2.282(0.2141) = 0.4886$$

$$LCL = D_3\bar{R} = 0.00(0.2141) = 0.000$$

From Table of Control chart constants in Appendix C, for n = 4, $A_2 = 0.729$, $d_2 = 2.059$, $D_3 = 0$, $D_4 = 2.282$

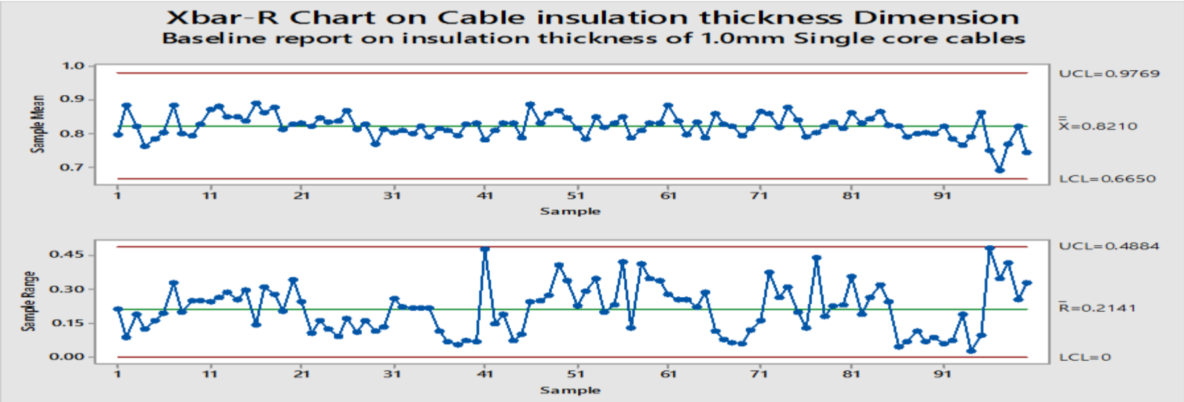


Figure 4.9. X-Bar-R chart of the Cable Insulation thickness data

From figure 4.9, the center line on the $\bar{X}$ chart is at 0.8210, implying that the process falls within the specification limits, implying a stable process. The center line on the R chart is 0.2141, and is also quite large considering the maximum allowable variation of ± 0.18. This implies that there is excess variability in the process.

4.2.3.2 Test Validation of the Second Assumption for Insulation Thickness Measurements

Graphical methods including the histogram and normal probability plot are used to check the normality of the data used for the case study. Figure 4.10 display the histogram, and the sample data appears to be normal.

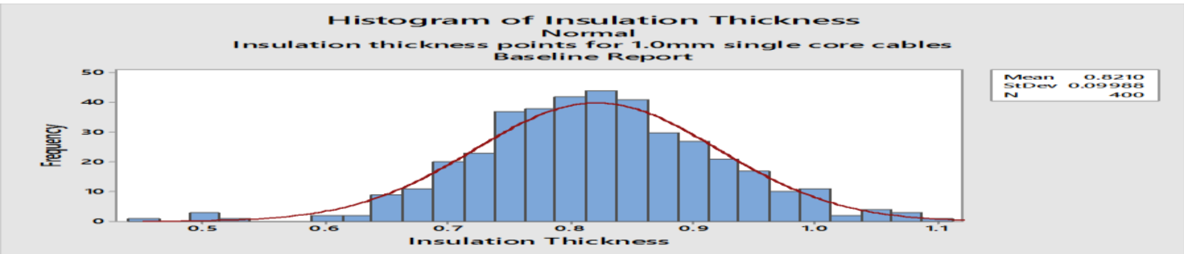


Figure 4.10. Histogram of the cable Insulation thickness baseline data

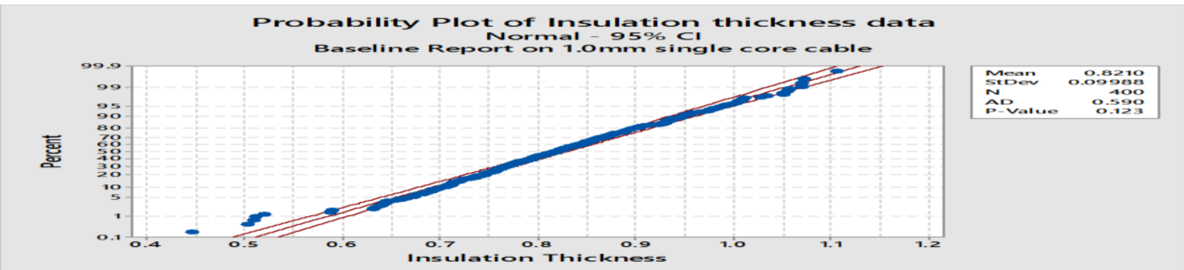


Figure 4.11. Normal Probability plot on the cable Insulation thickness baseline data.

The test results for normal probability plot are as follows: Mean: 0.8210, standard deviation: 0.09988, Anderson Darling test statistic value: 0.590 and P-value: 0.123 is greater than the significance level (**α = 0.05**), and this implies that the data is distributed normally.

4.2.4 Process Capability Index Estimations for the Insulation Thickness Baseline Process Conditions.

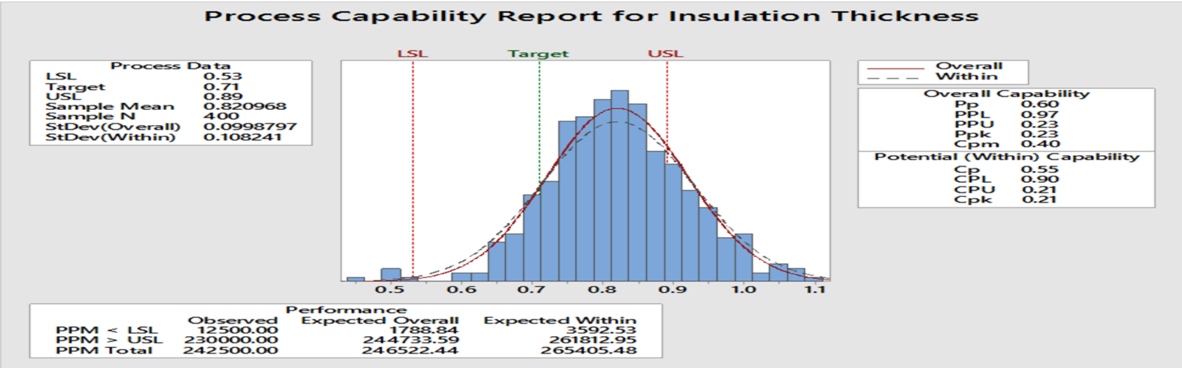


Figure 4.12. Graphical illustration of the cable insulation thickness baseline data

From figure 4.12 illustrations, both the tails of the distribution fall outside the specification limits. This is an indication that some of the cables have lesser diameter than the lower specification of 0.53, while some have diameter greater than the upper specification of 0.89. The CP = 0.577 since the minimum acceptable value for this index is 1, the 0.577 result indicates that this process cannot meet the requirements most of the time. The CR is 173.3%, and with this value, it means that the “natural tolerance” of the process uses 173.3% of the engineering requirement, which is, of course, unacceptable. The Cpk is 0.21, and this value is smaller than that of Cp by 0.37, which is an indication that much can still be gained through centering the process. The calculated ZU for the process is 0.66, and checking from Appendix D, we have ZU = 1-0.7454 which is 25.46%. By this estimation, approximately 25.46% of the production will exceed the upper specification. The calculated ZL for the process is 2.79, we have ZL = 1-0.9974 which is 0.26%. By this estimation, approximately 0.26% of the extruded cable will have insulation thickness that is less than the lower specification. Total reject rate now becomes 25.72% (i.e 25.46% + 0.26%) and projected yield = 74.28%, checking from the abridged Six Sigma conversion table in Appendix E, the Sigma level is at 2.1.

4.3 The Analyze Phase

The first task on this phase was to map the process, followed by a brainstorming session with the CoP to identify and analyze the possible causes of these selected defects in the process line.

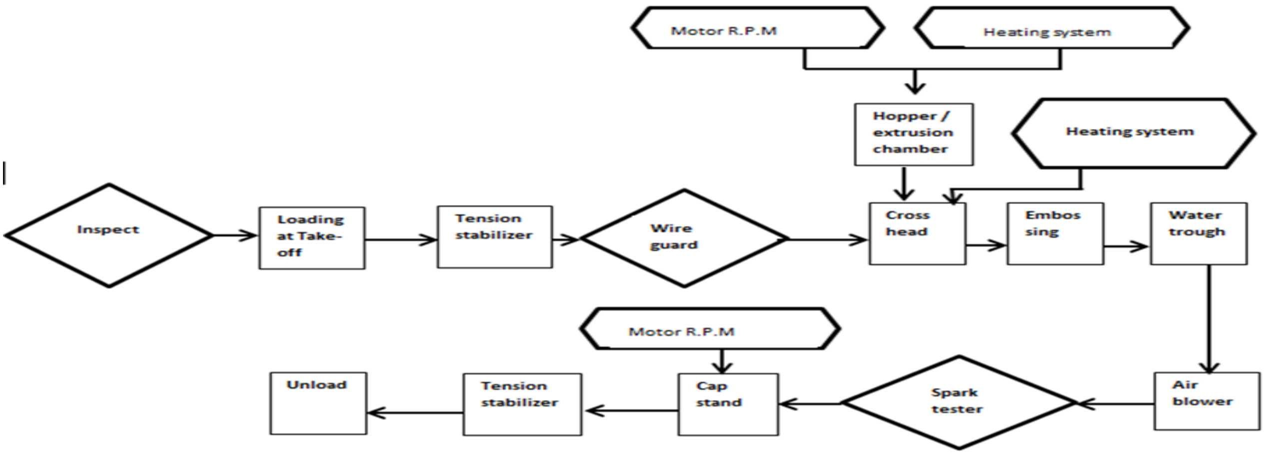


Figure 4.13. Process flow diagram (TEKO-50 extrusion process line)

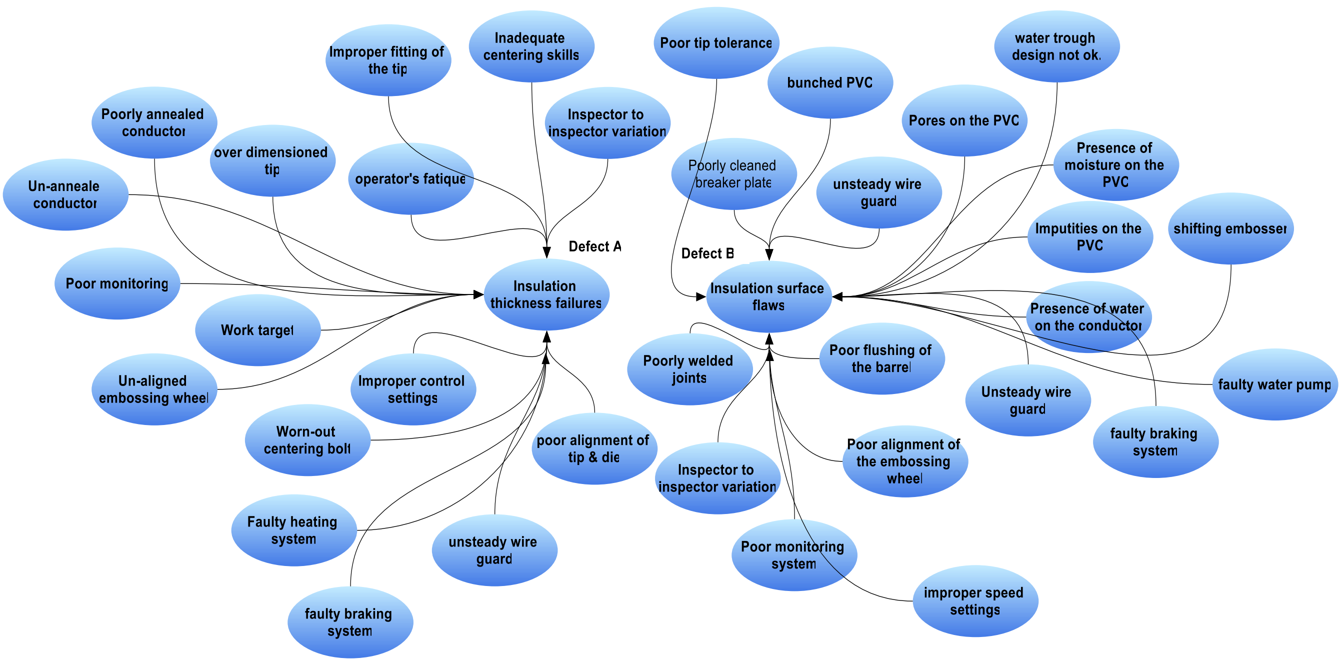


Figure 4.14. Brainstorming diagram of Insulation thickness & Insulation surface defect and causatives.

The brainstorming session was initiated among the selected community to stimulate and unlocks group's tacit knowledge of the process. This technique was potent in creating many solutions that were used to tackle the extrusion poor performance. The brainstorming results were arranged in rational categories and used to construct a cause and effect diagram. The cause and effect diagram accurately displayed the relationships of all the data in each category and these two activities were pictorially represented in fig.4.15 & fig 4.16..

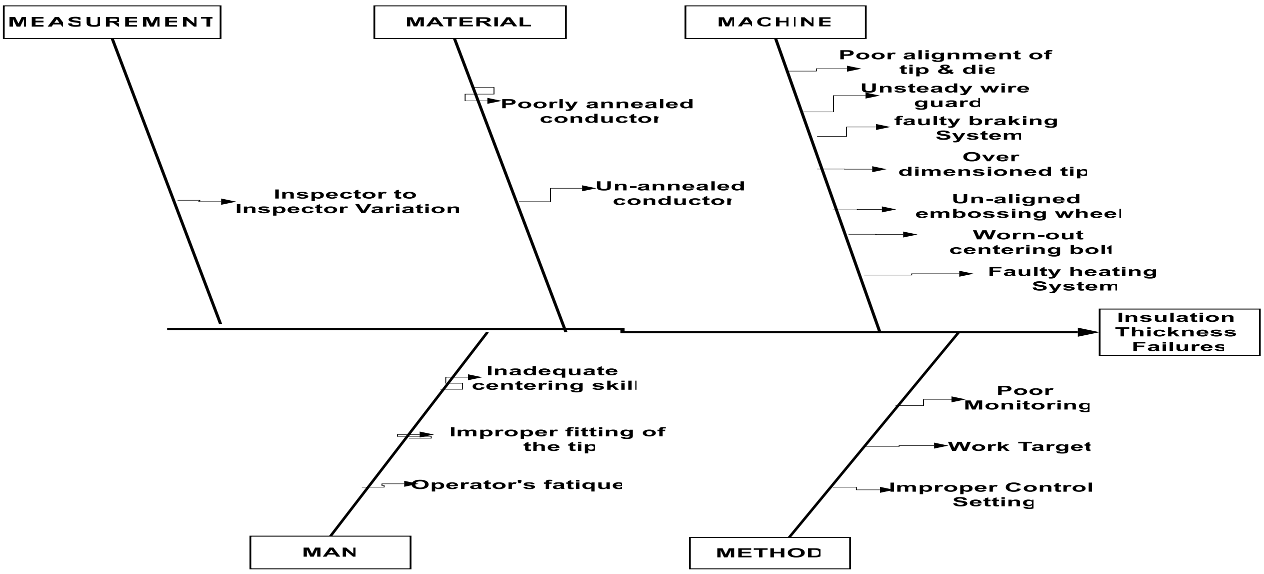


*Figure 4.15.*Cause and Effect diagram on the Cable Insulation Thickness Failures

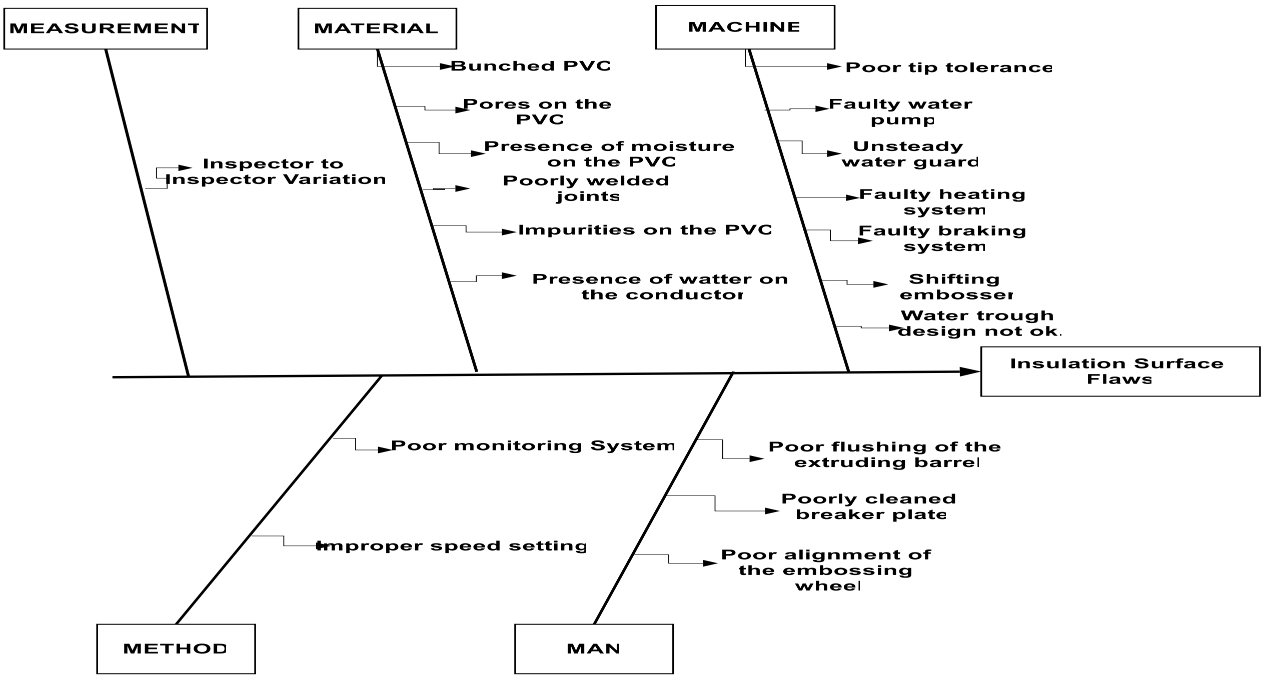


*Figure 4.16.*Cause and Effect diagram on the Cable Insulation Surface Flaws

Further inquest was undertaken to identify the root causes of these quality defects; and this prompted the team to engage in a detailed discussion with the process personnel (machine operators & process engineers) in identifying the possible data that could be collected on the potential causes. Based on the CoP's, interaction, a cause validation plan was prepared that detailed the type of data to be collected and the type of analysis that is possible for each of these potential causes. Potential causes are shown in Table 4.13 such as unaligned embossing wheel, worn-out centering bolts, faulty heating system, poor monitoring system, unsteady wire guide, poorly annealed copper conductor, faulty tensioning system, operator's fatigue, and unsteady wire guide. The unsteady wire guide could not be validated using measuring devices, but by direct observation (**GEMBA**). In GEMBA, process was closely observed for few days, after which the differences were recorded. Factors like over dimensioned tip, inspector to inspector variation, improper speed setting; faulty measuring tools were validated using measuring devices and design of experiment.

Table 4.13: *Cause Validation Matrix for Insulation Thickness Failures*

S/N	Causes	Error Description / Quality Consequences	Confirmation Plan
1	**Un-aligned embossing wheel**	➢ When the embosser presses hard on the cable, it affects the cable diameter.	GEMBA
2	**Worn-out centering bolts**	➢ When a bolt or two bolts are worn-out, the molten PVC now exerts uneven pressure to the die cup, thereby pushing it to one end, thus leading to off-centeredness.	Online cut test
3	**Poorly annealed copper conductor**	➢ Due to sinusoidal movement of poorly annealed copper conductor, off centering becomes imminent, and this lead to insulation thickness failures.	GEMBA / touch

Table 4.13: *Cause Validation Matrix for Insulation Thickness Failures*

S/N	Causes	Error Description / Quality Consequences	Confirmation Plan
4	**Faulty heating system**	➢ When the heating system is not heating well, (i.e. either any of the heater bands are not heating well or not heating at all) there is always PVC leakage at the crosshead, and this leakages leads to a drop in the dimension of the cable. This drop in dimension of the able insulation invariably affects the thickness of the insulation.	GEMBA / water spray
5	**Over dimensioned tip**	➢ When the tip is over dimensioned, there is always a flow back, whereby the molten PVC often moves back into the tip in backward direction. This backward movement of molten PVC through the tip opening pushes the wire to one direction thereby, leading to uneven insulation thickness.	GEMBA / Caliper
6	**Inspector to inspector variation**	➢ This is the variation that occurs when the same part is measured by different operators.	Gage R & R
7	**Faulty Measuring tools**	➢ Poorly handled calipers and micrometer screw gauge.	Measurement validation
8	**Inadequate skill and operators recklessness**	➢ When an operator lacks the proper knowledge of centering. ➢ Poor tightening of the tip to the core tube, resulting to flow back of the molten PVC. ➢ Wrong use of tip and die.	GEMBA, and Process yield

Table 4.13: *Cause Validation Matrix for Insulation Thickness Failures*

S/N	Causes	Error Description / Quality Consequences	Confirmation Plan
9	**Faulty tensioning / braking system**	➢ When the braking system fails to regulate the movement of the input reel, the input conductor wire dangles as it move through the core tube. it leads to poor centering and subsequent poor insulation thickness	GEMBA / Touch
10	**Operator's fatigue**	➢ When an operator becomes uneasy with common tasks and finds it difficult to concentrate. As a result of this uneasiness, the operator often, take longer time to start up extrusion operation.	GEMBA/ survey
11	**Improper Speed setting**	➢ When the speed of the capstan is higher than the speed of the extruder, the insulation thickness is greatly affected. On the other hand. ➢ When the speed of the extruder is also higher than the speed of the Capstan there is also a witnessed increase in the cable dimension.	DOE
12	**Poor Monitoring System**	➢ When the process is not properly monitored. For example; when process errors are always detected late, when the insulation thickness checks are not done as it should, when the operators use non-preheated PVC instead of preheated PVC for production, when water trough cotton guides slips-off and the extruded wire is in contact with the trough surface, use of bunched PVC pellets without separating it by bits, when there is volume reduction in the water level in the trough needed to cool off extruding cable and lots more.	GEMBA
13	**Unsteady wire guard**	➢ When the two opposing metals guide that direct the movement of the wire to the core tube is not steady.	GEMBA
14	**Poor fitting of the tip to the core tube**	➢ If the tip is not properly fitted to the core tube, Molten PVC from the tip base now penetrate the tube, pushing the conductor to off center position	Opening of the crosshead

Table 4.14: *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 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 coloration.	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 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 leads to presence of a balloon-like spots on the body of the cable when used for production.	Visual inspection
5	**Poor Monitoring System**		GEMBA
6	**Presence of moisture on the PVC**	➢ PVC's produced after 24hrs that were not preheated before use 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)

Table 4.14: *Cause Validation Matrix for Insulation Surface Flaws*

S/N	Causes	Error Description/ Quality Consequences	Confirmation Plan
8	**Poor flushing of the extrusion barrel**	➢ When the extruding barrel is not properly flushed, it could lead to coloration, insulation surface pores due to 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.**	➢ When the embossing wheel is pressing too tight on the extruding cable. ➢ When the embosser is dangling at its position, thereby scratching the insulation surface. ➢ when the embosser is in loose contact with extruding cable, there are always faint imprints, because the embosser groove is too deep	GEMBA
11	**Bunched PVC (PVC pellets stringing together)**	➢ PVC blocking the hopper base, thereby minimizing the inflow of the molten PVC to the Crosshead	GEMBA

Table 4.14: *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 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 draws. So when capstan draws and releases the wire, there are always bumps on the cable insulation surface.	GEMBA
14	**Inadequate skill/ negligence**	➢ Not allowing the heating system to get to the designed temperature setting. Result of this negligence often lead to production of cables with coarse surface. ➢ Reuse of wire mesh after a particular product color has been changed result in colour variation.	GEMBA
15	**Impurities on the PVC**	➢ When there are sands or dirt's on the PVC material.	GEMBA
16	**Poorly welded Joints.**	➢ When the wire are not properly welded, it often obstruct free movement of the wire across the tip, and when this happens, there is always bumps at the surface of the insulation.	Measurement

Table 4.14: *Cause Validation Matrix for Insulation Surface Flaws*

S/N	Causes	Error Description / Quality Consequences	Confirmation Plan
17	**Management Interferences/ Poor material Logistic / lack of motivation**	➢ Management interference during production activities in terms of abrupt decisions on product color change. ➢ Complacency to provide necessary replacement materials when minor production defects are noticed. ➢ Management inability to document operator's intuitive knowledge of the process. ➢ No incentives program for operators that meet the production target.	GEMBA Survey

To analyze the decision of eliminating defects in extrusion of primary cable, a judgmental model, known as the Analytical Hierarchy Process (AHP) was developed.

4.3.1 **Analytical Hierarchy Process (AHP)**

Analytical Hierarchy Process (AHP) was applied to prioritize the criticality of these defect causes. Starting with the Insulation Thickness Failures, the first step was to model the decision by building a hierarchy for the decision. The developed model for the decision was decomposed into a hierarchy of goal, and criteria as seen in figure (4.17).

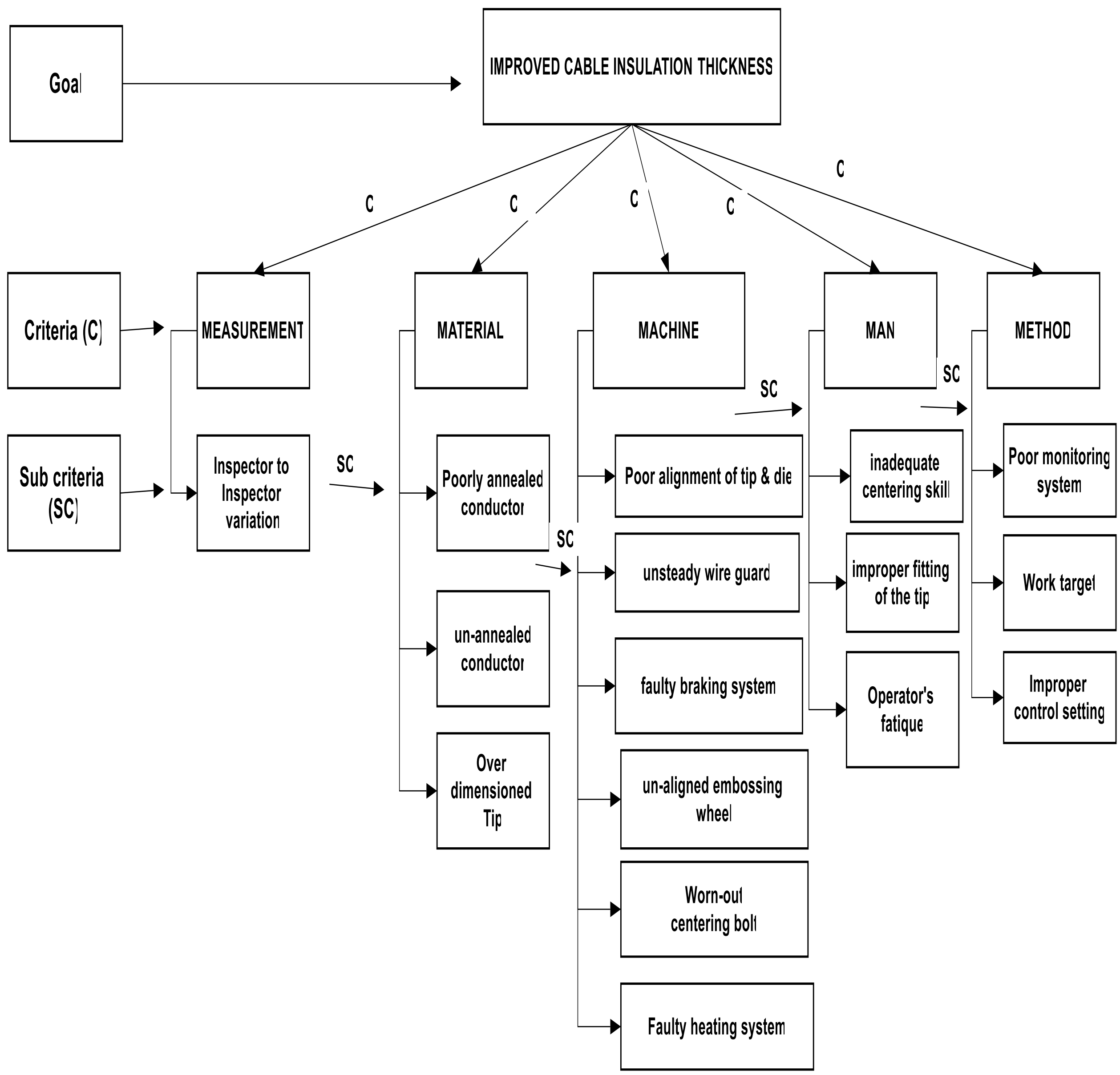


Figure 4.17. Modeled decision hierarchy for producing cable with improved Insulation Thickness.

In figure 4.17, the first level of the hierarchy is our goal i.e. improving the Insulation thickness of extruded cable), while the second level in the hierarchy is constituted with the criteria used to achieve the goal. The pairwise comparison of the Insulation thickness criteria were made and are shown in Table (4.15). Thereafter, a comparison matrix of the criteria in the decision was created also (see Table 1 of Appendix F) to reflect the relative intensity judgment in each of the compared pair.

Table 4.15: *Main Criteria Comparison Table for the Improved Cable Insulation Thickness*

Name		Criteria		More Important	Intensity
I	j	A	B	A or B	(1-9)
1	2	Measurement	Material	B	3
1	3		Machine	B	3
1	4		Man	B	3
1	5		Method	B	3
2	3	Material	Machine	A	3
2	4		Man	A	3
2	5		Method	B	2
3	4	Machine	Man	A	3
3	5		Method	A	2
4	5	Man	Method	B	3

The comparison matrix was normalized using approximate method to obtain the final priorities or the principal priority vector as shown in Table (4.16).The Cop and few other experienced personnel from the manufacturing department contributed to this stage of AHP, which is the pairwise comparison between every two sub-causes. The influence of one cause compared to the influence of the other causes on generation of defects associated with Insulation thickness failures was judged.

Table 4.16: *Normalized Matrix for the Principal Eigen Vector for the Main Criteria*

Criteria	Material	Machine	Man	Method	Measurement	Principal Priority vector
Measurement	0.076923	0.083271	0.049955	0.032227	0.124906	0.073456
Material	0.230769	0.250063	0.450045	0.290332	0.187547	0.281751
Machine	0.230769	0.083271	0.150015	0.290332	0.187547	0.188387
Man	0.230769	0.083271	0.049955	0.096777	0.124906	0.117136
Method	0.230769	0.500125	0.30003	0.290332	0.375094	0.33927

For the consistency check at the criteria level 1: Lambda (λ) = 5.382073, C.I = 0.095518, C.R = 0.088 < 0.1 for n= 5; R.I = 1.1086 (acceptable)

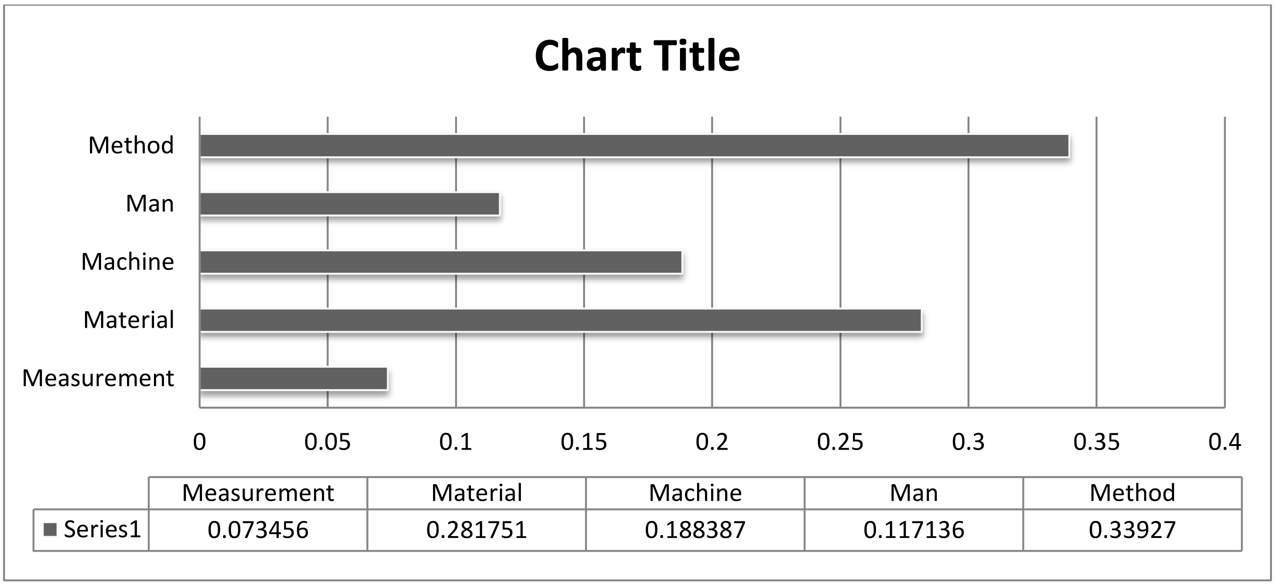


Figure 4.18. Graphical representation of criteria and their prioritized judgments

In the measurement subgroup, there is only one pair of sub criteria, so they were compared to how important they are with respect to the measurement criterion. In the material subgroup, each pair of sub criteria was compared regarding their importance with respect to the material criterion, and so on for the other criteria. Judgments consistencies were tabulated in Table (4.17). The consistency ratio as you can see from the table are all less than 0.10.

Table 4.17: *Consistency Indices for the Improved Insulation Thickness Sub criteria*

AHP indices	λ_{max}	C.1	N	R.I	C.R	Decision
Material	3.038166	0.019083	3	0.5245	0.036	Acceptable
Machine	6.525585	0.105116	6	1.2476	0.084	Acceptable
Man	3.03814	0.01907	3	0.5245	0.036	Acceptable
Method	3.03814	0.01907	3	0.5245	0.036	Acceptable

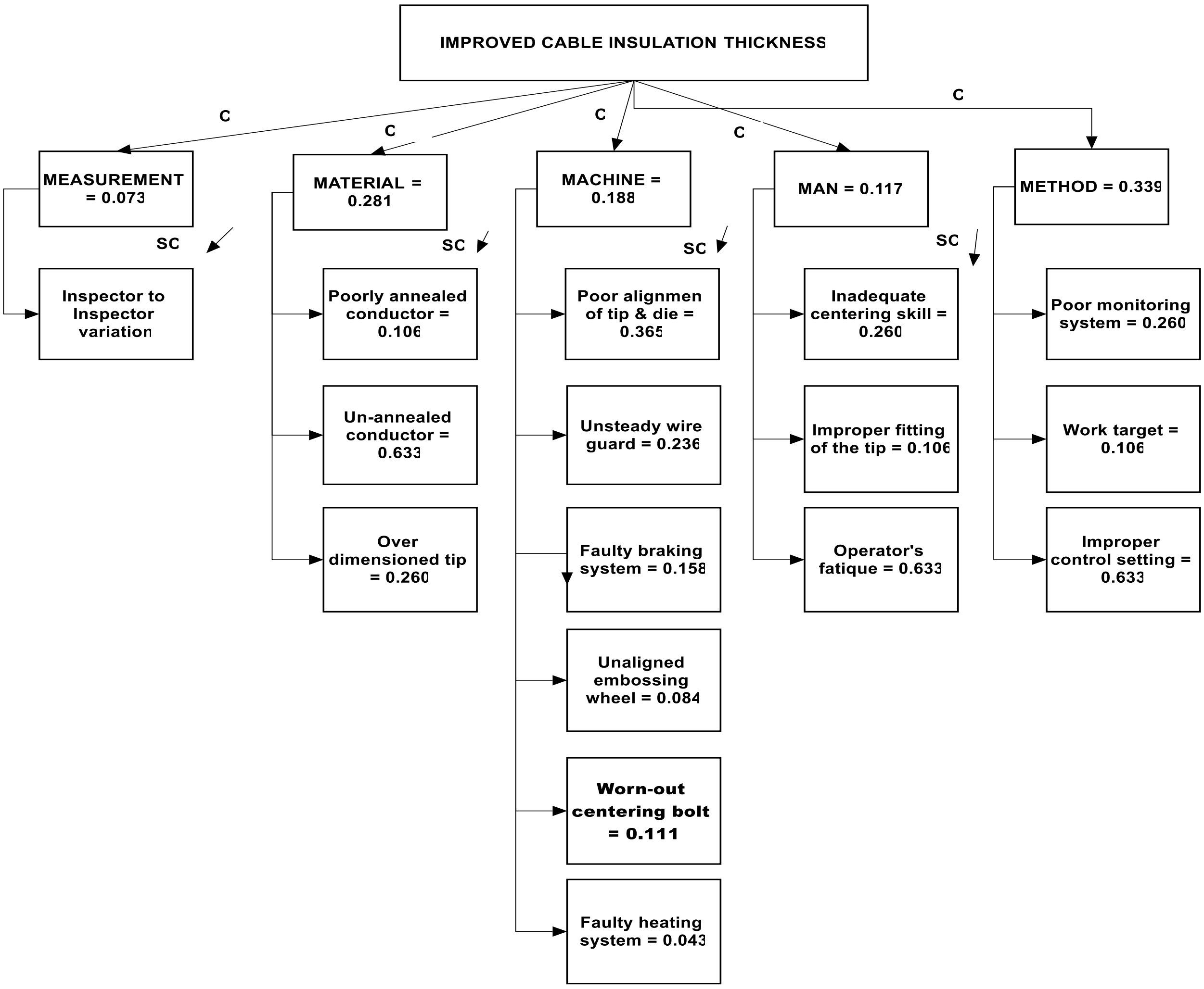


Figure 4.19. Modeled decision hierarchy with the prioritized judgments for the Cable Insulation thickness

At this point, using the Analytic Hierarchy Process (AHP), all the comparisons for the criteria and sub criteria have been made and the local priorities for each group at each level as shown in figure 4.19. The priority of each criterion contributes to the priority of the goal (G = 1) and the priority of each sub criteria contributes to the priority of its parent therefore the global priority throughout the hierarchy is equal to one. Based on the judgments entered by the Cop, with the use of AHP, we have derived priorities for the factors and are shown from highest to lowest in Table (4.18) as well as in figure (4.19).

Table 4.18: *Derived Factor Priorities for the Improved Cable Insulation Thickness*

S/N	Factors	Global Priority	Factors	S/N	Global Priority
1	Poor monitoring	0.215	Work target	9	0.036
2	Un-annealed conductor	0.178	Inadequate centering skill	10	0.03
3	Improper control setting	0.089	Poorly annealed conductor	11	0.03
4	Operator's fatigue	0.074	Un-aligned embossing wheel	12	0.029
5	Over dimensioned tip	0.073	Faulty braking system	13	0.021
6	Measurement	0.073	Faulty heating system	14	0.016
7	Poor alignment of tip & die	0.068	Improper fitting of the tip	15	0.012
8	Worn-out centering bolt	0.044	Unsteady wire guard	16	0.008

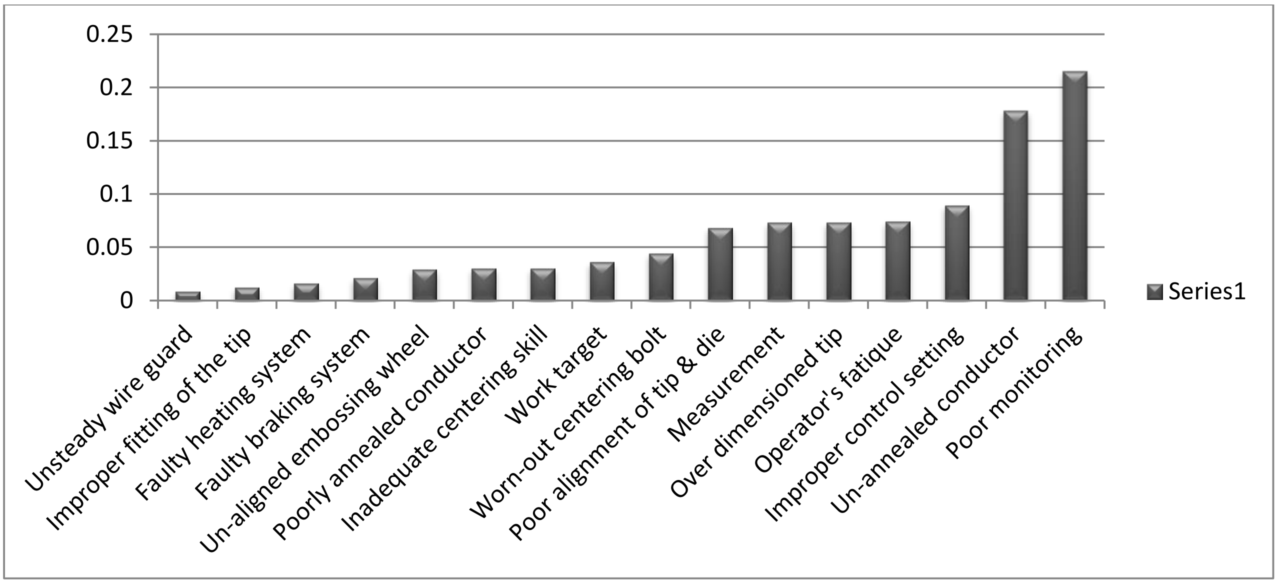


Figure 4.20. Ranking of the sub criteria/ sub causes for improving Insulation thickness in cable.

Figure (4.20) shows the ranking of the fourteen sub causes, the aggregations of the decision-making group pairwise comparisons are illustrated with the normalized weights. The bar chart in figure 4.20 shows a descending order of the sub-causes organized by their normalized weight. From this chart, we see that poor monitoring had the highest effect, and then the use of un-annealed conductor to improper control setting and so on till reaching the factor that had the lowest effect on the generation of Insulation thickness defect cables, which is the unsteady wire guard. The 80-20 rule was used to recognized sub-causes/ sub criteria that have most influences on the generation of cables with failed Insulation thickness. The rule showed that there are eight sub causes that account for 80% of the defects, and they are as follows: poor monitoring, un-annealed conductor, improper control setting, and operator's fatigue, over dimensioned tip, measurement, poor alignment of tip & die, and worn-out centering bolt.

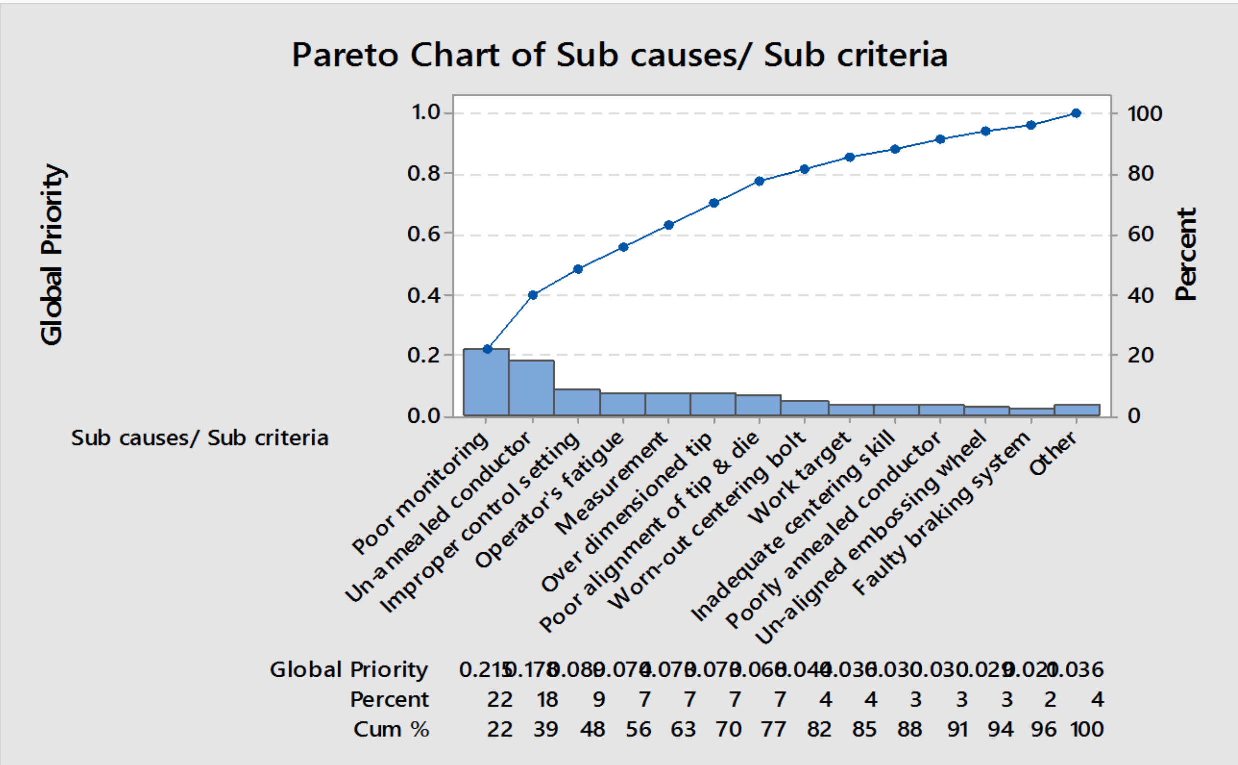


Figure 4.21. Pareto Chart of sub causes of Insulation Thickness Failures

However, all the identified sub causes were considered in the Improve phase of the DMAIC process for possible improvement according to the available company resources. Sequel to prioritization approach applied for different causatives for Insulation thickness failure, similar model was also developed for the decision of eliminating Insulation Surface Flaws in the extrusion of primary cable. The developed model was also decomposed into a hierarchy of goal, and criteria as shown in figure 4.22. The pairwise comparisons of the Insulation Surface Flaws criteria were made and are as shown in Table 1 of Appendix G. After which, a comparison matrix of the criteria in the decision was created also (see Table 2 of Appendix G) to reflect the relative intensity judgment in each of the compared pair.

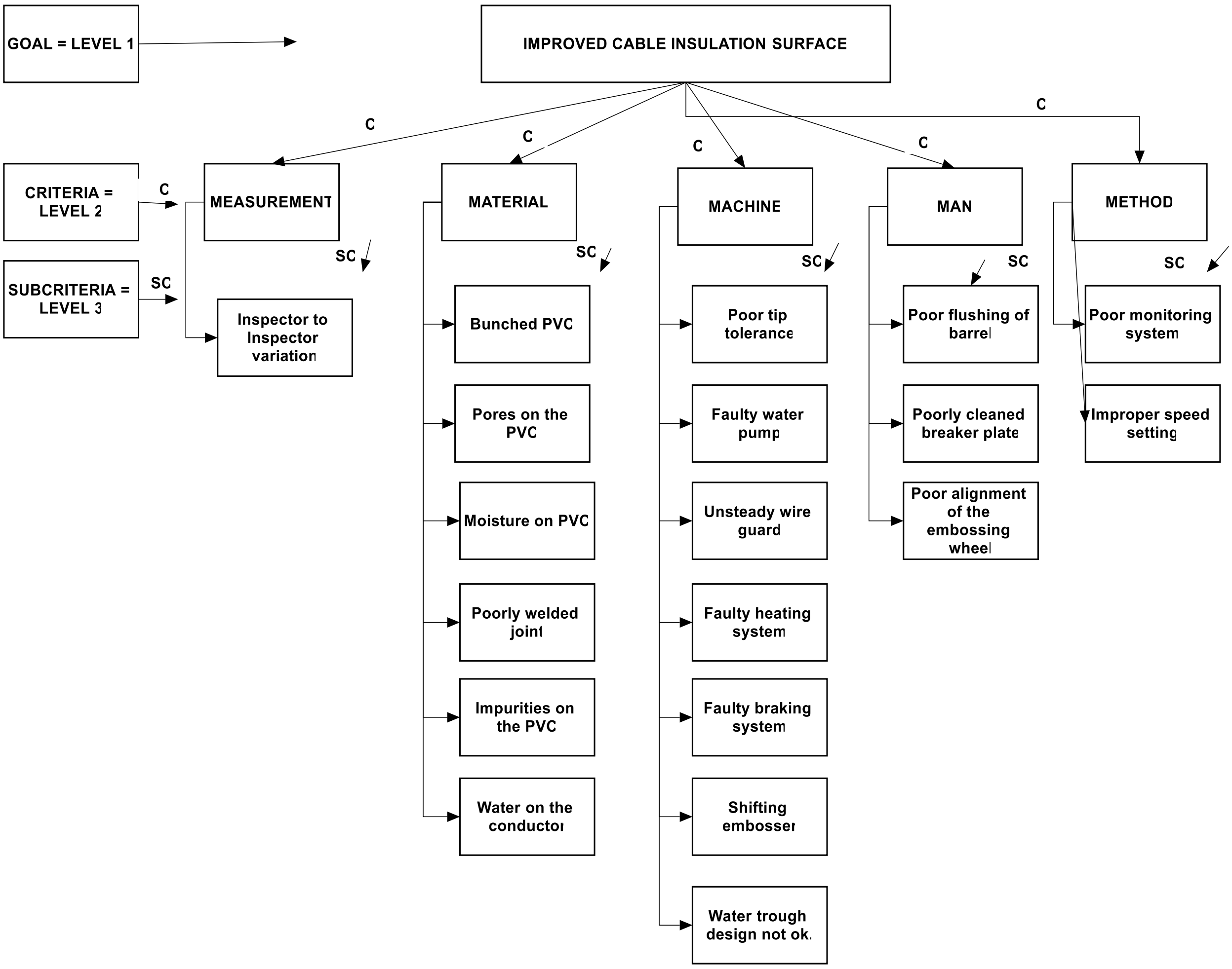


Figure. 4.22. Modeled decision hierarchy to improve cable Insulation Surface

The comparison matrix was normalized using approximate method to obtain the final priorities or the principal priority vector as shown in Table (4.19). The influence of one cause compared to the influence of the other causes on generation of defects associated with cable Insulation Surface Failures was judged also as were previously done for the cable Insulation thickness Failure.

Table 4.19: *Normalized Matrix for the Principal Eigen Vector for the Main Criteria*

Criteria	Material	Machine	Man	Method	Measurement	Principal Priority vector
Measurement	0.058824	0.076128	0.068434	0.034451	0.023233	0.052214
Material	0.411765	0.533106	0.616523	0.517277	0.348845	0.485503
Machine	0.176471	0.177524	0.205508	0.310366	0.348845	0.243743
Man	0.176471	0.106621	0.068434	0.103455	0.209307	0.132858
Method	0.176471	0.106621	0.041102	0.034451	0.069769	0.085683

For the consistency check at the criteria level: Lambda (λ) = 5.39735, C.I = 0.0993, C.R = 0.089 < 0.1 for n= 5; R.I = 1.1086 (acceptable).

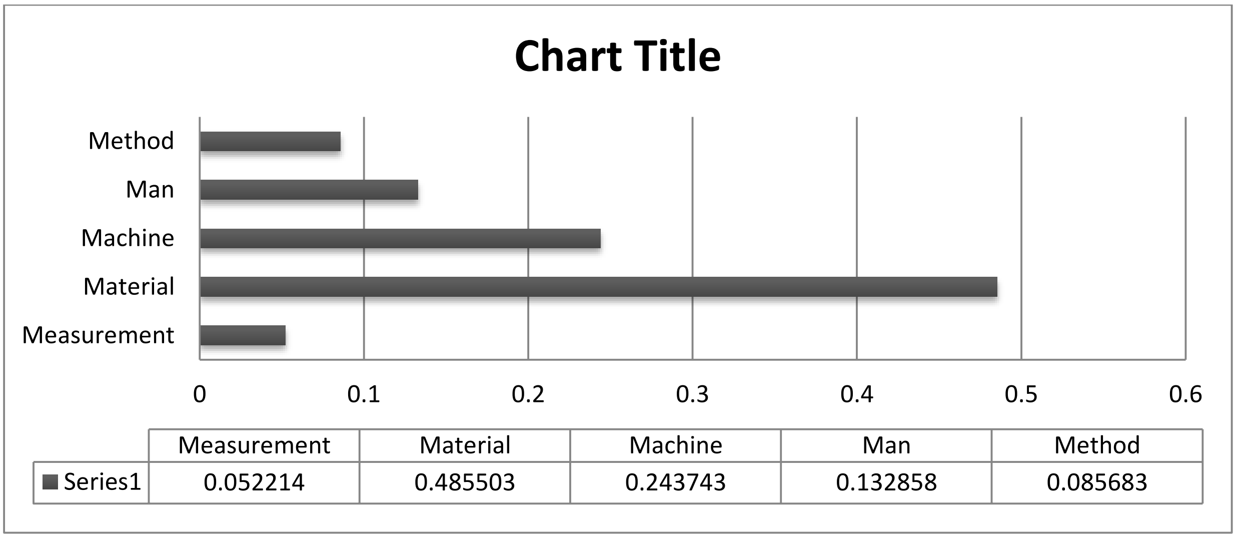


Figure.4.23. Graphical representation of criteria and their prioritized judgments for Insulation Surface Flaws.

From figure 4.23 starting with the measurement subgroup, there is only one pair of sub criteria, so they were compared to how important they are with respect to the measurement criterion. The material subgroup has six pairs, bunched PVC, pores on the PVC, poorly welded joint, impurities on the PVC, water on the conductor. Each pair of the material subgroup was compared regarding their importance with respect to the material criterion and the same approach was used on the other defect criteria. Judgments consistencies are shown in Table (4) of Appendix G

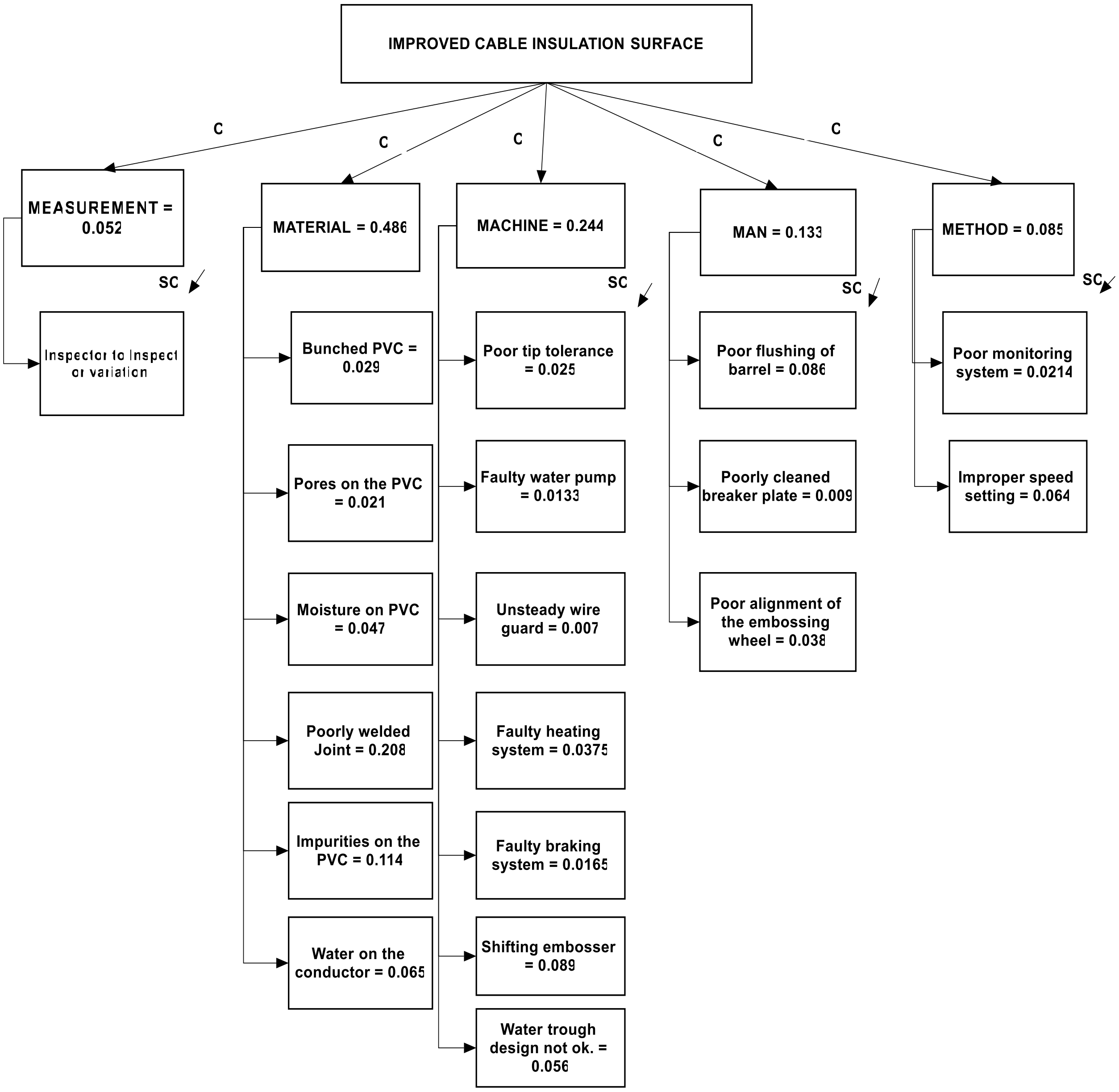


Figure.4.24. Modeled decision hierarchy with the prioritized judgments for the Cable Insulation Surface.

All the comparisons for the criteria and sub criteria have been made and the local priorities for each group at each level as shown in figure 4.24. The priority of each criterion contributes to the priority of the goal (**G = 1**) and the priority of each sub criteria contributes to the priority of its parent therefore the global priority throughout the hierarchy is equal to one.

Based on the judgments entered by the Cop, with the use of the AHP, factor priorities have been derived and are shown from highest to lowest in Table (4.20) as well as in figure (4.27).

Table 4.20: *Derived Factor Priorities for the Improved Cable Insulation Surface*

S/N	Factors	Global Priority	S/N	Factors	Global Priority
1	Poorly welded joint	0.208	12	Bunched PVC	0.029
2	Impurities on PVC	0.114	13	Poor tip tolerance	0.025
3	Shifting embosser	0.089	14	Poor monitoring system	0.021
4	Poor flushing of the extruder barrel	0.085	15	Pores on the PVC	0.021
5	Water on input conductor	0.0651	16	Faulty braking system	0.0165
6	Improper speed setting	0.0643	17	Faulty water pump	0.0133
7	Water trough designed not ok.	0.056	18	Poorly cleaned breaker plate	0.0098
8	Measurement	0.052	19	Unsteady wire guard	0.007
9	Moisture on PVC	0.047			
10	Poor alignment of the embossing wheel	0.0376			
11	Faulty heating system	0.0375			

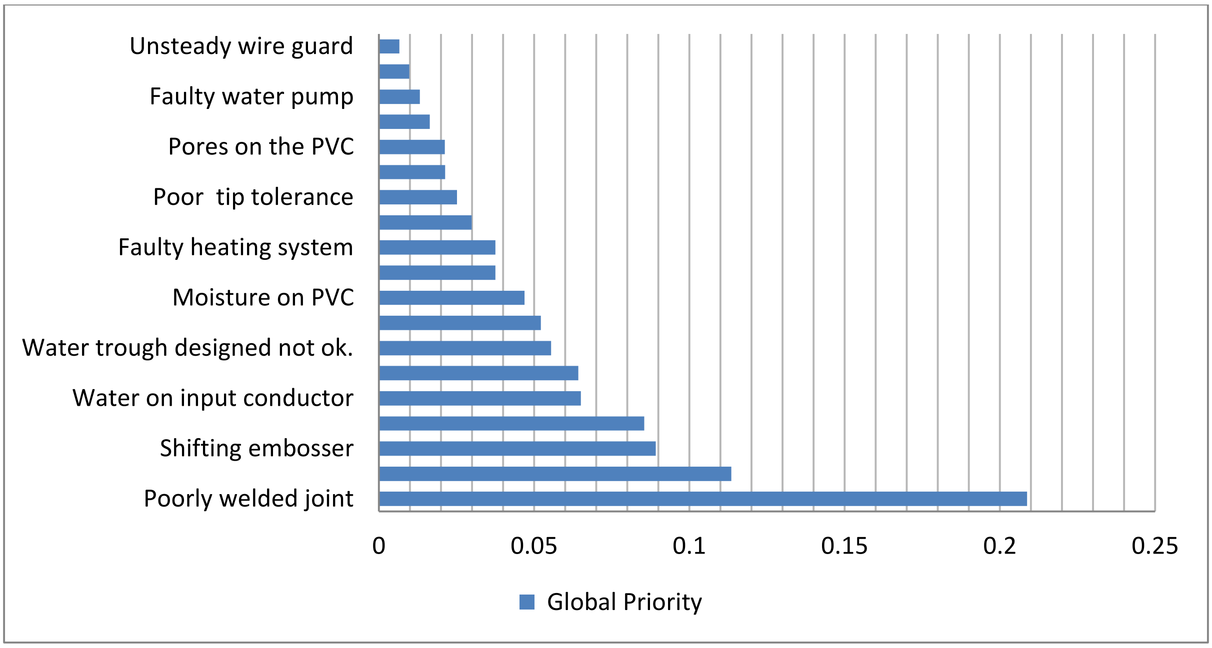


Figure.4.25. Ranking of the sub criteria/ sub causes for Cable Insulation Surface flaws

Figure (4.25) has shown the ranking of the nineteen sub causes, the aggregations of the decision-making group, pairwise comparisons are illustrated with the normalized weights.

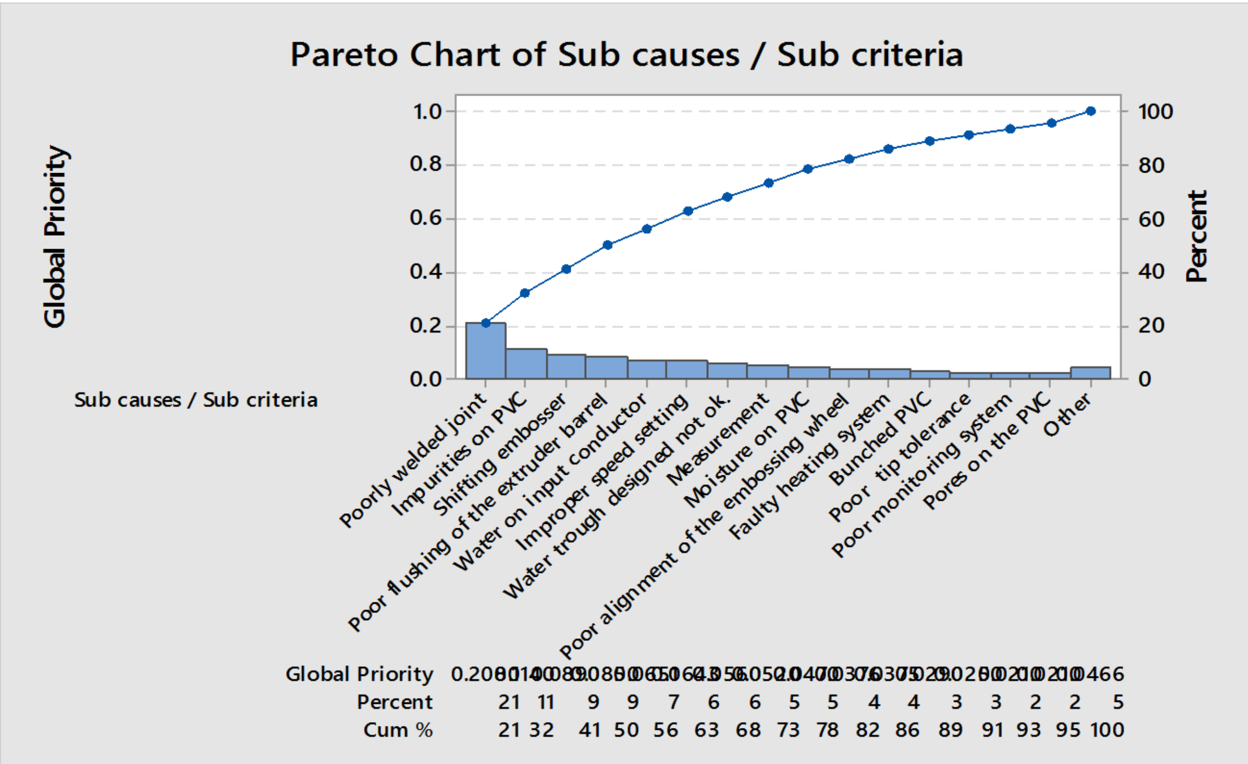


Figure. 4.26. Pareto Chart of sub-causes for Insulation Surface Flaws

Figure (4.26) shows a descending order of the sub-causes organized by their normalized weight. From this chart, we see that poorly welded joint had the highest effect, and then the shifting embosser to water on the input conductor and so on till reaching the factor that had the lowest effect on the generation of Insulation Surface Flaws, which is the unsteady wire guard. The 80-20 rule was used to recognize sub-causes/ sub criteria that have most influences on Insulation Surface Flaws. The rule showed that there are nine sub causes that account for 80% of the cable Insulation Surface Flaws and they are as follows: poorly welded joint, impurities on PVC, shifting embosser, poor flushing of the extruder barrel, water on the input conductor, improper speed setting, water trough design not ok, measurement, moisture on PVC. However, all the identified sub causes were considered in the Improve phase, of the DMAIC process for possible improvement according to the available company resources.

4.3.2 **After Action Review**

Having identified earlier the opportunities to be targeted for investigation in the Improve phase, the team members also deliberated on other common reoccurring challenges in the extrusion process line that affect productivity such as wire entanglement, incessant tip break, tensioning problem, colour variations and material wastes.

4.3.3 **The 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 4.21 & 4.22. 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: 4.21: *Solutions for Reducing Insulation Thickness Failures*

S/N	Causes for Cable Insulation thickness failures.	Solutions for reducing the rate of cable failure due to poor concentricity of cables.
1	**Un-aligned embossing wheel**	➢ Careful check by the operator on the position of the embossing wheel to the cable, and confirmed by the process engineer on the line immediately after secondary centering has taken place. The process engineer should from time to time check the movement of the embosser in relation to the extruding cable, and also feel the extruding cables to check the quality of the embossment.
2	**Worn-out centering bolts**	➢ Improvement on centering techniques and use of high temperature yielding bolts and nut, basically medium carbon steel composition of 8.8MPa and above.
3	**Faulty measuring tools**	➢ Digital calipers should not be placed on vibrating machines. Secondly, before measurement, operators must first measure a reference dimension with the caliper before taking any online measurements.
4	**Faulty heating system**	➢ The condition of the heating system should be checked properly by both the operator and the process engineer and validated at the start of every production shift. The functionality of the heater bands should always be checked at least every 20 minutes using water sprays. Always use candle stick heater bands at the crosshead section for easy replacement and correction.
5	**Inadequate skill**	➢ Training on “centering” techniques and Standard Operating Procedures (**SOP**).

Table: 4.21: *Solutions for Reducing Insulation Thickness Failures*

S/N	Causes for cable Insulation thickness failures.	Solutions for reducing the rate of cable failure due to poor concentricity of cables.
6	**Faulty heating system**	➢ The condition of the heating system should be checked properly by both the operator and the process engineer and validated at the start of every production shift. The functionality of the heater bands should always be checked at least every 20 minutes using water sprays. Always use candle stick heater bands at the crosshead section for easy replacement and correction.
7	**Poorly annealed copper conductor**	➢ If it will be used at all, then extremely care must be taken by assigning the job to the most experienced operator. Secondly, the extrusion parameter settings must be varied in such a way to increase the cable dimension, thus eliminating the possibility of producing off-centered cables.
8	**Over dimensioned tip**	➢ Not to be used at all.
9	**Poor monitoring system**	➢ Improve monitoring system 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].

Table: 4.21: *Solutions for Reducing Insulation Thickness Failures*

S/N	Causes for cable Insulation thickness failures.	Solutions for reducing the rate of cable failure due to poor concentricity.
9	**Faulty tensioning system**	➢ Total overhaul on the braking system.
10	**Operator's fatigue**	➢ Work appraisal
11	**Improper speed setting**	➢ Optimal setting of the extrusion parameters
12	**Poor tip fitting**	➢ The fitted tip should be sighted by the process engineer before in use

Table: 4.22: *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].

Table: 4.22: *Solutions for Reducing Insulation Surface Flaws in Cable Extrusion Process*

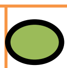
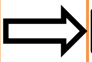
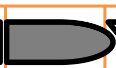
S/N	Causes of cable Insulation Surface flaws.	Solutions for reducing the rate of cable failures due to Insulation surface flaws.
5	**Improper setting of speed**	➢ Optimal parameter settings through experimental designs.
6	**Poor flushing of the extrusion barrel**	➢ Proper flushing and adequate monitoring. 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 to also make sure that the operators always adhere to standard operating procedure.
12	**Poorly welded wire.**	Careful filling of the welded joint (measure the welded point after weld)
13	**Management problems / lack of motivation**	Review the existing incentive programme, improvise adequate resource planning system that will ensure needed parts and materials are readily available.

Further attempts to solutions on the identified root causes of these defects were made by the team through work study so that most of the production anomalies that often lead to production defects are eliminated. The team engaged in a systematic analysis of all the elements, factors, resources and relationships affecting the efficiency and effectiveness of the extrusion process of 1.0mm single house wiring cable in TEKO-50 Production line. This investigation on work situations was conducted to identify production weaknesses and reasons for poor performance. The existing operating methods were evaluated, which encompass the nature of the extrusion machine, layout of operations, material supply and handling, the effectiveness of planning procedures, possible idle times.

4.3.4 **Method Study**

The mnemonic SREDIM which is a common-sense heuristic that followed a six-stage approach was employed in the Method Study. A task was selected such that with the proposed method there will be an improvement in quality with lesser scrap and elimination of unnecessary operations and movements.

Table 4.23: *Flow Process Chart (AS -IS)*

Step	**Time**	**Distance (meter)**						**Step Description**
1		17		X		X		Conveying of the reels (input/output). Most times operators have to wait for the conveying forklift
2					X	X		Inspection of the input diameter by the QA staff
3			X					Load the input reel at the take-off end
4			X					Pass the input wire through the core tube, tip and the die
5			X					Open the crosshead
6			X					Clean the breaker plate and change the wire mesh

The task that was selected for the method study was considered across these aspects, economic, technical and human. Extrusion of the primary coil is one of the key business processes of the company, and the extrusion task that was chosen for investigation was the "Start-up Operation" which is the bottleneck operations. Based on the above highlights, "Start-up Operation" is the most important part of the extrusion activities due to its production relevance, and it requires more care and adequate attention to execute. The selected task was broken down into elements for easy examination as shown in Table 4.23.

Table 4.23: *Flow Process Chart (AS -IS)*

Step #	**Time**	**Distance (meter)**	●	⇨	▭	D	▽	**Step Description**
7			X					Flush the barrel and couple back the crosshead
8			X					Tie the input wire with the existing wire
9			X					Load the output reel and tie with the wire at the pay-off section.
10			X					Start the line at low speed and do centering
11		-			X	X		Inspect Centricity with QA staff
12		-	X					Extrusion
13		-	X					Unloading the output reel
14		3		X				Transport to corner

In Table 4.23, the "**Start-up**" task was split into fourteen (14) elements for an in-depth examination. It was observed that some activities need to be eliminated from the operation in order to save time and improve product quality. Table 4.24 summarized the "**AS-IS**" process sequence, and from the table, the number of operational steps are ten (10), transportation = 2, inspection = 2. It was found from the existing process that most of the idle times were as a result of time wasted in conveying the input copper conductor from the wire drawing section to the extrusion line, and this takes about 5-to-10 minutes to get the input reel. This is because, most times the input reel are not readily available at the extrusion line, and requires the use of forklift to convey the reels to the process line by the machine operator.

Table 4.24: *Summary of the Process Sequence (AS -IS).*

	Operation	Transport	Inspection	Delay	Store
Number of steps	10	2	2	2	0
Time (min)	-	5-10+5	(5+5)	10	0
Distance (meters)	-	20	-	-	-

Apart from productive hours that are being wasted in getting the input material for a normal operation, the workers are also stressed unnecessarily and this leads to operator's fatigue, and to some other quality consequences in the production line.

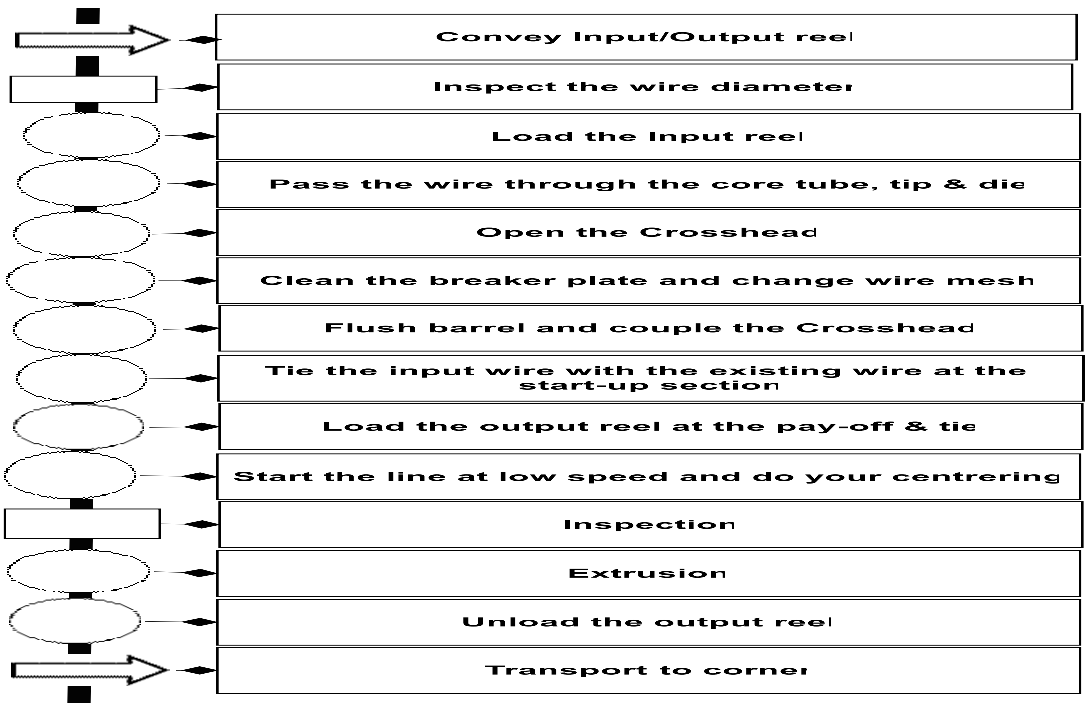


Figure.4.27. Process Flow Chart (AS-IS Method)

In addition, time is also wasted unnecessarily during inspection of the diameter of the input wire. Since all the drawn wires at the drawing section were certified by the Quality Assurance staff after drawing ,and were designated with tags, so waiting for further inspection of the input material before starting up an operation amounts to idle time and waste of productive hours.

Table: 4.25. *Flow Process Chart (Improved method)*

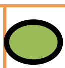
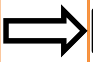
Step	**Time**	**Distance (meters)**						**Step Description**
1		-	X					Load the input reel at the take-off end
2		-	X					Pass the input wire through the core tube, tip and the die
3		-	X					Open the crosshead
4		-	X					Clean the breaker plate and change the wire mesh
5		-	X					Flush the barrel and couple back the crosshead
6		-	X					Load the output reel at the pay-off & tie
7		-	X					Continue to flush the barrel while the line is still and start your centering.
8		-	X					Start the line at low speed and continue centering
9		-			X	X		Inspect Centricity with QA staff

Table: 4.25. *Flow Process Chart (Improved method)*

Step	**Time**	**Distance (meters)**						**Step Description**
10		-	X					Extrusion
11		-	X					Unload the output reel
12		3		X				Transport to corner

After studying the existing process, an improved method was proposed as shown in Table 4.25. Although an in-depth study on the basic functions of the organizations MRP system like inventory control, bill of material processing and elementary scheduling were not deeply treated. The company's Master schedule was followed all through in the improved method in ensuring that materials and components were available for production and final products were readily made available for dispatch. The machine Operators were exempted from the task of transporting especially the input reels. The input materials were conveyed before the start of every production shifts, and the number of input reels are always made higher in number than other input materials during conveyance, due to possibilities of having entangled wires in a reel. Minimum of two machine operators were proposed to work in a single extrusion line such that when there is a material shortage during operation, one of the operators can fill in the position of procuring the needed material without necessarily halting the production sequence.

Table 4.26: *Summary of the Process Sequence (Improved Method)*

	Operation	**Transport**	**Inspection**	**Delay**	**Store**
Number of steps	10	1	1	1	0
Time (min)		5	5	5	0
Distance (meters)		3	-	-	-

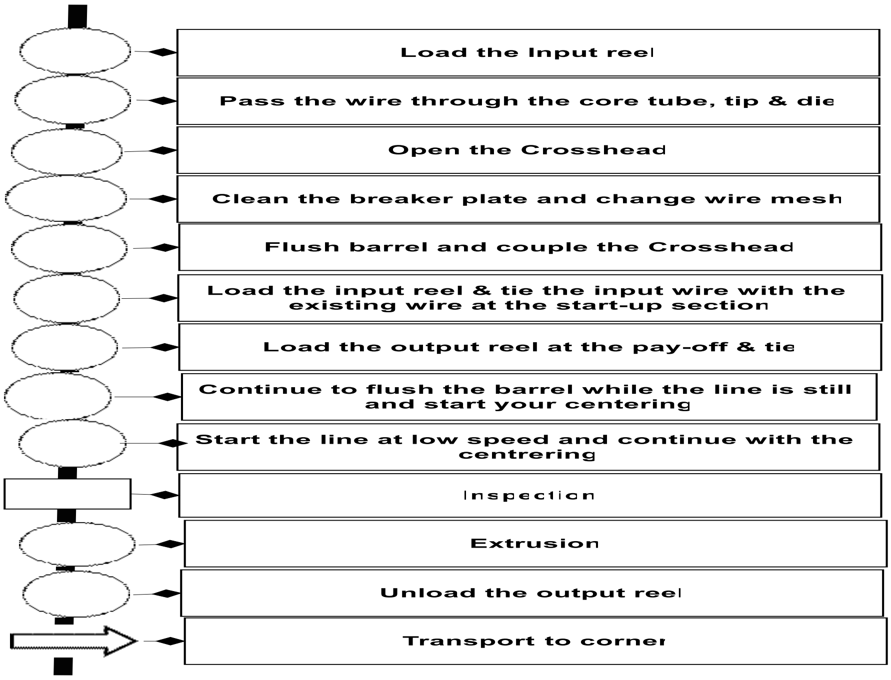


Figure. 4.28. Extrusion Start-up Operation (Improved Method)

The summary of the process sequence on the new method has shown that with the new method that some wasteful production activities can save considerable amount of time. It was also found that the workers have varying methods of "Centering". A centering operation is majorly positioning the conductor during extrusion in a central position to the middle of the die opening such that when rounding with the molten PVC from the extruder, the Insulation thickness will not be compromised.

4.3.4.1 Conductor Positioning in Cable Extrusion Process

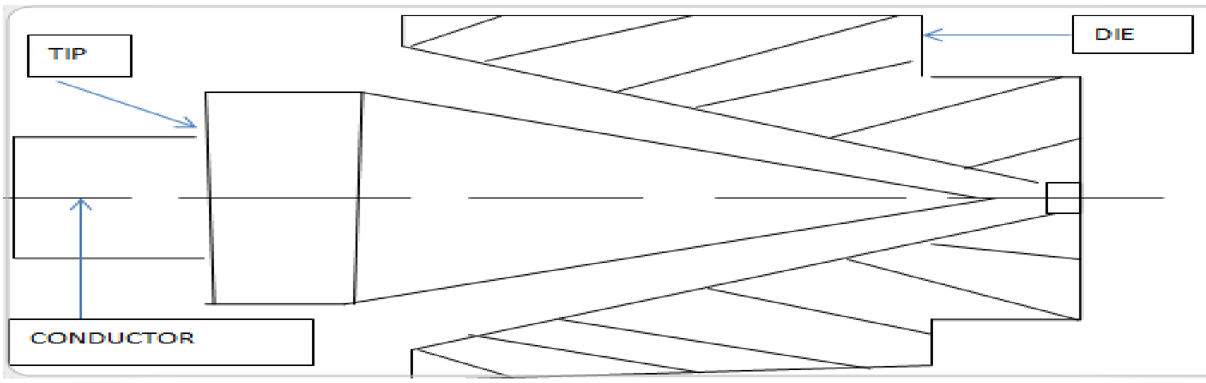


Figure 4.29. Diagrammatic representation of Extrusion Machine's Tips and Die

From the drawing in Fig. 4.29, the conductor is being passed through the tip and the die openings. The tip guides the conductor to alignment, while the die guides the tip in position during extrusion. These two extrusion machine components have a great impact on the positioning of the conductor in cable extrusion; as well as with other quality characteristics. Figure 4.30 is the Cross head section of the extrusion machine, which is the only domain where cable concentricity is controlled through a process called "Centering".

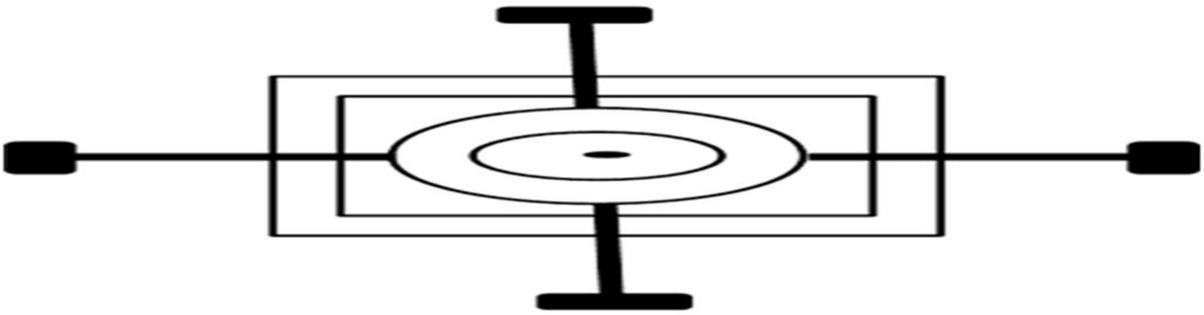


*Figure 4.30***.** Cross sectional view of Cross head and the centering bolts

Better centering method was suggested after observing the centering processes a good number of times. The team resolved that it will be best to first start centering operation even while the line is stationary than the lone practice of taking centering while the line is at low speed. This new improved method of centering was carefully followed in the subsequent productions. On the other hand, poor adjustment of bolts during centering was also identified as part of the human causatives to poor concentricity. Because of most operators' poor centering skills, they enforce more pressure on the bolt while trying to force a die cup movement which often leads to the breaking of the bolts, and subsequently die cup wobbling.

Appropriate bolt adjustment technique was suggested to the operators (for instance: if the flow of the PVC is one-sided, let’s say towards the right side and needs to be adjusted a bit to the right side), the operator should loosen the opposite side bolt, and if one intends to move the bolt for one revolution, it is advised that the opposite end is loosened by two so that the die cup will give room for adjustment. Secondly, it was observed that the bolt and the nut guiding the die cup are of different material compositions. While the bolt is made of medium carbon steel, the nut is made of mild steel. The medium carbon steel bolt is of 8.8MPa tensile strength, while the nut is of mild steel of 4.8Mpa tensile strength. However, because the tensile strength of the bolt and the nuts are different, the mild steel tends to yield more easily than the medium carbon steel. As the mild steel yield due to the high temperature of the crosshead, there is an inevitable shift in the bolt grip, thereby resulting in off-centering of the cable. It is best advised to always clean the centering bolts with iron brush before starting up a line to ensure the bolt threads are not patched with the worn-out deposits from the nut.

4.3.5 **Analysis on the Experimental Design**

Common knowledge of the extrusion process drawn from the CoP interaction has linked the existence of a correlation between capstan and extruder speed with variations in the dimension of cable. An experiment was further designed to investigate whether the assumed correlation was statistically significant. In particular, an experiment was designed to investigate whether these parameters Capstan and Extruder speed has a negative effect on the process, thus leading to failure in the minimum prescribed insulation thickness and material wastes. In order to analyze the experiment's results, two-way analysis of variance (ANOVA) was used. According to Pyzdek, (2003), two-way analysis of variance is best suited for investigating two factors which might interact with one another, and where you can obtain more than one result for each combination of experimental parameters (treatment).

Table 4.27: *Cable Diameter Experimental Data*

Extruder (*rpm*)	*Caps* tan (*rpm*)	*Caps* tan (*rpm*)	*Caps* tan (*rpm*)	*Caps* tan (*rpm*)
875	375	400	425	450
	2.710	2.591	2.670	2.600
	2.760	2.680	2.590	2.530
	2.760	2.620	2.603	2.504
	2.700	2.532	2.501	2.510
	2.740	2.570	2.530	2.490
900	2.810	2.820	2.700	2.660
	2.640	2.770	2.691	2.620
	2.790	2.710	2.691	2.690
	2.770	2.740	2.720	2.606
	2.700	2.700	2.680	2.590
925	2.901	2.800	2.741	2.680
	2.844	2.730	2.782	2.790
	2.920	2.770	2.790	2.700
	2.840	2.800	2.706	2.600
	2.800	2.740	2.732	2.690
950	2.910	2.870	2.860	2.710
	2.890	2.791	2.790	2.800
	2.923	2.911	2.890	2.710
	2.802	2.890	2.760	2.770
	2.850	2.760	2.710	2.770

In this study, the team was interested in improving the extrusion process for 1.0mm single cable. Two factors are to be evaluated, the capstan and extruder speed at four different speed levels. The feasible space for extrusion parameter was defined by ranging the capstan speed in the range 375-450 rpm, and the extruder speed in the range 875-950 rpm. Each experimental combination of the parameters was repeated five times and was analyzed using Microsoft Excel 2010. In the two-way ANOVA experiment with replicates, any P-value less than 0.05 would indicate a significant effect. The ANOVA table P-value of less than 0.05 indicates there is significant difference between the different columns (Capstan speed). The

P-value of 1.08E-18 indicate there is a significant difference between the rows (Extruder speed), while the interaction of capstan speed and extruder speed is not significant by the level of 0.202625.

Table 4.28. *ANOVA Table for the Cable Diameter Experiment (Output from Microsoft Excel)*

ANOVA

Source of Variation	SS	D*f*	MS	F	P-value	F *crit*
Sample	0.485774	3	0.161925	60.67432	1.08E-18	2.748191
Columns	0.242544	3	0.080848	30.2943	2.61E-12	2.748191
Interaction	0.03871	9	0.003763	1.4102	0.202625	2.029792
Within	0.1708	64	0.002669			
Total	0.932989	79				

The result from the Table 4.28 indicated there was a correlation between the capstan speed and extruder speed at a 5% (0.05) significance level. Detailed analysis on the two-way ANOVA with replicate is found in Appendix J. The next step was to determine the optimum parameter settings that would result in the lowest amount of defects by using Taguchi method and Response Surface Method of experiment to create a fractional design of the experiment. The method is related to finding the best values of the controllable factors to make the problem less sensitive to the variation in uncontrollable factors. In the Taguchi method,

Table 4.29: *Determining the Degree of Freedom (DOF)*

Factors	Degree of Freedom (DOF)
Overall mean	1
Capstan speed	(4-1) = 3
Extruder speed	(4-1) = 3
Total DOF	∑ 1+3+3 = 7

the degree of freedom (DOF) rules was used to determine the number of experimental runs. In the present study, the interaction between the two extruding parameters is neglected, and the Taguchi orthogonal array design of L16 (4^2) was selected for the study as described in Table 4.30. In order words, the experiment was designed to undergo 16 runs at different parameter settings.

Table 4.30: *Experimental Layout using an L16 Orthogonal Array*

Experimental run	Extrusion parameter level	
	A	B
	Capstan speed	Extruder speed
1	1	1
2	1	2
3	1	3
4	1	4
5	2	1
6	2	2
7	2	3
8	2	4
9	3	1
10	3	2
11	3	3
12	3	4
13	4	1
14	4	2
15	4	3
16	4	4

In this experimental study, cable dimension is the quality characteristics under investigation, thus a nominal-is-best quality characteristic was chosen. This **S/N ratio** assumes that the given target is best and is appropriate when there is a target value with both upper and lower tolerance limits. Taguchi method uses a statistical measure of performance S/N ratio borrowed from electrical control theory to choose control levels that best cope with noise (Phadke 1989). The S/N ratio takes both the mean and the variability into account, thus did not consider the mean response variable and its standard deviations as performance measures (Unal & Dean 1991).

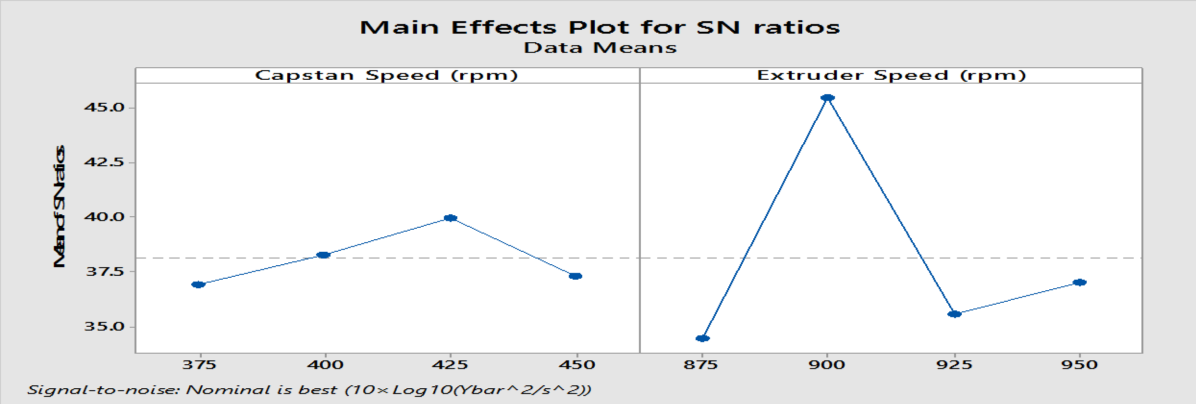


Figure 4.31. Main effect plot for signal-to-noise (nominal is best) for the Cable diameter

The Capstan speed and Extruder speed are the two input parameters affecting the cable dimension. A parameter level corresponding to the maximum average S/N ration is called optimum level for that parameter (Gill et al 2012). According to figure 4.31, the Capstan speed's greatest S/N ratio value is found to be at 425(rpm) which is the peak point on the Capstan segment of the display, and the Extruder speed's greatest S/N ratio point is also at 900 (rpm). According to Yang and Tarng (1998), a greater S/N ratio corresponds to a better quality characteristic, thus the optimal level of the process parameter is the level with the greatest S/N ratio which is found at the Capstan speed of 425(rpm) and Extruder speed of 900(rpm).

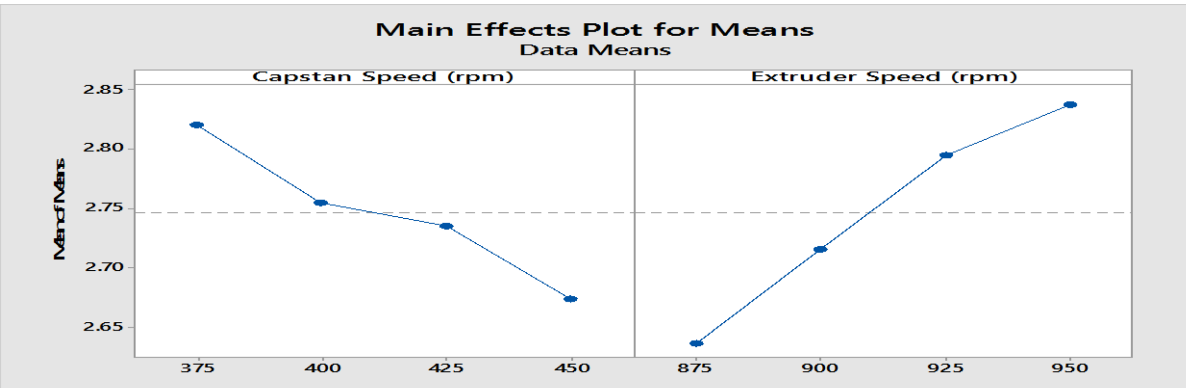


*Figure 4.32***.** Main effect plot for means (nominal is best) for the Cable diameter

In Fig. 4.32, the target mean is 2.715, and the control factors setting that bring the mean close to the target were identified at 425rpm for Capstan and 900rpm for the Extruder. Further details on the design are found in Appendix K.

Table 4.31: *Results / Outcome of the Experimental Design using Taguchi Method*

S/N	Capstan speed	Extruder speed	Preheated PVC (mm)	Non Preheated PVC (mm)	SNRA1	MEAN1
1	375	875	2.71	2.76	37.7700	2.735
2	375	900	2.81	2.64	27.1087	2.725
3	375	925	2.90	2.84	36.6049	2.870
4	375	950	2.91	2.89	46.2377	2.900
5	400	875	2.59	2.68	32.3411	2.635
6	400	900	2.76	2.77	51.8442	2.765
7	400	925	2.80	2.73	34.9422	2.765
8	400	950	2.87	2.79	33.9842	2.830
9	425	875	2.67	2.59	33.3476	2.630
10	425	900	2.70	2.69	51.6215*	2.695*
11	425	925	2.74	2.78	39.7873	2.760
12	425	950	2.86	2.79	35.1287	2.825
13	450	875	2.60	2.53	34.2901	2.565
14	450	900	2.61	2.62	51.3597	2.615
15	450	925	2.68	2.79	30.9216	2.735
16	450	950	2.71	2.80	32.7279	2.755

In other to achieve 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). The results of the optimization engineering are as shown in Table 4.32, 4.33, 4.34, 4.35, 4.36 and 4.37 respectively.

Table 4.32. *Experimental design using Central Composite Design and response value*

		Factor 1	**Factor 2**	**Response 1**	**Response 2**
Std	Run	A: Capstan speed	B: Extruder speed	R1	R2
		Rpm	Rpm	Mm	Mm
5	1	359.467	912.5	2.75	2.74
6	2	465.533	912.5	2.66	2.68
4	3	450	950	2.77	2.77
13	4	412.5	912.5	2.72	2.72
1	5	375	875	2.73	2.74
11	6	412.5	912.5	2.73	2.71
9	7	412.5	912.5	2.70	2.69
8	8	412.5	965.533	2.77	2.78
3	9	375	950	2.92	2.88
1	10	450	875	2.60	2.58
10	11	412.5	912.5	2.68	2.73
7	12	412.5	859.467	2.65	2.63
12	13	412.5	912.5	2.74	2.72

Table 4.33: *Fit summary Response 1: Preheated PVC*

Source	**Sequential p-value**	**Lack of Fit p-value**	**Adjusted R^2**	**Predicted R^2**	
Linear	0.0005	0.1115	0.7416	0.5666	Suggested
2FI	0.8133	0.0867	0.7148	0.2174	
Quadratic	0.7998	0.0468	0.6559	-0.2462	
Cubic	0.1585	0.0493	0.7694	-3.1115	Aliased

Table 4.34: *Response 2: Non preheated PVC*

Source	**Sequential p-value**	**Lack of Fit p-value**	**Adjusted R^2**	**Predicted R^2**	
Linear	0.0002	0.1172	0.7792	0.6327	Suggested
2FI	0.7728	0.0918	0.7571	0.3515	
Quadratic	0.7402	0.0519	0.7134	-0.0299	
Cubic	0.0643	0.1237	0.8661	-0.7796	Aliased

Fit summary in Table (4.33) & Table (4.34) has shown that both the quadratic model and the cubic model are ruled out, because their Prob > F falls below 0.05. Therefore, linear model is the identified model, as it does not show significant lack of fit.

Table 4.35: *ANOVA table for cable dimension using Preheated PVC*

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0558	2	0.0279	18.22	0.0005	Significant
A-Capstan speed	0.0207	1	0.0207	13.54	0.0042	
B-Extruder speed	0.0351	1	0.0351	22.90	0.0007	
Residual	0.0153	10	0.0015			
Lack of Fit	0.0130	6	0.0022	3.73	0.1115	not significant
Pure Error	0.0023	4	0.0006			
Cor Total	0.0711	12				

Table 4.36: *ANOVA table for cable dimension using Non-preheated PVC*

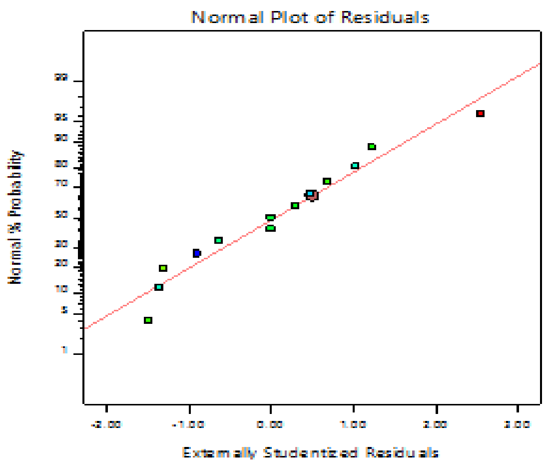
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0455	2	0.0228	22.17	0.0002	Significant
A-Capstan speed	0.0180	1	0.0180	17.49	0.0019	
B-Extruder speed	0.0276	1	0.0276	26.86	0.0004	
Residual	0.0103	10	0.0010			
Lack of Fit	0.0087	6	0.0014	3.61	0.1172	not significant
Pure Error	0.0016	4	0.0004			
Cor Total	0.0558	12				

The ANOVA in this study confirms the adequacy of the linear model, i.e. Model Prob > F is less than 0.005. The probability values for each individual term in the model can be seen from the ANOVA tables. **The** Model F-value **of** 18.22 and 22.17 respectively from Table

(4.35) & (4.36) implies that the models are significant. The p-values for A & B for both responses are less than 0.0500, an indication that A and B are significant model terms. Lack of fit f-value of 3.73 and 3.61 are not significant relative to the pure error. Fit statistics for R1 response as shown in Table 6 of Appendix L, the predicted R^2 of 0.5666 is in reasonable agreement with the adjusted R^2 of 0.7416; adequate precision ratio is 12.460, an indication of adequate signal. For the response (R2) as shown in Appendix L, the predicted R^2 of 0.6327 is in reasonable agreement with the adjusted R^2 of 0.7792; with adequate precision ratio of 13.7840, an indication of adequate signal. The factors are orthogonal as shown by the VIF value of 1 in the Table 9 of appendix L. 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 extruding parameters can be estimated. The developed mathematical models are listed below in terms of actual factors. Equation 4.1 & 4.2 is for the prediction of cable dimension.

Cable dimension = 1.81243 + -0.00126332 * A + 0.00156569 * B (4.1)

Cable dimension = 1.67344 + -0.0013576 * A+ 0.00176569 * B (4.2)



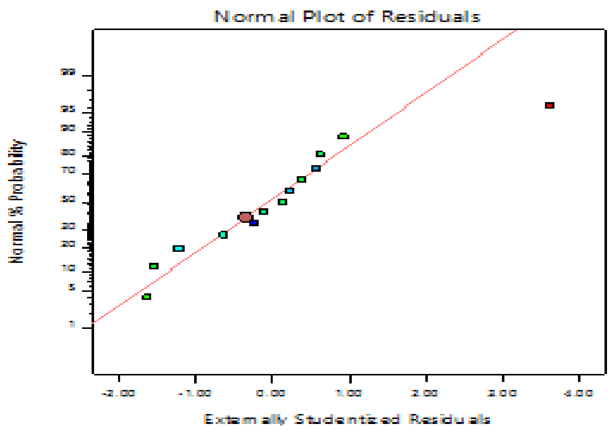


Fig.4.33 (a) Normal probability plot of the residual (R1) *Fig.4.33 (a)* Normal probability plot of the residual (R2).

The diagnosed statistical properties of the model as displayed in figs. 4.33 (a) & (b) have shown that the data points are approximately linear since most of the points lie close to a straight line. From the results, it can therefore be seen that the model is suitable for use and can be used to identify the optimal extrusion speed settings.

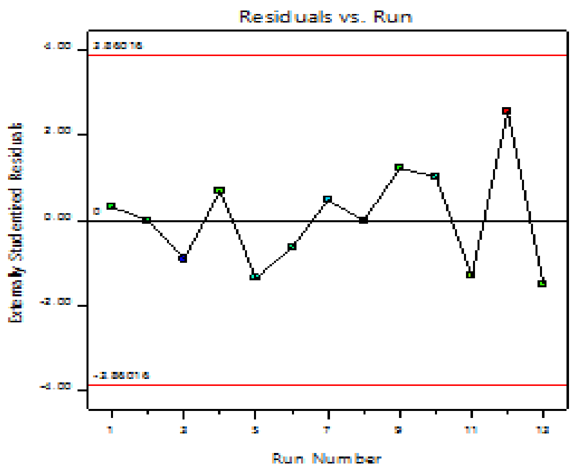


Fig.4.34 (a) Residual vs. Run for R1

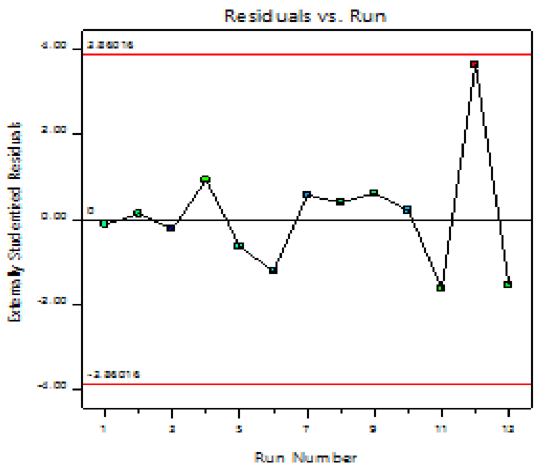


Fig. 4.34(b) Residual vs. Run for R2

From figs. 4.34(a) & 4.34 (b) it can be inferred that the residuals are randomly scattered indicating that they are independent.

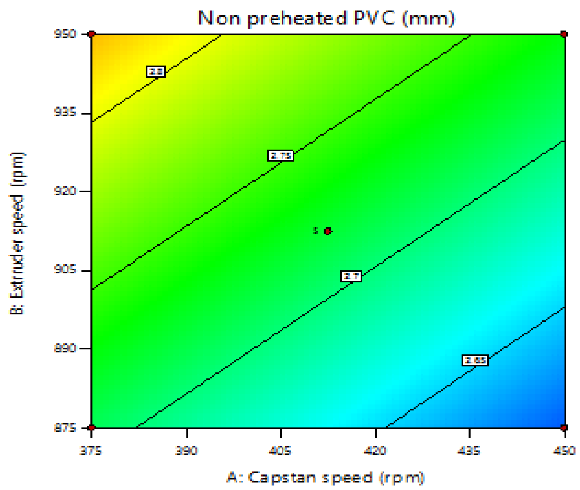


Fig. 4.35(a). 2D Contour plot

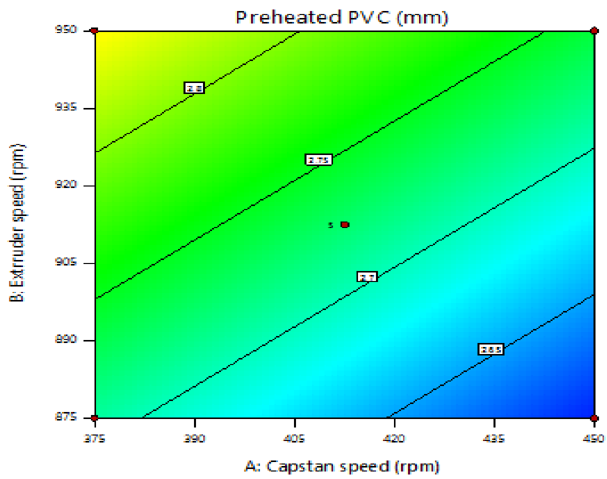


Fig. 4.35(b). 2D Contour plot

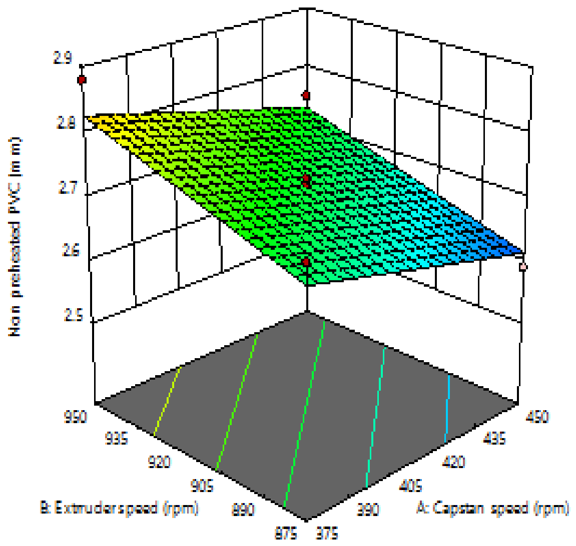


Fig. 4.36(a) 3D Contour Plot

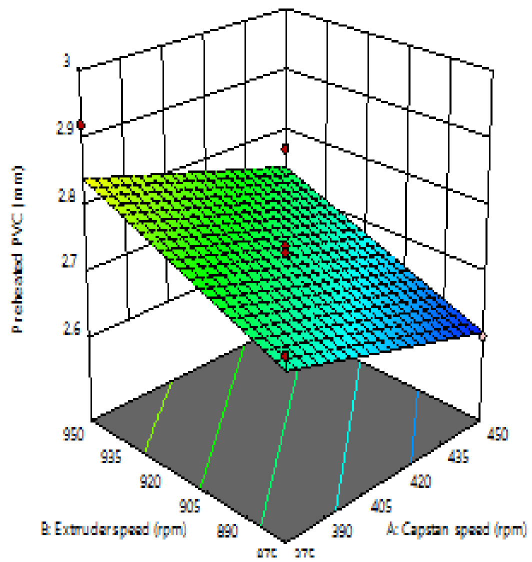


Fig.4.36 (b) 3D Contour Plot

Figures 4.35 (a), 4.35 (b), and 4.36 (a), 4.36 (b), shows the 2D contour plots and three-dimensional (3D) of 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, decrease in the cable diameter values were also noticed when there is an increase in the Capstan speed. The point estimation method was conducted in order to optimize the level of each variable for 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 4.37: *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 4.37, 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. Therefore, it is recommended that the RSM (CCD) be used to obtain an accurate optimization condition, and it can be concluded that the nominal cable diameter measurement values can be achieved through experimental design. This will improve the dimensional accuracy of the extruding system and also help to curtail the production anomalies of often extruding over-dimensioned and under-dimensioned cable products.

4.3.5.1 Confirmation Test

The confirmation test was performed, and conclusions drawn from the analysis was 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.

Table 4.38: *Cable Diameter Measurements after the Process Improvement*

Subgroup	*Sample* (1)	*Sample* (2)	*Sample* (3)	*Sample* (4)	*Sample* (5)	$\overline{X}$	$\overline{R}$
1	2.720	2.707	2.689	2.708	2.710	2.7068	0.031
2	2.693	2.705	2.708	2.711	2.716	2.7066	0.023
3	2.718	2.718	2.700	2.714	2.699	2.7098	0.019
4	2.700	2.708	2.712	2.719	2.700	2.7078	0.019
5	2.712	2.713	2.711	2.720	2.713	2.7138	0.009
6	2.701	2.711	2.709	2.719	2.698	2.7076	0.021
7	2.704	2.700	2.702	2.709	2.707	2.7044	0.009
8	2.711	2.709	2.699	2.725	2.701	2.7090	0.026
9	2.699	2.719	2.706	2.720	2.719	2.7126	0.021
10	2.720	2.713	2.709	2.719	2.711	2.7144	0.011
11	2.703	2.711	2.709	2.701	2.719	2.7086	0.018
12	2.711	2.709	2.713	2.717	2.710	2.7120	0.008
13	2.697	2.719	2.716	2.707	2.723	2.7124	0.026
14	2.703	2.710	2.714	2.711	2.712	2.7100	0.011
15	2.710	2.700	2.719	2.713	2.696	2.7076	0.023
16	2.703	2.710	2.719	2.730	2.703	2.7130	0.027
17	2.700	2.719	2.702	2.711	2.720	2.7104	0.020
18	2.711	2.716	2.705	2.701	2.699	2.7064	0.017
19	2.721	2.701	2.700	2.715	2.709	2.7092	0.021
20	2.709	2.720	2.720	2.712	2.713	2.7148	0.011

4.3.6.1 Test Validation of First Assumption for Normality of Data

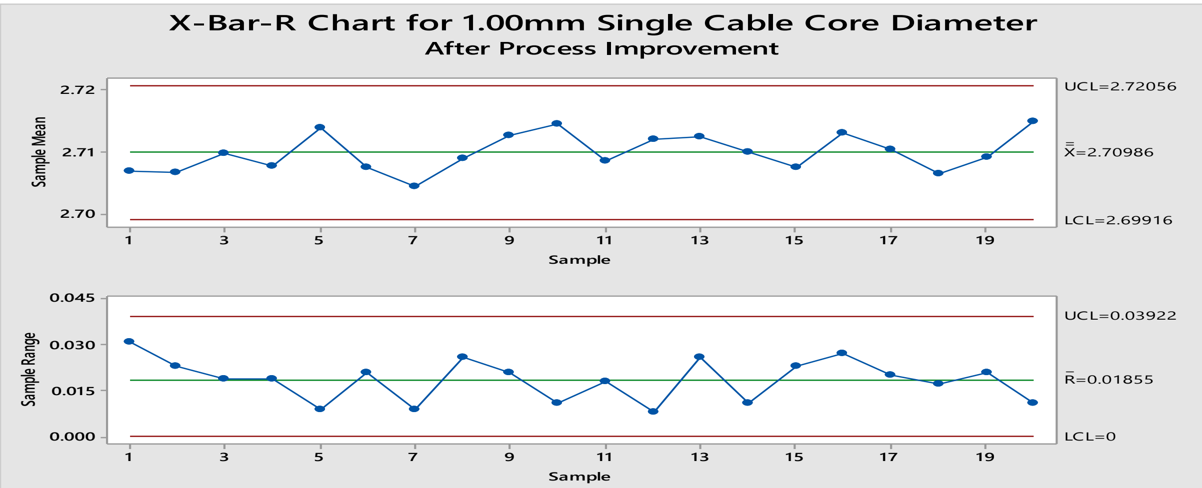


Figure 4.37. X-Bar-R Chart for core Cable diameter after process improvement

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

$UCL = \bar{\bar{X}} + A_2\bar{R}$ = 2.70986 + 0.577(0.01855) = 2.70986 + 0.01070= 2.72056

$LCL = \bar{\bar{X}} - A_2\bar{R}$ = 2.70986 - 0.577(0.01855) = 2.70986 – 0.01070 = 2.69916

Control limits for R-Chart:

$UCL = D_4\bar{R}$ = 2.114(0.01855) = 0.03921

$LCL = D_3\bar{R}$ = 0.00(0.01855) = 0.000

From Control chart constants in Appendix C, for n = 5, $A_2 = 0.577$, $d_2 = 2.326$, $D_3 = 0$, $D_4 = 2.114$. From figure 4.37, the center line on the $\bar{X}$ chart is at 2.70986, implying that the process falls within the specification limits and is a stable process. The center line on the R chart is 0.01855, is also quite small considering the maximum allowable variation of ± 0.032. It implies that variability has been reduced in the process.

4.3.6.2 **Test Validation of the Second Assumption for Normality of Data**

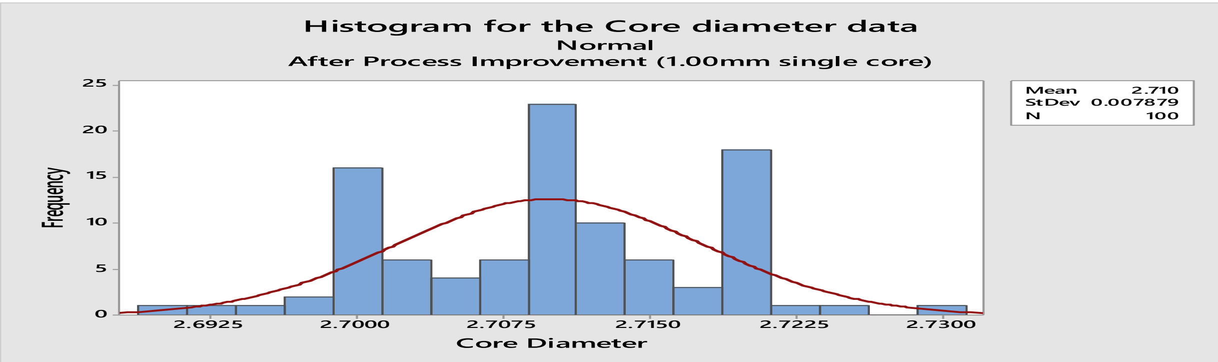


Figure 4.38. Histogram for the Cable diameter data after the process improvement

Graphical methods including the histogram and normal probability plot were used to check the normality of the data used for the study. From the display on figure 4.38, a visual inspection reveals that the fitted normal distribution is not a perfect fit. Anderson-Darling statistics on probability plots were used to quantitatively test how well the data follow a particular distribution.

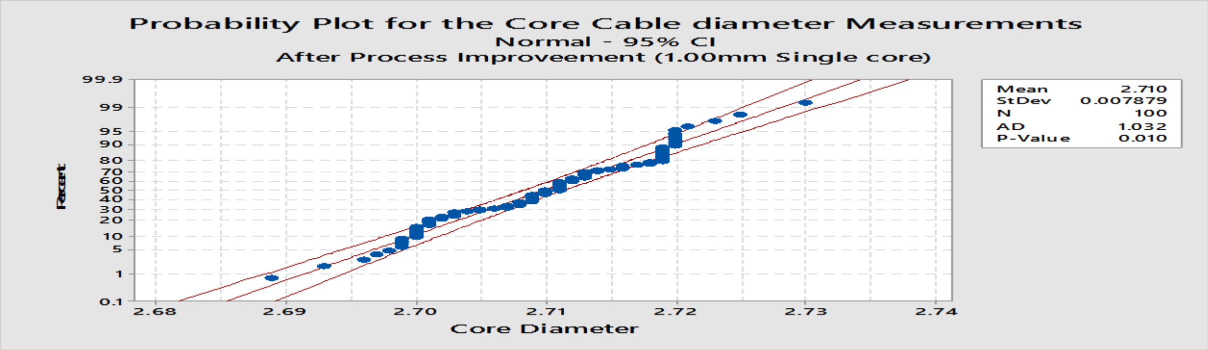


Figure 4.39. Normal Probability plot for the Cable diameter data after the process improvement.

From figure 4.39, the test results for the normal probability plot for the data have shown that the Mean is 2.710, standard deviation: 0.007879, Anderson Darling test statistic value: 1.032 and P-value is 0.010, which is less than the significance level ($\alpha = 0.05$), and this implies that the data is not distributed normally and need to be transformed. In transforming the data, a lambda (λ) value of 0.5 was used in the Box-Cox transformation and this is as shown in equation (4.0).

$$Y' = \sqrt{Y} \tag{4.0}$$

where Y' is the transform of the data Y.

Table 4.39: *Cable Diameter Data after Improvement (after Transformation)*

Subgroup	*Sample* (1)	*Sample* (2)	*Sample* (3)	*Sample* (4)	*Sample* (5)	$\bar{x}$	*R*
1	1.64924	1.64530	1.63982	1.64560	1.64621	1.645233	0.00943
2	1.64104	1.64469	1.64560	1.64651	1.64803	1.645173	0.00699
3	1.64864	1.64864	1.64317	1.64742	1.64286	1.646145	0.00577
4	1.64317	1.64560	1.64682	1.64894	1.64317	1.645538	0.00577
5	1.64682	1.64712	1.64651	1.64924	1.64712	1.647361	0.00273
6	1.64347	1.64651	1.64590	1.64894	1.64256	1.645477	0.00638
7	1.64438	1.64317	1.64378	1.64590	1.64530	1.644506	0.00273
8	1.64651	1.64590	1.64286	1.65076	1.64347	1.645902	0.00789
9	1.64286	1.64894	1.64499	1.64924	1.64894	1.64995	0.00638
10	1.64924	1.64712	1.64590	1.64894	1.64651	1.647543	0.00334
11	1.64408	1.64651	1.64590	1.64347	1.64894	1.6455781	0.00547
12	1.64651	1.64590	1.64712	1.64833	1.64621	1.646815	0.00243
13	1.64225	1.64894	1.64803	1,64530	1.65015	1.646934	0.00790
14	1.64408	1.64621	1.64742	1.64651	1.64682	1.646207	0.00334
15	1.64621	1.64317	1.64894	1.64712	1.64195	1.645477	0.00699
16	1.64408	1.64621	1.64894	1.65227	1.64408	1.647116	0.00819
17	1.64317	1.64894	1.64378	1.64651	1.64924	1.646327	0.00607
18	1.64651	1.64803	1.64469	1.64347	1.64286	1.645113	0.00517
19	1.64955	1.64347	1.64317	1.64773	1.64590	1.645963	0.00638
20	1.64590	1.64924	1.64924	1.64682	1.64712	1.647664	0.00334

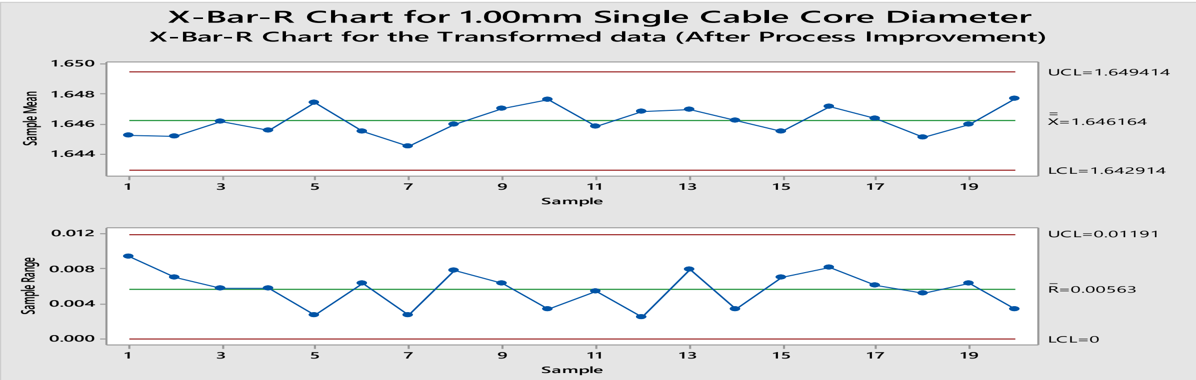


Figure 4.40. X-Bar-R chart for the transformed data after the process improvement

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

UCL = $\overline{\overline{X}}$ + $A_2\overline{R}$ = 1.646164 + 0.577(0.00563) = 1.646164 + 0.00324851= 1.64941251

$LCL = \bar{\bar{X}} - A_2\ \bar{R} = 1.646164 - 0.577(0.00563) = 1.646164 – 0.00324851 = 1.64291549$

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 Control chart constants in Appendix C, for n = 5, $A_2 = 0.577$, $d_2 = 2.326$, $D_3 = 0$, $D_4 = 2.114$. Using the lambda (λ) transformation equation (4.0) on the UCL, $\bar{\bar{x}}$, and LCL values for the sample mean on figure 4.37, $Y' = \sqrt{Y}$; then:

$UCL = (1.649414)^2 = Y;\ Y = 2.72056$

$\bar{\bar{x}} = (1.646164)^2 = Y;\ Y = 2.70985$, and

$LCL = (1.642914)^2 = Y;\ Y = 2.69916$

$UCL = D4\ \bar{R} = (0.011901)^2 = Y;\ Y = 0.00014165$

In comparison with the X-Bar chart values for UCL, LCL and $\bar{\bar{x}}$ from figure 4.40, it was observed that after the transformation that the mean of the process mean does not change except the mean of the sample range. This is an indication that transformation has taken place; thereby reducing variability between individual points from initial value of 0.01855 to 0.00563 such that the data will be close to each other to observe a normal distribution.

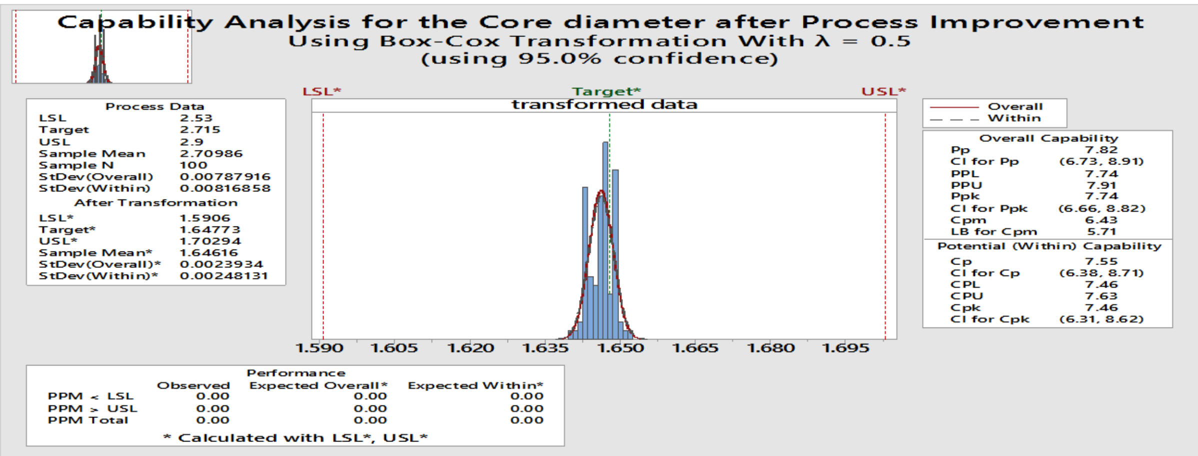


Figure 4.41. Capability analysis for the Cable diameter measurements after the process improvement

Table 4.40: *Process Capability Index Estimations Values for the Cable Diameter (After the Process Improvement)*

Process data before transformation	**Process data after transformation**
Lower specification limit (LSL) = 2.53	Lower specification limit (LSL)= 1.5906
Upper specification limit (USL) = 2.90	Upper specification limit (USL) = 1.70294
Target = 2.715	Target = 1.64773
Sample mean = 2.70986	Sample mean = 1.64616
StDev (Within) = 0.00816858	StDev(within) = 0.00248131

Cp = 7.55, CR = 13.25%, ZU = 22.88, ZL = 22.39, CPK = 7.46, CPM = 6.4. From figure 4.43 and some of the calculations that followed, it was made clear that the index values are all 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 taken was to derive an appropriate tolerance intervals that can clearly depict Six Sigma Process.

4.3.6.3 **Tolerance Design**

In Table 4.41, 20 samples were randomly selected from a stable process population, and their standard deviation was found using equation (3.53) and (3.54). S = $\sqrt{\frac{0.0014706}{19}}$ = 0.0087977

Tolerance intervals now becomes;2.7114 ± K(0.0087977). finding K value for two sided limits in Appendix M, for n = 20, P = 0.99 and ϒ = 0.95, K= 3.615. 2.7114±3.615(0.0087977) = 2.7114±0.032. in the new estimation, from 2.67 to 2.74 will contain 99% of the population with 95% confidence.Using 2.67 as the lower specification limit and 2.74 as the upper specification limit, we conducted further capability analysis on the core cable diameter samples gotten after the process improvement.

Table 4.41: *Population Standard Deviation Derivations*

S/N	x	$\bar{x}$	$(x-\bar{x})$	$(x-\bar{x})^2$
1	2.697	2.7114	-0.0144	$2.074E-04$
2	2.699	2.7114	-0.0124	$1.538E-04$
3	2.700	2.7114	-0.0114	$1.3E-04$
4	2.702	2.7114	-0.0094	$8.836E-05$
5	2.703	2.7114	-0.0084	$7.056E-05$
6	2.705	2.7114	-0.0064	$4.096E-05$
7	2.708	2.7114	-0.0034	$1.156E-05$
8	2.709	2.7114	-0.0024	$5.76E-06$
9	2.710	2.7114	-0.0014	$1.96E-06$
10	2.711	2.7114	-0.0004	$1.6E-07$
11	2.712	2.7114	0.0006	$3.6E-07$
12	2.713	2.7114	0.0016	$2.56E-06$
13	2.714	2.7114	0.0026	$6.76E-06$
14	2.715	2.7114	0.0036	$1.296E-05$
15	2.717	2.7114	0.0056	$3.136E-05$
16	2.718	2.7114	0.0066	$4.356E-05$
17	2.719	2.7114	0.0076	$5.776E-05$
18	2.720	2.7114	0.0086	$7.396E-05$
19	2.725	2.7114	0.0136	$1.85E-04$
20	2.730	2.7114	0.0186	$3.46E-04$
	$\sum = 54.227$	$\sum = 2.71139$		$\sum = 0.0014706$

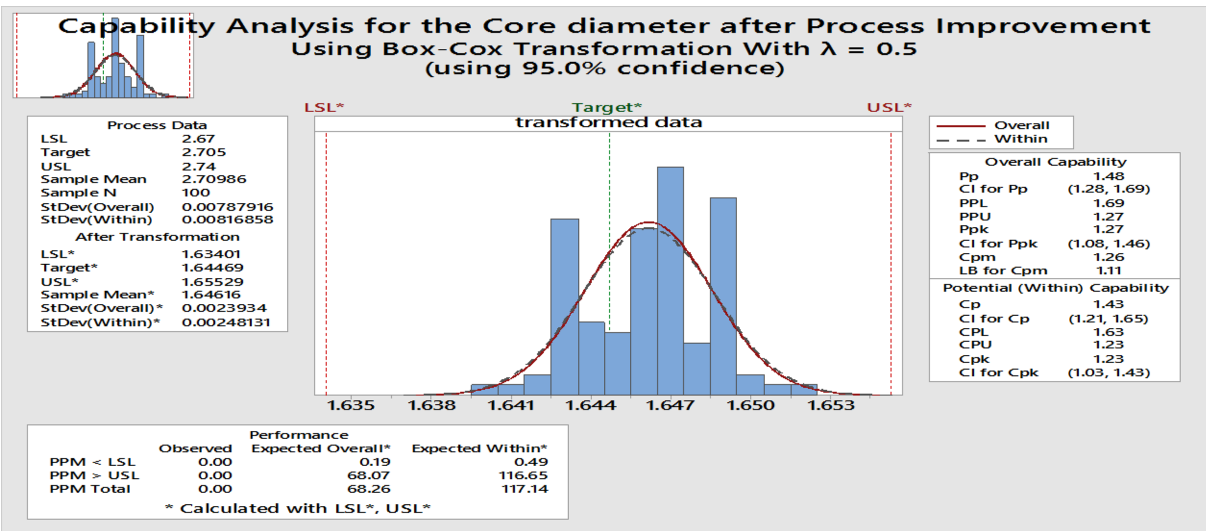


Figure 4.42. Capability analysis for the Cable diameter after the process improvement

CP = 1.43 since the minimum acceptable value for this index is 1, the 1.43 result indicates that this process can meet the requirements. CR = 69.96%. With this value, it means that the "natural tolerance" of the process uses 69.96% of the engineering requirement, which is, about 14.71% reduction from initial value of 84.67%. Cpk = 1.23, the value of Cpk is smaller than that of Cp by 0.2, thus an indication that much can still be gained through centering the process. The calculated Z_U for the process is 3.68, and checking from Appendix D, we have ZU = 1-0.9999 which is 0.01%. By this estimation, approximately 0.01% of the production will exceed the upper specification, the calculated Z_L for the process is 4.89, and since Z_L value of at least +3, so 4.98 is acceptable. Total reject rate is 0.01%, thus the estimated yield is 99.99%.

4.3.6.4 Process Capability Estimation for Cable Insulation Thickness after the Process Improvement

Table 4.42: *Cable Insulation Thickness Data after the Process Improvement*

Sample	Point (1)	Point (2)	Point (3)	Point (4)	$\bar{X}$	$\bar{R}$
1	0.7829	0.8072	0.8415	0.8083	0.8100	0.0586
2	0.7798	0.7743	0.7616	0.8374	0.7883	0.0758
3	0.7235	0.8545	0.7390	0.7910	0.7770	0.1310
4	0.7835	0.8835	0.7460	0.7515	0.7911	0.1375
5	0.6860	0.8605	0.7975	0.7936	0.7844	0.1745
6	0.8065	0.7740	0.7660	0.7710	0.7803	0.0370
7	0.7665	0.8539	0.7980	0.7737	0.7900	0.0879
8	0.6921	0.8341	0.7985	0.8073	0.7829	0.1420
9	0.6815	0.8707	0.8390	0.8101	0.7902	0.1892
10	0.8470	0.6775	0.8390	0.8090	0.7931	0.1695
11	0.8170	0.7895	0.7670	0.8000	0.7934	0.0500
12	0.8006	0.7246	0.8066	0.8441	0.7940	0.1195
13	0.7401	0.8190	0.7810	0.7605	0.7752	0.0789
14	0.6735	0.8817	0.7844	0.7330	0.7682	0.2082
15	0.7495	0.7980	0.7011	0.7431	0.7479	0.0690
16	0.7203	0.8380	0.7798	0.7918	0.7825	0.1177
17	0.8678	0.7055	0.7789	0.7984	0.7877	0.1623
18	0.8871	0.6806	0.8128	0.7784	0.7987	0.2065
19	0.8194	0.7472	0.7794	0.8111	0.7893	0.0722
20	0.7885	0.8315	0.7439	0.7931	0.7893	0.0876
21	0.8140	0.6855	0.8390	0.8420	0.7951	0.1565

Table 4.42: *Cable Insulation Thickness Data after the Process Improvement*

Sample	Point (1)	Point (2)	Point (3)	Point (4)	$\bar{X}$	$\bar{R}$
22	0.7712	0.8851	0.7860	0.7850	0.8068	0.1139
23	0.8199	0.7813	0.7674	0.8443	0.8032	0.0769
24	0.8435	0.6676	0.8290	0.8230	0.7908	0.1759
25	0.7975	0.8108	0.8177	0.7530	0.7947	0.0647
26	0.8297	0.6690	0.8511	0.8081	0.7895	0.1821
27	0.7850	0.7619	0.8149	0.8031	0.7912	0.0530
28	0.7807	0.8270	0.7673	0.7868	0.7904	0.0597
29	0.8068	0.8106	0.7834	0.7716	0.7931	0.0390
30	0.8421	0.6477	0.7606	0.7905	0.7602	0.1944
31	0.8276	0.6799	0.8088	0.8717	0.7970	0.1918
32	0.7460	0.8117	0.7945	0.7894	0.7854	0.0657
33	0.8254	0.7138	0.8138	0.8100	0.7908	0.1116
34	0.8015	0.7816	0.7958	0.7690	0.7870	0.0325
35	0.7688	0.8610	0.7650	0.7590	0.7884	0.1020
36	0.7740	0.7835	0.8185	0.7965	0.7931	0.0445
37	0.7413	0.7900	0.7757	0.7673	0.7686	0.0487
38	0.7851	0.7395	0.7951	0.7485	0.7671	0.0556
39	0.8650	0.7847	0.8760	0.8905	0.8540	0.1058
40	0.8099	0.7255	0.8058	0.8048	0.7865	0.0844
41	0.7550	0.8940	0.7155	0.7250	0.7724	0.1785
42	0.8229	0.7487	0.7862	0.8442	0.8005	0.0955
43	0.8022	0.8780	0.7137	0.7954	0.7973	0.1643
44	0.7938	0.7754	0.8209	0.8058	0.7990	0.0455
45	0.8002	0.8356	0.7944	0.6686	0.7747	0.1670
46	0.7390	0.8255	0.8235	0.7835	0.7929	0.0865
47	0.8353	0.6510	0.7775	0.9023	0.7915	0.2513
48	0.8253	0.8311	0.8171	0.7442	0.8044	0.0869
49	0.7833	0.8717	0.7933	0.7697	0.8045	0.1020
50	0.7741	0.8861	0.7441	0.7676	0.7930	0.1420
51	0.7780	0.8190	0.8781	0.6090	0.7915	0.1872
52	0.7752	0.7972	0.7912	0.8187	0.7956	0.0435
53	0.7825	0.8100	0.8110	0.7755	0.7948	0.0355
54	0.8265	0.7815	0.6755	0.8790	0.7906	0.2035
55	0.8025	0.7999	0.8010	0.7965	0.8000	0.0060
56	0.8600	0.7570	0.6915	0.8635	0.7930	0.1720
57	0.7806	0.7915	0.7745	0.8225	0.7923	0.0480
58	0.7778	0.8920	0.7410	0.7665	0.7943	0.1510
59	0.7916	0.8115	0.8020	0.7805	0.7964	0.0310
60	0.8601	0.7125	0.8200	0.7790	0.7929	0.1476
61	0.7846	0.7670	0.7968	0.7854	0.7834	0.0298

Table 4.42: *Cable Insulation Thickness Data after the Process Improvement*

Sample	Point (1)	Point (2)	Point (3)	Point (4)	$\bar{X}$	$\bar{R}$
62	0.7984	0.8380	0.7885	0.7525	0.7944	0.0855
63	0.8356	0.6843	0.7983	0.8538	0.7930	0.1695
64	0.7714	0.8920	0.7085	0.7860	0.7895	0.1835
65	0.7987	0.7862	0.7780	0.7893	0.7880	0.0207
66	0.7690	0.7250	0.7775	0.8295	0.7752	0.1045
67	0.7906	0.7180	0.7785	0.7955	0.7706	0.0775
68	0.7865	0.7000	0.8065	0.8705	0.7909	0.1705
69	0.8320	0.8250	0.7169	0.7975	0.7928	0.1151
70	0.7660	0.8935	0.7715	0.7755	0.8016	0.1275
71	0.7855	0.8645	0.7385	0.7920	0.7951	0.1260
72	0.7955	0.7560	0.7980	0.8235	0.7933	0.0675
73	0.7936	0.7881	0.8001	0.8101	0.7980	0.0200
74	0.8539	0.7590	0.7743	0.7798	0.7917	0.0949
75	0.7740	0.7690	0.8072	0.7829	0.7833	0.0382
76	0.8941	0.7412	0.7992	0.7235	0.7895	0.1706
77	0.8042	0.7673	0.8170	0.7835	0.7930	0.0497
78	0.7318	0.8028	0.9000	0.7553	0.7975	0.1682
79	0.7895	0.8663	0.7740	0.7823	0.8030	0.0923
80	0.7246	0.8048	0.8539	0.7665	0.7874	0.1293
81	0.8190	0.7689	0.8941	0.6760	0.7895	0.2181
82	0.8406	0.8236	0.8502	0.6815	0.7990	0.1687
83	0.8090	0.8064	0.6995	0.8470	0.7905	0.1475
84	0.8380	0.7690	0.7895	0.8170	0.8034	0.0690
85	0.7055	0.7590	0.7246	0.8006	0.7474	0.0951
86	0.7171	0.8329	0.8190	0.8130	0.7955	0.1158
87	0.7782	0.7983	0.8817	0.7355	0.7984	0.1462
88	0.8315	0.7697	0.7980	0.7707	0.7925	0.0618
89	0.6855	0.8905	0.8518	0.7341	0.7905	0.2050
90	0.8325	0.8048	0.6792	0.8415	0.7895	0.1623
91	0.8083	0.7790	0.7076	0.8871	0.7955	0.1795
92	0.7633	0.8121	0.7472	0.8194	0.7855	0.0722
93	0.8216	0.7630	0.7992	0.7562	0.7850	0.0654
94	0.8941	0.7690	0.6855	0.8140	0.7907	0.2086
95	0.8067	0.7590	0.8211	0.7712	0.7895	0.0621
96	0.6982	0.8172	0.8020	0.8406	0.7895	0.1424
97	0.7895	0.7978	0.7286	0.8435	0.7899	0.1149
98	0.7689	0.7928	0.8108	0.7975	0.7925	0.0419
99	0.8190	0.8734	0.6690	0.8212	0.7956	0.2044
100	0.8386	0.7904	0.7619	0.7850	0.7940	0.0767

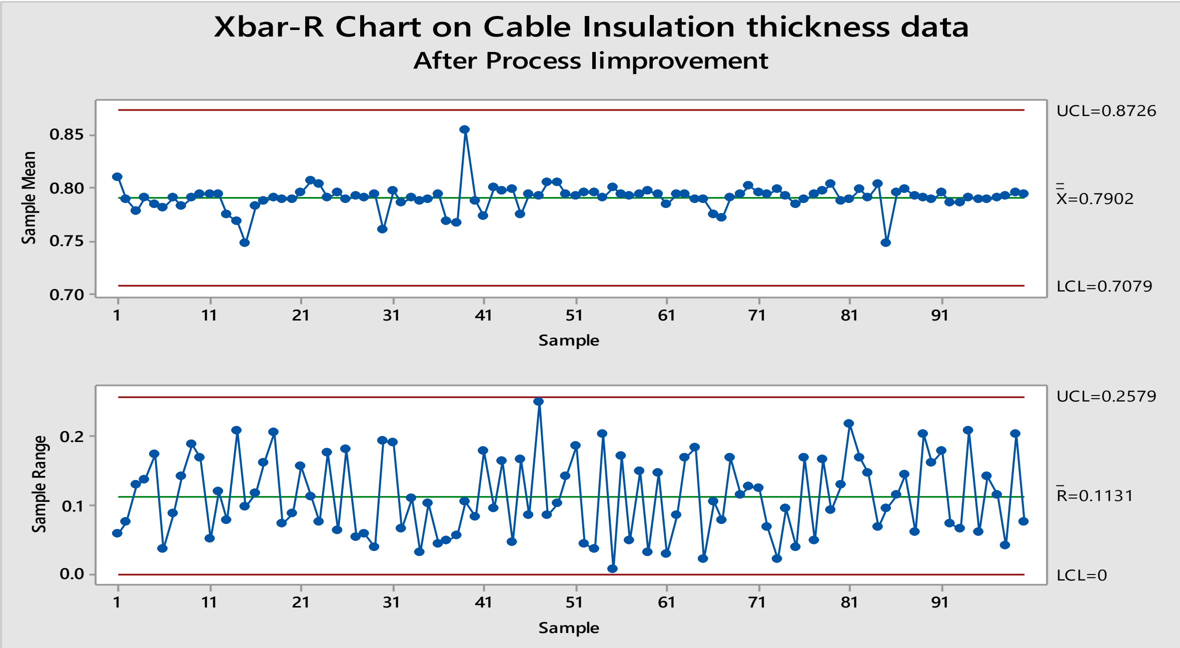


Figure 4.43. X-bar-R chart on Cable Insulation thickness after the process improvement

From figure 4.43, the center line on the $\bar{X}$ chart is at 0.7902, implying that the process falls within the specification limits and is stable. The center line on the R chart is 0.1131, and is also quite small considering the maximum allowable variation of ± 0.14. It implies that variability has been reduced in the process.

4.3.6.5 . Test validation of first Assumption for Cable Insulation Thickness

Control limits for $\bar{X}$ –Chart:

$$UCL = \bar{\bar{X}} + A_2\bar{R} = 0.7902 + 0.729(0.1131) = 0.87264$$

$$LCL = \bar{\bar{X}} - A_2\bar{R} = 0.7902 - 0.729(0.1131) = 0.70775$$

Control limits for R-Chart:

$$UCL = D_4\bar{R} = 2.282(0.1131) = 0.2580$$

$$LCL = D_3\bar{R} = 0.00(0.1131) = 0.000$$

From Table of Control chart constants in Appendix C, for n = 4: $A_2 = 0.729$, $d_2 = 2.059$, $D_3 = 0$, $D_4 = 2.282$

4.3.6.6 Test Validation of the Second Assumption for Cable Insulation Thickness

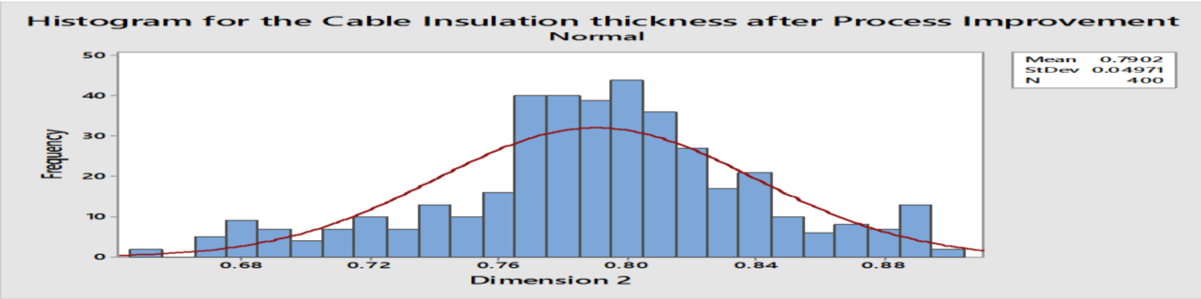


*Figure 4.44***.** Histogram for the Cable insulation thickness after the process improvement

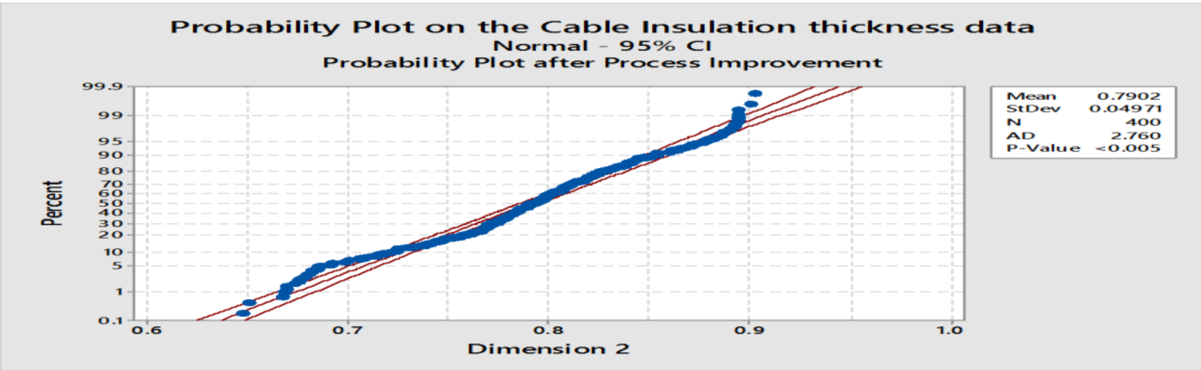


Figure 4.45. Normal Probability plot on the Cable insulation thickness data after the process improvement.

A test result for the normal probability plot for the data has shown that the Mean is 0.7902, standard deviation: 0.04971, Anderson Darling test statistic value: 2.760 and P-value is also less than the significance level (α = 0.05), and this implies that the data is not distributed normally. However, to make the data more normal, we transformed the data, by first finding the optimal lambda value for the transformation.

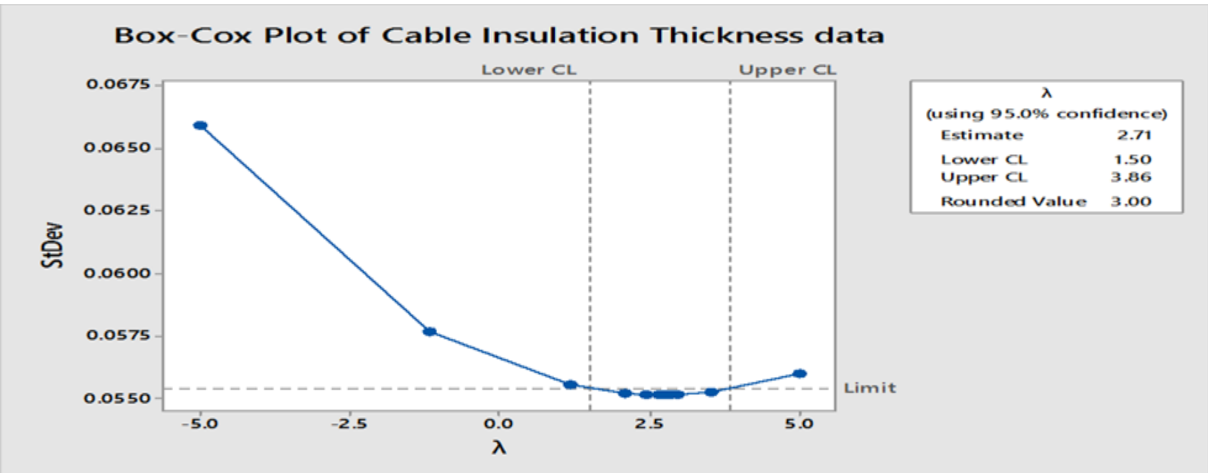


*Figure 4.46***.** Box-Cox plot of Cable insulation thickness after the process improvement

From the Box-Cox Plot in figure 4.46 above, the optimal lambda value for the transformation is 2.71. However, to have an understandable transformation, the transformation was carried out using lambda (λ) value of 0.5.

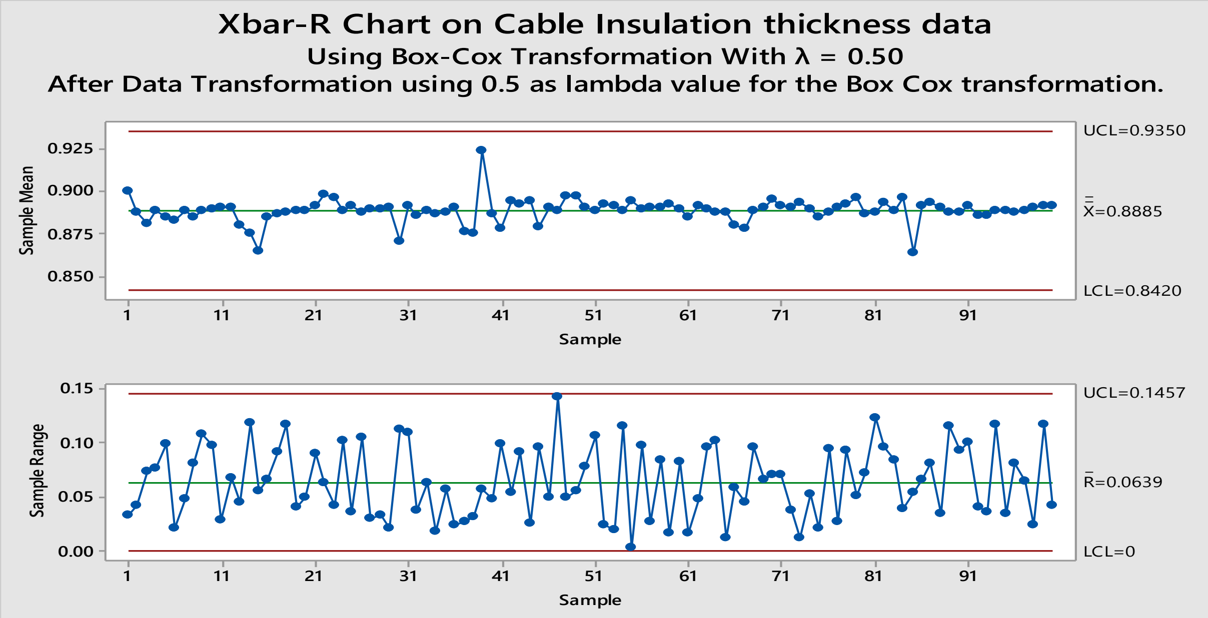


Figure: 4.47. X-Bar-R chart on Cable insulation thickness on transformed data

After the transformation, the value for the range mean now reduced from 0.1131 to 0.0639 thereby making the data to be normally distributed. To conduct PCA, for the Cable Insulation thickness requires USL derivation from the newly designed engineering limit of 2.74 (USL) and 2.67 (LSL), thus;

Derivations:

$$USL = \frac{USL - Input\ conductor}{2} = \frac{2.74 - 1.13}{2} = 0.805$$

Table 4.43: *Engineering Specification for Cable Insulation Thickness after Improvement*

Process data before transformation	**Process data after transformation**
Lower Specification Limit (LSL) = 0.53	Lower Specification Limit (LSL) = 0.728011
Upper Specification Limit (USL) = 0.805	Upper Specification Limit (USL) = 0.897218
Target (T) = 0.67, Sample mean = 0.790239	Target (T) = 0.818535, Sample mean = 0.888509

Table 4.44: *Transformed Insulation Thickness Data after Process Improvement*

Sample	Point (1)	Point (2)	Point (3)	Point (4)	$\bar{X}$	$\bar{R}$
1	0.884816	0.898443	0.917333	0.899055	0.8999	0.0325
2	0.883063	0.879943	0.872697	0.915096	0.8877	0.0424
3	0.850588	0.924392	0.859651	0.889382	0.8810	0.0738
4	0.885155	0.939947	0.863713	0.866891	0.8889	0.0762
5	0.828251	0.927631	0.892973	0.890842	0.8849	0.0994
6	0.898053	0.879773	0.877211	0.878066	0.8833	0.0208
7	0.875500	0.924067	0.875214	0.879602	0.8886	0.0489
8	0.831925	0.913291	0.893308	0.898499	0.8843	0.0814
9	0.825530	0.933113	0.893588	0.900056	0.8881	0.1076
10	0.920326	0.823104	0.915969	0.899444	0.8897	0.0972
11	0.903881	0.888538	0.875785	0.894427	0.8907	0.0281
12	0.894763	0.851234	0.898109	0.918749	0.8907	0.0675
13	0.860291	0.904986	0.883742	0.872067	0.8803	0.0447
14	0.820670	0.938989	0.885664	0.856154	0.8754	0.1183
15	0.865737	0.893308	0.837317	0.862032	0.8646	0.0560
16	0.848705	0.915423	0.883063	0.889831	0.8843	0.0667
17	0.931558	0.839940	0.882553	0.893532	0.8869	0.0916
18	0.941860	0.824985	0.901554	0.882270	0.8877	0.1169
19	0.905207	0.864407	0.882836	0.900611	0.8883	0.0408
20	0.887975	0.911866	0.862496	0.890562	0.8882	0.0494
21	0.902219	0.827949	0.915969	0.917606	0.8909	0.0897
22	0.878180	0.940798	0.886566	0.886002	0.8779	0.0626
23	0.905483	0.883912	0.876014	0.918858	0.8961	0.0428
24	0.918423	0.817068	0.910449	0.907193	0.8883	0.1014
25	0.893029	0.900444	0.904268	0.867756	0.8914	0.0365
26	0.910879	0.817924	0.922551	0.898944	0.8876	0.1046
27	0.886002	0.872869	0.902718	0.896158	0.8894	0.0298
28	0.883572	0.909395	0.875957	0.887017	0.8890	0.0334
29	0.898220	0.900333	0.885099	0.878408	0.8905	0.0219
30	0.917660	0.804798	0.872124	0.889101	0.8709	0.1129
31	0.909725	0.824560	0.899333	0.933649	0.8918	0.1091
32	0.863713	0.900944	0.891347	0.888482	0.8861	0.0372
33	0.908515	0.844867	0.902109	0.900000	0.8889	0.0636
34	0.895265	0.884081	0.892076	0.876926	0.8871	0.0183
35	0.876812	0.927901	0.874643	0.871206	0.8876	0.0567
36	0.879773	0.885155	0.904710	0.892468	0.8905	0.0249
37	0.860988	0.888819	0.880738	0.875957	0.8766	0.0278
38	0.886059	0.859942	0.891684	0.865159	0.8757	0.0317
39	0.930054	0.885833	0.935949	0.943663	0.9239	0.0578

Table 4.44: *Transformed Insulation Thickness Data after Process Improvement*

Sample	Point (1)	Point (2)	Point (3)	Point (4)	$\bar{X}$	$\bar{R}$
40	0.899944	0.851763	0.897664	0.897106	0.8866	0.0482
41	0.868907	0.945516	0.845872	0.851469	0.8779	0.0996
42	0.907138	0.865275	0.886679	0.918804	0.8945	0.0535
43	0.895656	0.937017	0.844808	0.891852	0.8923	0.0922
44	0.890955	0.880568	0.906035	0.897664	0.8938	0.0255
45	0.894539	0.914112	0.891291	0.817680	0.8794	0.0964
46	0.859651	0.908570	0.907469	0.885155	0.8902	0.0489
47	0.913947	0.806846	0.881760	0.949895	0.8881	0.1430
48	0.908460	0.911647	0.903936	0.862670	0.8967	0.0490
49	0.885042	0.933649	0.890674	0.877325	0.8967	0.0563
50	0.879830	0.941329	0.862612	0.876128	0.8900	0.0787
51	0.882043	0.904986	0.937070	0.831204	0.8888	0.1059
52	0.880454	0.892861	0.889494	0.904820	0.8919	0.0244
53	0.884590	0.900000	0.900555	0.880625	0.8914	0.0199
54	0.909120	0.884025	0.821888	0.937550	0.8881	0.1157
55	0.895824	0.894371	0.894986	0.892468	0.8944	0.0034
56	0.927362	0.870057	0.831565	0.920247	0.8896	0.0977
57	0.883516	0.889663	0.880057	0.906918	0.8900	0.0269
58	0.881930	0.944458	0.860814	0.875500	0.8907	0.0836
59	0.889719	0.900833	0.895545	0.883459	0.8924	0.0174
60	0.927416	0.844097	0.905539	0.882610	0.8899	0.0833
61	0.885776	0.875785	0.892637	0.886228	0.8851	0.0169
62	0.893532	0.915423	0.887975	0.867468	0.8911	0.0480
63	0.914112	0.827224	0.893476	0.924013	0.8897	0.0833
64	0.878294	0.944458	0.841724	0.886566	0.8878	0.0968
65	0.893700	0.886679	0.882043	0.888426	0.8877	0.1027
66	0.876926	0.851469	0.881760	0.910769	0.8802	0.0968
67	0.889157	0.847349	0.882326	0.891908	0.8777	0.0117
68	0.886848	0.836660	0.898053	0.933006	0.8886	0.0593
69	0.912140	0.908295	0.846699	0.893029	0.8900	0.00654
70	0.875214	0.945251	0.878351	0.880625	0.8949	0.0700
71	0.886284	0.929785	0.859360	0.889944	0.8905	0.0704
72	0.891908	0.869483	0.893308	0.907469	0.8905	0.0380
73	0.890842	0.887750	0.894483	0.900056	0.8933	0.0123
74	0.924067	0.871206	0.879943	0.883063	0.8896	0.0529
75	0.879773	0.876926	0.898443	0.884816	0.8850	0.0215
76	0.945569	0.860930	0.893980	0.850588	0.8878	0.0950
77	0.896772	0.875957	0.903881	0.885155	0.8904	0.0279
78	0.855453	0.895991	0.948683	0.869080	0.8923	0.0932
79	0.888538	0.930752	0.879773	0.884477	0.8959	0.0510

Table 4.44: *Transformed Insulation Thickness Data after Process Improvement*

Sample	Point (1)	Point (2)	Point (3)	Point (4)	$\bar{X}$	$\bar{R}$
80	0.851234	0.897106	0.924067	0.875500	0.8870	0.0728
81	0.904986	0.876869	0.945569	0.822192	0.8874	0.1234
82	0.916842	0.907524	0.922063	0.825530	0.8930	0.0965
83	0.899444	0.897998	0.836361	0.920326	0.8885	0.0840
84	0.915423	0.876926	0.888538	0.903881	0.8643	0.0385
85	0.839940	0.871206	0.851234	0.894763	0.8643	0.0548
86	0.846818	0.912634	0.904986	0.901665	0.8915	0.0658
87	0.882156	0.893476	0.938989	0.857613	0.8931	0.0814
88	0.911866	0.877325	0.893308	0.877895	0.8901	0.0345
89	0.827949	0.943663	0.922930	0.856796	0.8878	0.1157
90	0.912414	0.897106	0.824136	0.917333	0.8877	0.0932
91	0.899055	0.882610	0.841190	0.941860	0.8912	0.1007
92	0.873670	0.901166	0.864407	0.905207	0.8861	0.0408
93	0.906422	0.873499	0.893980	0.869598	0.8859	0.0368
94	0.945569	0.876926	0.827949	0.902219	0.8882	0.1176
95	0.898165	0.871206	0.906146	0.878180	0.8884	0.0349
96	0.835584	0.903991	0.895545	0.918423	0.8880	0.0813
97	0.888538	0.893197	0.853581	0.918423	0.8884	0.0648
98	0.876869	0.890393	0.900444	0.915751	0.8902	0.0236
99	0.904986	0.934559	0.817924	0.906201	0.8909	0.1166
100	0.915751	0.889044	0.872869	0.886002	0.8909	0.0429
					$x = \frac{1}{n}\sum \bar{x}$ = 0.8885	$\bar{R} = \frac{1}{n}\sum R =$ 0.0639

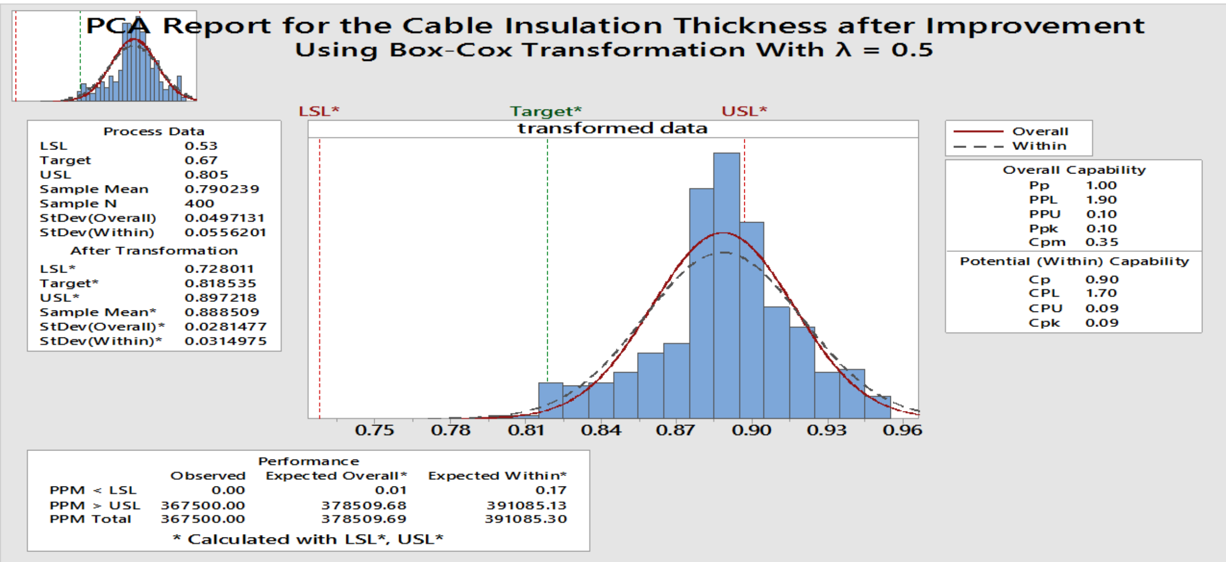


*Figure 4.48.*Process capability report on cable Insulation thickness after the process improvement.

CP = 0.9 since the minimum acceptable value for this index is 1, the 0.9 result indicates that this process will not meet the requirements most times. The CR = 110%. The number itself means that the "natural tolerance" of the process uses 110% of the engineering requirement, which is not acceptable, and indication that the process mean are still not clustered around the target mean. Cpk = 0.09, the value of Cpk is smaller than that of Cp, an indication that much can be gained through centering the process. The calculated Z_U for the process is 0.28; Zu = 1-0.6103, which is 38.97%, by this estimation, approximately 38.97% of the production will exceed the upper specification limit, projected yield = 61.03, the calculated Z_L = 5.17 checking from the 6-sigma conversion table in Appendix E the Sigma level is at 1.7.

4.3.6.7. Assessing the Capability of the Baseline Data for the Cable Diameter, using the newly designed engineering tolerance

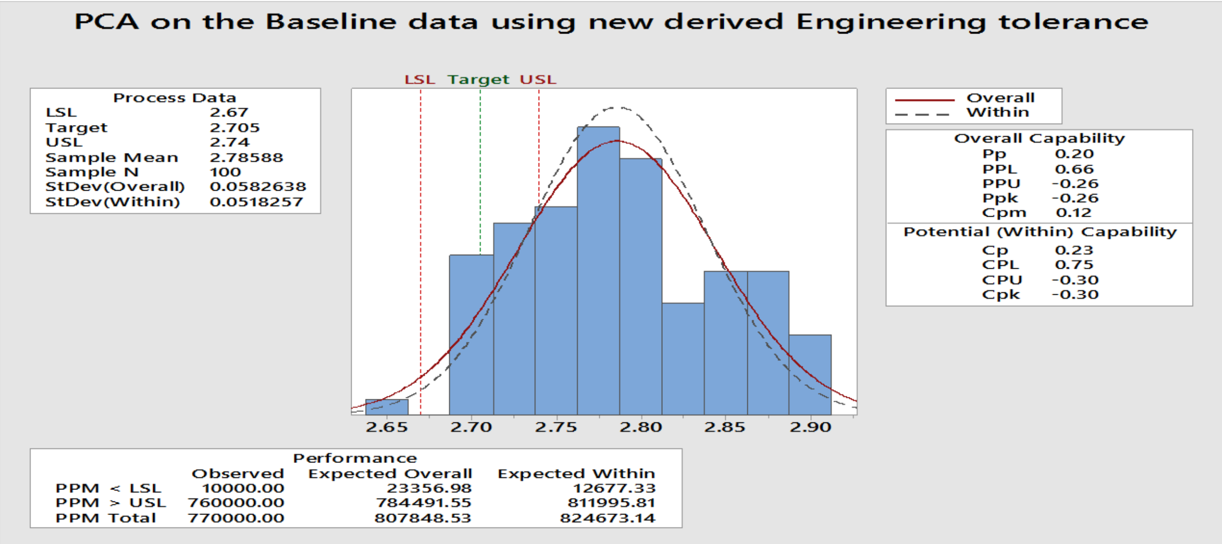


Figure 4.49. Process Capability analysis on the baseline data using the newly- derived engineering tolerance.

Referring to Table 4.10 and figure 4.49, capability index of the baseline process was assessed with the new designed engineering tolerance (2.705±0.032) to further ascertain the height of improvement. The capability index values are as follows: CP = 0.223, CR = 447.43%, ZU =-0.88, ZL 2.22, CPK = -0.3, CPM = 0.12, the calculated Z_U for the process is -0.88 and checking from Appendix D, ZU = 1-0.1894 which is 81.1%. By this estimation, approximately 81.1% of the produced cable is over dimensioned. The calculated Z_L for the process is 2.22, and checking from the Appendix D, ZL = 1-0.9868 which is 1.32%. By this estimation, approximately 1.32% of the produced cable is below the lower specification, and the total reject rate = 81.1% + 1.32% = 82.42%. Thus the estimated yield = 100%-Total Reject = 100%-82.42% = 17.58%.

Table 4.45: *Capability Index Results for the Core Cable Diameter Measurements*

S/N	**Index**	**Index before process improvement. (2.715±0.185)**	**Index values after process improvement. (2.715±0.185)**	**Index values after process improvement. (2.705±0.032)**
1	**Cp**	1.19	7.55	1.43
2	**Cpk**	0.73	7.46	1.23
3	**Cpu**	0.73	7.63	1.23
4	**Cpl**	1.65	7.46	1.63
5	**Cpm**	0.67	6.43	1.26
6	**CR**	84.67%	13.25%	69.96%
7	**Zu**	2.18	22.88	3.68
8	**ZL**	4.98	22.39	4.89
9	$\sigma_{Overall}$	0.0582638	0.0281477	0.0023934
10	σ_{Within}	0.0518257	0.0314975	0.00248131
11	**DPMO**	17,800	*********	10
12	**Total reject rate**	1.46%	**********	0.01%
13	**Estimated yield**	98.54%	**********	99.99%
14	**Sigma level**	3.6	*********	5.2

Table 4.46: *Comparing Index Results on the Baseline Data for the Cable Diameter using the Old and New Engineering Tolerance*

S/N	Index	Old Tolerance (2.715±0.185)	New Tolerance (2.705±0.032)
1	**Cp**	1.19	0.22
2	**Cpk**	0.73	0.3
3	**Cpu**	0.73	0.75
4	**Cpl**	1.65	-0.30
5	**Cpm**	0.67	0.12
6	**CR**	84.67%	447.43%
7	**Zu**	2.18	-0.88
8	**ZL**	4.98	2.22
9	$\sigma_{Overall}$	0.0582638	0.0582638
10	σ_{Within}	0.0518257	0.0518257
11	**DPMO**	13,900	810,000
12	**Total reject rate**	1.46%	82.42%
13	**Estimated yield**	98.54%	17.58%
14	**Sigma level**	3.7	0.6

Table 4.47: *Comparing Index Results on the Cable Diameter Measurements before and after the Process Improvement*

S/N	Index	Newly-designed Tolerance (2.705±0.032)	Newly-designed Tolerance (2.705±0.032)
1	**Cp**	0.22	1.43
2	**Cpk**	0.3	1.23
3	**Cpu**	0.75	1.23
4	**Cpl**	-0.30	1.63
5	**Cpm**	0.12	1.26
6	**CR**	447.43%	69.96%
7	**Zu**	-0.88	3.68
8	**ZL**	2.22	4.89
9	$\sigma_{Overall}$	0.0582638	0.0023934
10	σ_{Within}	0.0518257	0.00248131
11	**DPMO**	810,000	10
12	**Total reject rate**	82.42%	0.01%
13	**Estimated yield**	17.58%	99.99%
14	**Sigma level**	0.6	5.2

Table 4.48: *Capability Index Results for the Cable Insulation Thickness*

S/N	Index	Index values for the insulation thickness before process improvement. (0.71±0.18)	Index values for the cable insulation thickness after process improvement. (0.67±0.14)
1	**Cp**	0.55	0.90
2	**Cpk**	0.21	0.09
3	**Cpu**	0.21	0.09
4	**Cpl**	0.90	1.70
5	**Cpm**	0.40	0.35
6	**CR**	173.3%	110%
7	**Zu**	0.66	0.28
8	**ZL**	2.79	5.17
9	$\sigma_{Overall}$	0.0998797	0.00281477
10	σ_{Within}	0.108241	0.0314975
11	**DPMO**	274,000	420,000
12	**Total reject rate**	25.46%	38.97%
13	**Estimated yield**	74.54%	61.03%
14	**Sigma Level**	2.1	1.7

4.3.6.8 Assessing the capability of the baseline data for the cable Insulation thickness, using newly derived engineering tolerance.

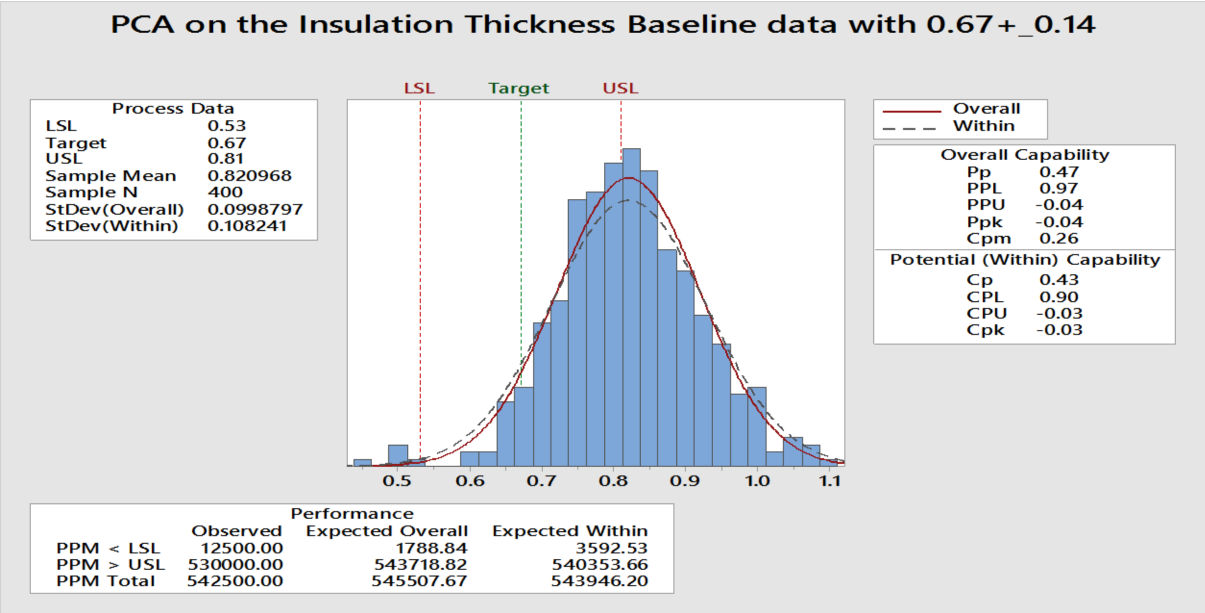


*Figure 4.50***.** Process Capability analysis on the baseline data for the Cable Insulation thickness using the newly- derived engineering tolerance.

With the newly-derived engineering tolerance, **σ** = 0.10398, CP = 0.45, CR = 223%, ZU = -0.106, ZL = 2.79, CPK = -0.03, CPM = 0.26, the calculated Z_U for the process is -0.11, and checking from Appendix D, ZU = 1-0.4562 which is 54.38%. By this estimation, approximately 54.38.1% of the produced cable will have Insulation thickness exceeding the upper specification. The calculated Z_L for the process is 2.79, and checking from the Appendix D, ZL = 1-0.9974 which is 0.26%. By this estimation, approximately 0.26% of the produced cable will have their Insulation thickness below the lower specification. Total Reject rate = 54.38% + 0.26% = 54.64%., thus the estimated yield = 100%-Total Reject = 100%-54.64% = 45.36%

Table 4.49: *Comparing Index Results on the Baseline Data for the Cable Insulation Thickness using the Derived Tolerance before and after the Process Improvement*

S/N	Index	Derived (0.71±0.18)	Newly-derived (0.67±0.14)
1	**Cp**	0.55	0.45
2	**Cpk**	0.21	-0.035
3	**Cpu**	0.21	-0.03
4	**Cpl**	0.90	0.90
5	**Cpm**	0.40	0.26
6	**CR**	173.3%	223%
7	**Zu**	0.66	-0.11
8	**ZL**	2.79	2.79
9	$\sigma_{Overall}$	0.0998797	0.0998797
10	σ_{Within}	0.108241	0.108241
11	**DPMO**	274,000	570,000
12	**Total reject rate**	25.46%	54.64%
13	**Estimated yield**	74.54%	45.36%
14	**Sigma level**	2.1	1.3

Table 4.50: *Comparing Index Results on the Cable Insulation Thickness Measurements before and after the Process Improvement*

S/N	Index	Before (0.67±0.14)	After (0.67±0.14)
1	**Cp**	0.45	0.90
2	**Cpk**	-0.035	0.09
3	**Cpu**	-0.03	0.09
4	**Cpl**	0.90	1.70
5	**Cpm**	0.26	0.35
6	**CR**	223%	110%
7	**Zu**	-0.11	0.28
8	**ZL**	2.79	5.17
9	$\sigma_{Overall}$	0.0998797	0.00281477
10	σ_{Within}	0.108241	0.0314975
11	**DPMO**	570,000	420,000
12	**Total reject rate**	54.64%	38.97%
13	**Estimated yield**	45.36%	61.03%
14	**Sigma level**	1.3	1.7

4.4 Derivation of Standard Time and Work Target Estimation

The first preliminary effort to sample time elements is to study the work environment to determine all elements of the operation to study. The extrusion start–up task was divided into work elements, and timed. Using Equations (4.2), (4.3), (4.4) and (4.5), the average time for each element was calculated, and the result of the calculations were tabulated in Table 4.51, while the procedural workout are shown in Appendix N.

Table 4.51: *Observed Time for Start-up Operation*

S/N	Elements	Average time (t) Sec	Standard deviation (Sx)
1	**Element 1**	45.19	9.235
2	**Element 2**	398.70	*47.94
3	**Element 3**	185.1	3.35
4	**Element 4**	134.80	5.93
5	**Element 5**	484.82	7.16
6	**Element 6**	274.14	8.71
7	**Element 7**	305.16	5.35
8	**Element 8**	602.49	*20.06
9	**Element 9**	506.83	9.97
	Total	2937.23	

From Table 4.49, the observed time (t) for the start-up operation = 49.53 min.

Basic Time (B_T) = $49\ x\ \frac{105}{100}$ = 52 minutes

Taking into account rests, possible breakdowns and personal fatigue. Considering time allowances (See Appendix O: 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%

$$ST = 52 + 52\ \text{x}\ \frac{30}{100} = 68 \text{ minutes}$$

Since Standard time is a common denominator for measuring productivity, the value gotten was implied to ascertain the expected productivity rate for this operation.

4.4.1 **Study Assumptions**

1. Start-up operation was conducted once (i.e. at the beginning of the shift).
2. Time to load and unload an output reel are the same.

To estimate the expected production yield for an 8hour shift, under the new designed extrusion parameter settings,given that the prescribed time for routine clean-up and minor quality checks (the heating system, spark tester, water trough, oil gauge, embossing wheel, and braking system) at the beginning of every shift is 30minutes; Start-up time = 67minutes;

useful time for work = 480-30minutes = 450minutes, observed time to get an output reel at the optimun designed parameter setting = 1.40hrs (100minutes);time to unload an output reel= 5.086. The expected number of reel that can be produced within an 8hour shift is tabulated in Table 4.52.

Table 4.52: *Production / Work Target Estimation Analysis*

S/N	**Available time (Minutes)**	**Processing time (Minutes)**	**New available time (minutes)**	**Output reel**	**Output coil**
1	450	100+68+5.086	450-[173.086] = 276.914	1	90
2	276.914	100+5.086+5.086	276.914-[110.172]= 166.742	1	90
3	166.742	100+5.086+5.086	166.742-[110.172] = 56.57	1	90
4	56.57	*******	*************	*****	
Total		393.43		3	270

From Table 4.52, the expected number of 1.0mm coil to be produced within an 8hour working shift is 270. With this observed estimation, the organisation can use this to structure their performance and estimate their production throughput. This estimation approach will go a long way in reducing the high rate of producing defective cables due to unrealistic work targets. Basically, there are about four inferences drawn from the study that will help the management enormously. They are as follow:

1. This study will enable efficient manpower requirement planning and proper knowledge of the process in terms of start and end time of a particular extrusion activity.
2. This study introduces the basis for an incentive, as estimated data will be used to prepare for standards that needs to be achieved by a worker.

3. This study would increase the management's knowledge of the process and therefore offer them control over workers.
4. This will enable the management to determine the expected production rate of an extrusion operation.

4.5 The Control Phase

Control phase is concerned with establishing procedures to sustain improvements made, and emphasize on the operators, materials, machine, and method of operation. Control charts were used to monitor the process, and the main reason of using control charts is to perceive the special causes of course variation so that examination and counteractive action will be carried out to eliminate them before having an excessive number of non-conforming cables produced. 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. Part of the process control is to identify causes of process variation, and categorize them into special and common causes. It is believed that by eliminating the special causes of variation that the process will stabilize into a state of control. Obvious characteristics of special and common causes of variation are contained in Table 4.53, and Table 4.54 categorized special causes and common causes of variation as were identified in the projects.

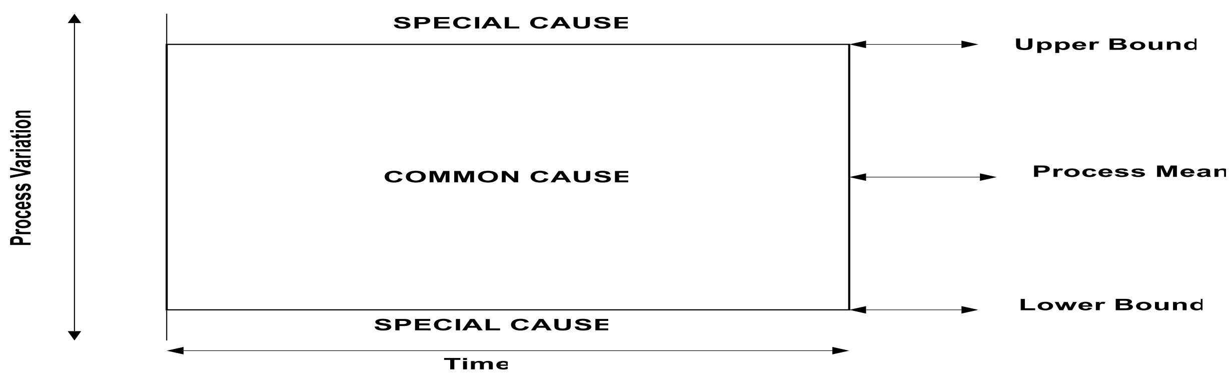


Figure 4.51. Six Sigma Common Causes and Special Causes (Adapted from http://www.sixsigma-institute.org/Six

Table 4.53: *Characteristics of Common Causes and Special Causes of Variation*

S/N	Common Cause of Variation	Special Cause of Variation
1	Present all the time.	Not always present
2	Have a small effect individually	Have a large negative impact on product quality.
3	Result in random variation	Result in between variations across subgroups.
4	Its effect can be tolerated	Its effect cannot be tolerated.

As part of 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 the process location, the between-sample component of variation, and the within-sample component of variation. During the assessment period, the process engineer measures randomly five parts from the extruding cable at 30 minutes intervals using the digital calipers. The assessment lasted for three days, during which nine consecutive operational shifts were assessed. The stability of the process as represented in figure 4.52-4.61 clearly signifies a stable process, one devoid of any special cause.

Table 4.54: *Categorization of Special and Common Causes Variation in Cable Extrusion Process*

S/N	Special Cause Variation	Common Cause Variation
1	Over-dimensioned tips	Unsteady wire guard
2	Over dimensioned dies	Bunched PVC pellet stringing together
3	Use of un-annealed copper conductor	Faulty water Pumps
4	Use of low temperature yielding tips	Operator to Operator variation
5	Worn-out Centering Bolts/Nuts	Impurities on the PVC
6	Improper Parameter settings	Use of non-preheated PVC
7	Poor Monitoring System	Poor tip Tolerance
8	Presence of water on the Input conductor	Poor water trough design
9	Unaligned- embosser	Use of poorly-annealed Conductor
10	Faulty measuring tools	
11	Faulty Heating system	

Table 4.54: *Categorization of Special and Common Causes Variation in Cable Extrusion Process*

S/N	Special Cause Variation	Common Cause Variation
12	Faulty braking system	
13	Poorly welded joints	
14	Management Interference	
15	Poor flushing of the extrusion barrel	
16	Inadequate operators skills	
17	Poor fitting of the tip to the core tube	

Table 4.55: *Cable Diameter Measurements Used for the Control Charts*

S / N	*Subgroup*	*Shift* 1	*Shift* 2	*Shift* 3	*Shift* 4	*Shift* 5	*Shift* 6	*Shift* 7	*Shift* 8	*Shift* 9
1	1	2.705	2.710	2.711	2.706	2.705	2.702	2.685	2.705	2.690
2	1	2.702	2.699	2.706	2.706	2.702	2.689	2.688	2.702	2.701
3	1	2.700	2.700	2.702	2.700	2.700	2.689	2.701	2.700	2.704
4	1	2.702	2.703	2.702	2.700	2.702	2.699	2.700	2.702	2.709
5	1	2.703	2.706	2.703	2.701	2.700	2.703	2.705	2.709	2.707
6	2	2.700	2.701	2.708	2.690	2.705	2.709	2.702	2.709	2.700
7	2	2.706	2.700	2.708	2.701	2.703	2.707	2.703	2.705	2.705
8	2	2.707	2.688	2.706	2.704	2.709	2.707	2.702	2.704	2.700
9	2	2.706	2.688	2.706	2.709	2.706	2.700	2.702	2.698	2.702
10	2	2.709	2.703	2.709	2.709	2.688	2.701	2.707	2.700	2.713
11	3	2.699	2.709	2.700	2.709	2.689	2.687	2.701	2.687	2.690
12	3	2.702	2.710	2.699	2.705	2.704	2.688	2.698	2.690	2.708
13	3	2.709	2.705	2.709	2.705	2.701	2.702	2.699	2.700	2.708
14	3	2.710	2.711	2.689	2.705	2.709	2.701	2.700	2.703	2.708
15	3	2.709	2.690	2.705	2.704	2.705	2.700	2.702	2.702	2.714
16	4	2.710	2.708	2.701	2.689	2.700	2.700	2.713	2.700	2.702
17	4	2.705	2.708	2.706	2.690	2.702	2.699	2.710	2.706	2.690
18	4	2.711	2.708	2.704	2.688	2.702	2.699	2.702	2.708	2.699
19	4	2.702	2.714	2.702	2.703	2.702	2.704	2.702	2.701	2.704
20	4	2.714	2.702	2.700	2.709	2.711	2.701	2.711	2.700	2.701
21	5	2.711	2.706	2.711	2.707	2.708	2.710	2.710	2.701	2.700
22	5	2.709	2.706	2.709	2.700	2.708	2.708	2.706	2.708	2.688
23	5	2.706	2.689	2.706	2.702	2.704	2.708	2.702	2.690	2.701
24	5	2.706	2.710	2.700	2.706	2.700	2.705	2.702	2.699	2.704
25	5	2.706	2.704	2.700	2.703	2.699	2.705	2.704	2.698	2.700

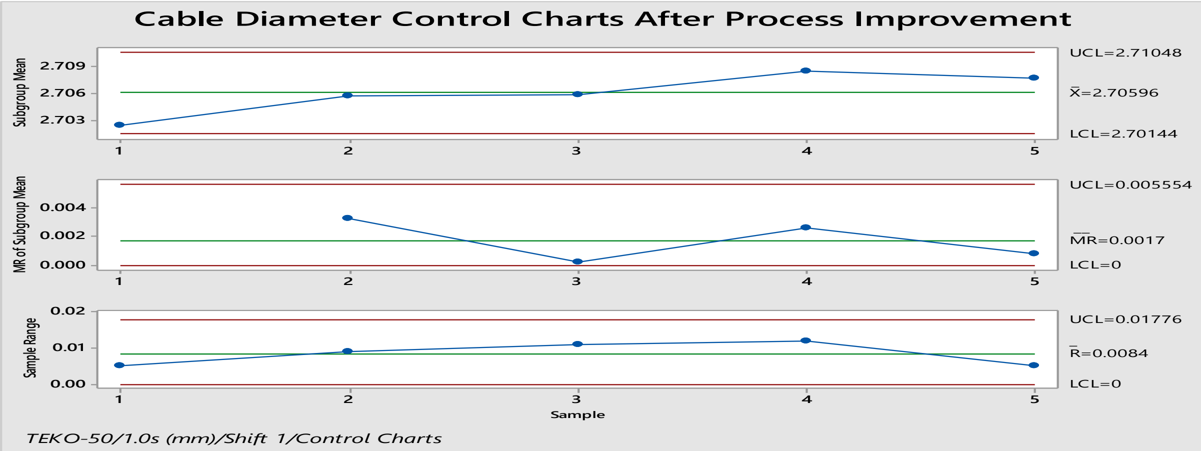


*Figure 4.53***.** I-MR-R/S chart for cable diameter for the first production shift

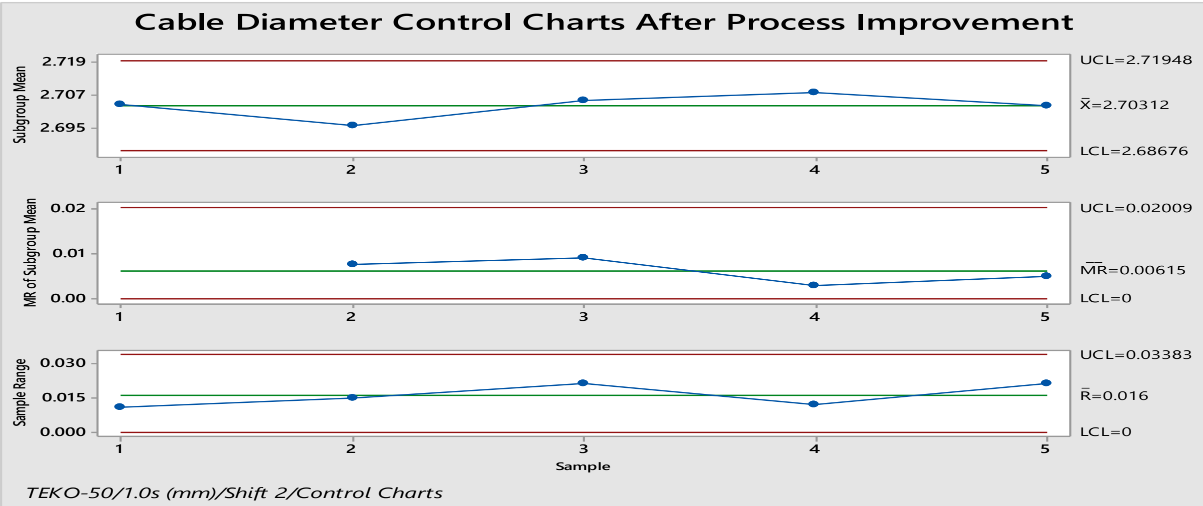


Figure 4.54. I-MR-R/S chart for cable diameter for the second production shift

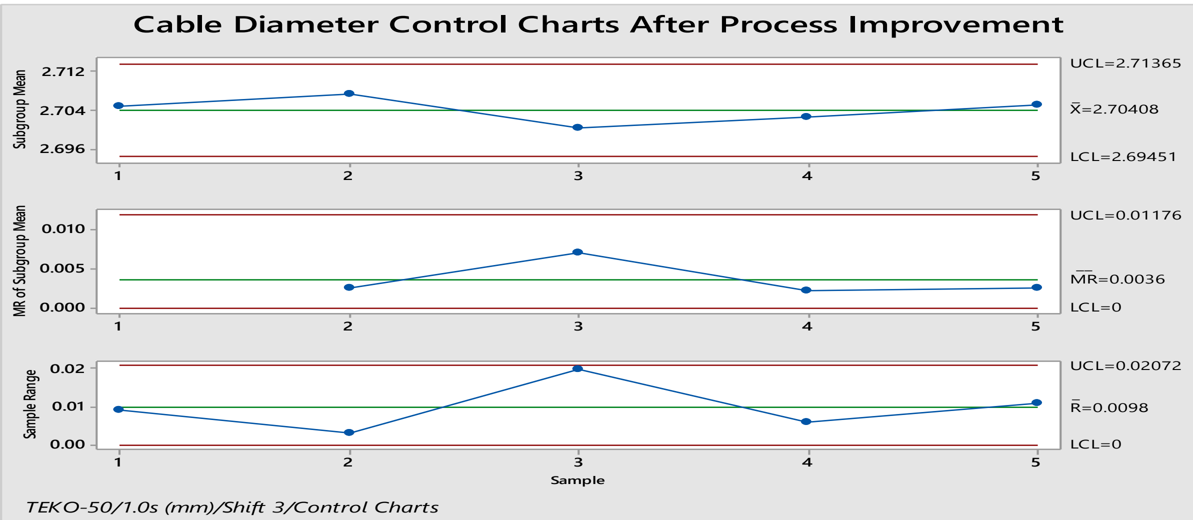


Figure 4.55. I-MR-R/S chart for the cable diameter for the third production shift

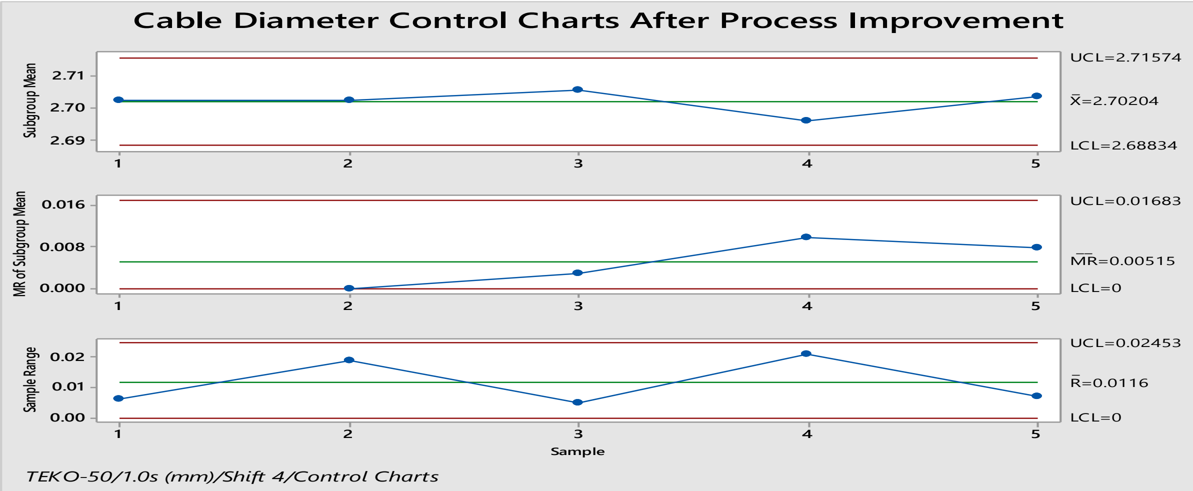


*Figure 4.56***.** I-MR-R/S chart for the cable diameter for the fourth production shift

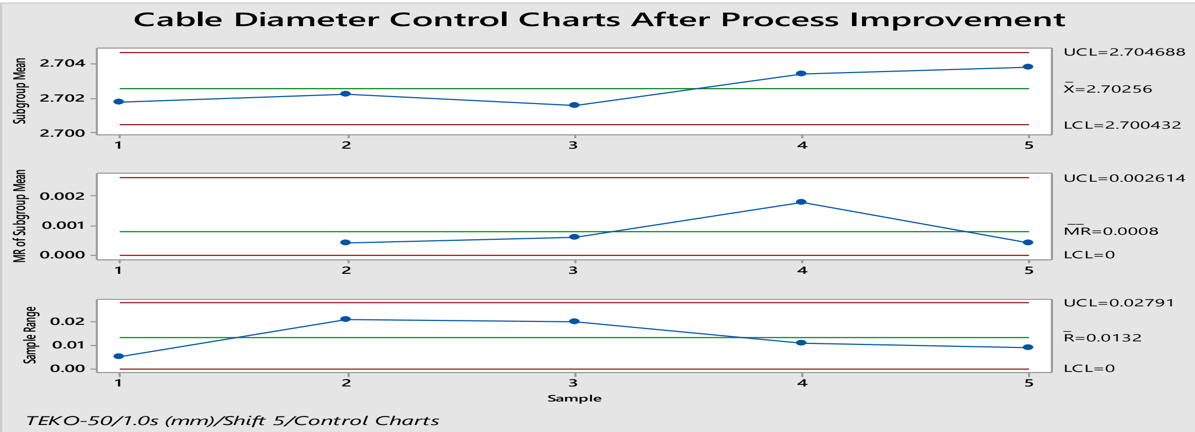


Figure 4.57. I-MR-R/S chart for cable diameter for the fifth production shift

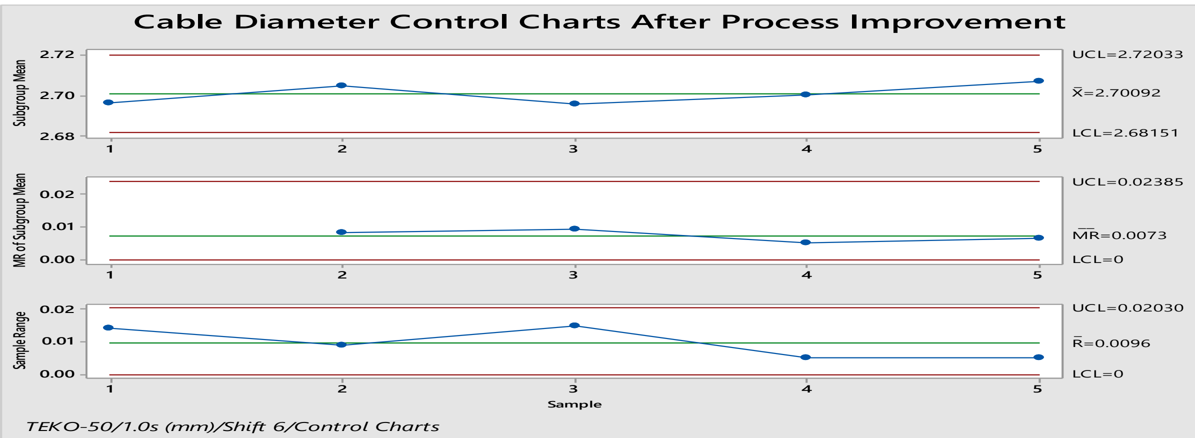


Figure 4.58. I-MR-R/S chart for cable diameter for the sixth production shift

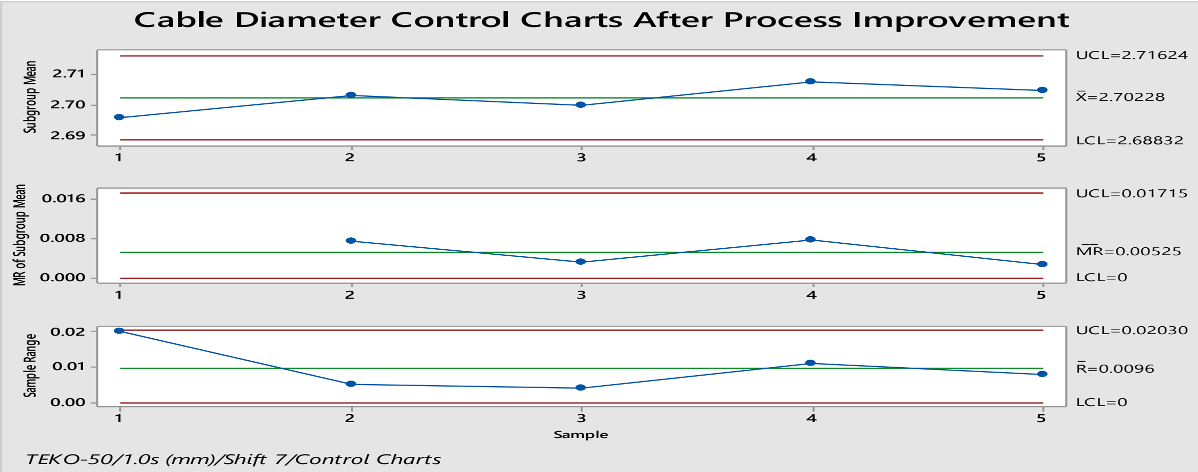


Figure 4.59. I-MR-R/S chart for Cable diameter for the seventh production shift

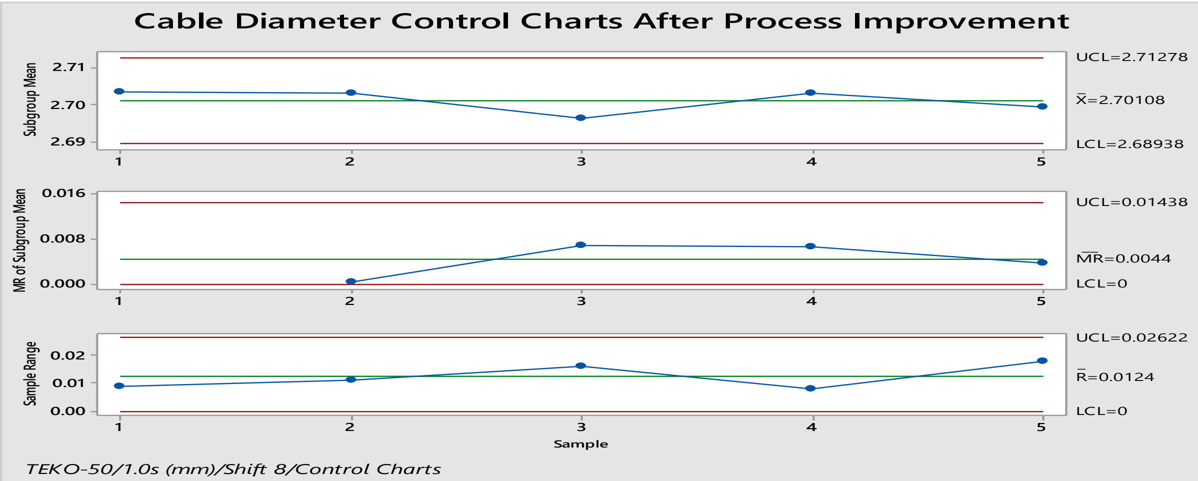


Figure 4.60. I-MR-R/S chart for cable diameter for the eight production shift

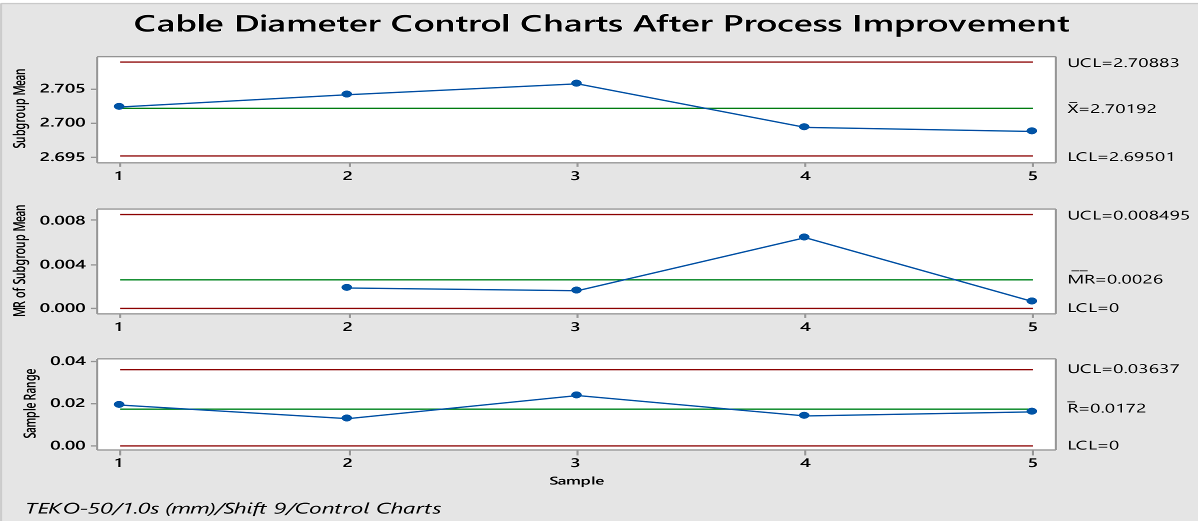


Figure 4.61. I-MR-R/S chart for cable diameter for the ninth production shift

Table 4.56: *Control Plan Template for Monitoring the Improved Process*

		Specifications				Performance Index							
Operation	**CTQ Characteristics**	**USL**	**LSL**	**Target**	**Unit of Measurement**	**Cpk**	**CR**	**Data Description**	**Measurement Method**	**Sample size**	**Frequency of Measurement**	**Who Measures**	**Corrective Actions**
Cable Extrusion	**Cable Concentricity**	**0.89**	**0.53**	**0.71**	**mm**	**≥1.33**	**≤ 75%**	**Variable**	**Profile enlarger**	**10 parts/ reel**	**End of every shift**	**Process Engineers**	**Ref. updated SOP**
	Cable Dimension	**2.74**	**2.67**	**2.705**	**mm**	**≥ 1.33**	**≤ 75%**	**Variable**	**Profile enlarger**	**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**

4.6 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***: In order to achieve continuous improvement of the process, the company should always attempt to redefine the voice of the process (Control chart) to match the expectation of the customers. The company's specification limits should be redefined to be properly centered in order to meet customer's requirements. It is shown in the study that much will not be gained by centering the process but by total overhauling the entire extrusion cavity.

Technically, this is so since the values of Cpk's were slightly smaller than that of Cp's from the performance assessments.

- ***Job Rotation and Transfers:*** When the experienced workers were transferred to other shifts, problems emanated due to the inexperience of the newly engaged operators. A proposed approach is to pair the experienced with the newly trained personnel together in all the shifts. The effects of using the newly trained personnel on a shift has always proven catastrophic, leading to lower production yield and the production of sub-standard quality of PVC (mostly bunched PVC and one's having pores).
- ***Training System:*** Proper training of the new operators on machine principles, alongside specific work procedures is advised. An operator should only be certified fit to manage an extrusion line only when he/she has become accustomed to the ways and strategies of tackling all the likely production challenges such that:

1. The operator should know by name, the peculiar machine problems.
2. The operator should have been trained on the basic maintenance skills of a particular machine of interest before handling an extrusion line.
3. The operator should have proven to be knowledgeable enough to conduct minor repairs on his machines, and when to seek for an external assistance.
4. In other to train the workforce with a versatile knowledge of the various machines, it is advisable to rotationally pair the operators with operators manned in different machines for cross learning.
5. Cleaning of the embosser with diesel to help peel off the stuck PVC should be strictly adhered to at the start of every production shift.

- ***Worn-out Centering Bolts/Nuts:*** Since changing and mounting a centering bolt is time consuming, it will be better to use high material composition of bolts, so that incessant breaks will be reduced. Bolts and nuts should be made of medium carbon steel (8.8MPa tensile strength), instead of using ones that is made of mild steel of 4.8MPa tensile strength.

- ***Design of Experiment:*** During experimental designs, make a complete record of the machine settings before making any change. Adjust only one setting at a time, choosing the easiest one first. If this change does not eliminate the defect, go back to the original settings after making notes of what was done and taking marked samples of what was produced. Allow sufficient time for the machine to respond to the changes and to come to equilibrium with each change before samples are taken.
- ***Poor Logistics and Material Resource Planning:*** The store section should always retain a staff member to assist in parts delivery during machine breakdowns. The store section is usually found closed after the second production shift. As a result of this, it is either the operators continue to manage the already damaged parts, or they wait at the start of the next shift for the store section to re-open. Secondly, it is considered a time waste for an operator to leave his working post just to bring an input material (mostly reel) needed for the extrusion process.

1. There should always be a routine review on material planning. There should be a good number of personnel assigned for the sole function of delivering production materials to every extrusion units even before any production shift. Review the production order for color and quantity and check that all necessary tools and equipment are in position. Unavailability of empty reels constitutes most of the idle times during the extrusion process.
2. One may want to change from one color of material to another and this causes both material and production time waste. To minimize such losses, the production should be carefully planned so that work flows in a logical sequence. In this way, light-

colored materials should be processed first so that when changing color, much time and material won't be wasted in purging the line.

3. The purged material should be dropped into a bucket of cold water to minimize the formation of fumes and to protect anyone from touching this hot, sticky, dangerous material.

- ***Machine Maintenance:*** At the Teko-50 section, remove the air pressure and install a spring in the loading section to stabilize the tension. This erratic tension on the payoff section often leads to wire cut, especially with the bunched wires. It also affects wire concentricity most especially when the conductor inputs are not properly annealed.

1. Installing the in-built preheating system to all the extrusion systems is paramount. The detached preheating systems, according to the operators are not friendly health wise. An operator, being afraid of inhaling gases from the preheating PVC's, tends to absconds from the **SOP** of using preheated PVC and tends toward using available non-preheated PVC for extrusion.
2. Unresponsive nature of the maintenance unit to take-on on minor repairs as reported by operators is a big co-factor to time wasting in the extrusion process. Total Productive Maintenance is recommended whereby the operators take up the autonomy of their machines by acquiring some maintenance skills and training from the maintenance department. This skill will help them to tackle minor maintenance activities and will also give the maintenance section more time to handle major repairs.
3. Faulty spooler at the **D14** contributes to a good number of lost hours and poor work output.

- ***Input Material Quality****:* There is also need to ascertain the composition of the PVC, their constituents and mixture ratios. This will aid to validate the reliability of the compounding section in producing PVC materials that are within the specification. The operators often complain that the PVC used often exhibit different quality features such that some PVC's will give a good output after 24hours of production even without preheating, while some others produced within the stipulated 24hour of direct use without preheating still fails to produce as required. There is the need for the quality Assurance section to always conduct material composition test on every batch of PVC to be used for extrusion.

1. A complaint should be tendered to the tip manufacturer/supplier, on the incessant tip break for him/her to check the heat treatment and improve on the material compositions used for the tip.
2. Uneven reel opening can cause low conductor diameter due to the pressure exerted on the conductor.
3. Breaker plates also cause PVC leakages when they bend or are not in the right circumference with the extruder outlet. It is recommended that the local manufacturer improve on the material composition and buffer its temperature yielding strength.

- ***Re-Assignment of Role:*** It was observed during the course of the study that it was not the responsibility of the operators to measure tip. The input conductor diameter test being conducted by the QA need to be redressed to avoid idling time of the operator to start-up line.

1. In situations where the actual tip dimension for production is not available, it is advised that the assignment is given to the most experienced operator. For instance, when there is tip shortage for a particular cable tip size resulting to the use of a higher tip dimension for a particular size. (The most experienced, not just a normal operator should do the replacement so as to make good with the known dimensional discrepancies).

- ***Wire entanglement:*** Wire entanglement should not be corrected at the time of extrusion. Alternate provision should be made to tackle this production anomaly in order to avoid the increased time of production and the associated costs.
- ***Abrupt Management Decisions / Interference*:** Erratic management decision on the product type (size & colour) to be produced has deep financial cost implications. This also gives the operators un-called relaxation cause, at best daily target cannot be accounted for and excessive time is wasted in preparing for another product type. Incessant change of production order results in frequent loosening and tightening of the crosshead. During this loosening and tightening process, a lot of pressures are impacted on the nut of the centering bolt resulting to worn out of the nuts.
- ***Process Control Tools:*** Visual Management (**VM**) tools should also be incorporated as part of the tools to be used in the control phase. VM will enable quick detection of performance concern and subsequent quick response delivery. The recommended VM tools are as follows:

1. Whiteboards showing daily progress against the target.
2. Team weekly scorecards displayed in the team's common area, which should be made the subject of discussion during the team's tollgate reviews.
3. Job aids posted in each work post.

4.7 Economic Impact Analysis Before and After the Improvement

To determine the quality levels of the production process for the cable diameter attributes before and after process improvement, we now express the quality level of the cable diameter in financial terms using the newly designed tolerance intervals of 2.74 for USL, and 2.67 for LSL, tolerance interval rangees from T-Δ to T +Δ; Δ = 0.035, $T = \frac{(USL \oplus LSL)}{2}$ = $\frac{(2.74 \oplus 2.67)}{2}$ = 2.705±0.035.

Assuming an estimated warranty cost of ₦30 for any 1.0mm single coil produced that do not meet with the target value, 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.

Table 4.57: *Quality Loss Attributes to Deviations of the Cable Diameter from its Specified Target Value* (Before the Improvement).

S/N	y	(y-T)	$(y-T)^2$
1	2.719	0.004	0.000016
2	2.896	0.181	0.032761
3	2.769	0.054	0.002916
4	2.773	0.058	0.003364
5	2.693	-0.022	0.000484
6	2.732	0.017	0.000289
7	2.894	0.179	0.032041
8	2.725	0.010	0.000100
9	2.716	0.003	0.000009
10	2.782	0.067	0.004489
11	2.864	0.149	0.022201
12	2.887	0.172	0.029584
13	2.824	0.109	0.011881
14	2.826	0.111	0.012321
15	2.796	0.081	0.006561
16	2.907	0.192	0.036864
17	2.846	0.131	0.017161
18	2.878	0.163	0.026569
19	2.755	0.040	0.001600
20	2.787	0.072	0.005184
21	2.792	0.077	0.005929
22	2.778	0.063	0.003969
23	2.823	0.108	0.011664
24	2.798	0.083	0.006889
25	2.801	0.086	0.007396
26	2.864	0.149	0.022201
27	2.756	0.041	0.001681
28	2.785	0.041	0.004900
29	2.840	0.070	0.015625
30	2.871	0.125	0.024336
31	2.734	0.156	0.000361
32	2.747	0.019	0.001024
33	2.726	0.032	0.000121
34	2.770	0.011	0.003025
35	2.709	0.055	0.000036
36	2.761	-0.006	0.002116
37	2.746	0.046	0.000961
38	2.713	0.031	0.000004

Table 4.57: *Quality Loss Attributes to Deviations of the Cable Diameter from its Specified Target Value* (Before the Improvement).

S/N	y	(y-T)	$(y-T)^2$
39	2.786	-0.002	0.005041
40	2.792	0.071	0.005929
41	2.691	-0.024	0.000576
42	2.743	0.028	0.000784
43	2.821	0.106	0.011236
44	2.790	0.075	0.005625
45	2.705	-0.010	0.000100
46	2.899	0.184	0.033856
47	2.787	0.072	0.005184
48	2.747	0.032	0.001024
49	2.864	0.149	0.022201
50	2.822	0.107	0.011449
51	2.761	0.046	0.002116
52	2.697	-0.018	0.000324
53	2.826	0.111	0.012321
54	2.765	0.050	0.002500
55	2.790	0.075	0.005625
56	2.820	0.105	0.011025
57	2.699	-0.016	0.002560
58	2.745	0.030	0.000900
59	2.789	0.074	0.005476
60	2.788	0.073	0.005329
61	2.891	0.176	0.030976
62	2.800	0.085	0.007225
63	2.721	0.006	0.000036
64	2.795	0.080	0.00640
65	2.700	-0.015	0.000225
66	2.866	0.151	0.022801
67	2.784	0.069	0.004761
68	2.756	0.041	0.001681
69	2.718	0.003	0.000009
70	2.758	0.043	0.001849
71	2.857	0.142	0.020164
72	2.810	0.095	0.009025
73	2.884	0.169	0.028561
74	2.767	0.052	0.002704
75	2.844	0.129	0.016641
76	2.708	-0.007	0.000049
77	2.772	0.057	0.003249
78	2.770	0.055	0.003025
79	2.795	0.080	0.006400
80	2.758	0.043	0.001849
81	2.854	0.139	0.019321
82	2.792	0.077	0.005929
83	2.812	0.097	0.009409

Table 4.57: *Quality Loss Attributes to Deviations of the Cable Diameter from its Specified Target Value* (Before the Improvement).

S/N	y	(y-T)	$(y\text{-}T)^2$
84	2.855	0.140	0.019600
85	2.775	0.060	0.003600
86	2.769	0.054	0.002916
87	2.725	0.010	0.000100
88	2.730	0.015	0.000225
89	2.740	0.025	0.000625
90	2.725	0.010	0.000100
91	2.771	0.056	0.003136
92	2.696	-0.019	0.000361
93	2.661	-0.054	0.002916
94	2.708	-0.007	0.000049
95	2.849	0.134	0.017956
96	2.844	0.129	0.016641
97	2.857	0.142	0.020164
98	2.767	0.052	0.002704
99	2.884	0.169	0.028561
100	2.810	0.095	0.009025

Substituting values in Table 4.57 in Equation (4.11)

$$\text{T (Original)} = \frac{(USL + LSL)}{2} = \frac{(2.90 + 2.53)}{2} = 2.715.$$

$$\text{Original } \Delta = (2.90\text{-}2.715) = 0.185,$$

$$\text{T (New)} = \frac{(USL + LSL)}{2} = \frac{(2.74 + 2.67)}{2} = 2.705 \pm 0.035.$$

$$\text{New } \Delta = (2.74\text{-}2.705) = 0.035,$$

Substituting the cable diameter values before the Improvement in Equation (4.11)

$$\text{MSD} = \text{MSD} = \frac{1}{n}\sum(yi - T)^2 = \text{MSD} = 1/100[0.838478] = 0.00838478$$

$$\text{L } (2.715) = [30]\,[0.00838478]/(0.185)^2 \quad = ₦7.34 \text{ per coil}$$

Total yearly loss before the experimental design = 7.34*300*810 = ₦1,783,620

4.7.1 **Economic Impact Estimation After Improvement**

Table 4.58: *Quality Loss Attributes to Deviations of the Core Cable Diameter from its Specified Target Value (after Improvement)*

S/N	y	(y-T)	$(y-T)^2$
1	2.720	0.015	0.000225
2	2.693	-0.012	0.000144
3	2.718	0.013	0.000169
4	2.700	-0.005	0.000025
5	2.712	0.007	0.000049
6	2.701	-0.004	0.000016
7	2.704	-0.001	0.000001
8	2.711	0.006	0.000036
9	2.699	-0.006	0.000225
10	2.720	0.015	0.000004
11	2.703	-0.002	0.000036
12	2.711	0.006	0.000036
13	2.697	-0.008	0.000064
14	2.703	-0.002	0.000004
15	2.710	0.005	0.000025
16	2.703	-0.002	0.000004
17	2.700	0.005	0.000025
18	2.711	0.006	0.000036
19	2.721	0.016	0.000256
20	2.709	0.004	0.000016
21	2.707	0.002	0.000004
22	2.705	0	0
23	2.718	0.013	0.000169
24	2.708	0.003	0.000009
25	2.713	0.008	0.000064
26	2.711	0.006	0.000036
27	2.700	-0.005	0.000025
28	2.709	0.004	0.000016
29	2.719	0.014	0.000196
30	2.713	0.008	0.000064
31	2.711	0.006	0.000036
32	2.709	0.004	0.000016
33	2.719	0.014	0.000196
34	2.710	0.005	0.000025
35	2.700	-0.005	0.000025
36	2.710	0.005	0.000025
37	2.719	0.014	0.000025
38	2.716	0.011	0.000121
39	2.701	-0.004	0.000016
40	2.720	0.015	0.000225
41	2.689	-0.016	0.000256
42	2.708	0.003	0.000009
43	2.700	-0.005	0.000025

Table 4.58: *Quality Loss Attributes to Deviations of the Core Cable Diameter from its Specified Target Value (after Improvement)*

S/N	y	(y-T)	$(y-T)^2$
44	2.712	0.007	0.000049
45	2.711	0.006	0.000036
46	2.709	0.004	0.000016
47	2.702	-0.003	0.000009
48	2.699	-0.006	0.000036
49	2.706	0.001	0.000001
50	2.709	0.004	0.000016
51	2.708	0.003	0.000009
52	2.711	0.006	0.000036
53	2.714	0.009	0.000081
54	2.719	0.014	0.000196
55	2.720	0.015	0.000225
56	2.719	0.014	0.000196
57	2.709	0.004	0.000016
58	2.725	0.020	0.000400
59	2.720	0.015	0.000225
60	2.719	0.014	0.000196
61	2.701	-0.004	0.000016
62	2.717	0.012	0.000144
63	2.707	0.002	0.000004
64	2.711	0.006	0.000036
65	2.713	0.008	0.000064
66	2.730	0.025	0.000625
67	2.711	0.006	0.000036
68	2.701	-0.004	0.000016
69	2.715	0.010	0.000100
70	2.712	0.007	0.000049
71	2.709	0.004	0.000016
72	2.713	0.008	0.000064
73	2.716	0.011	0.000121
74	2.714	0.009	0.000081
75	2.719	0.014	0.000196
76	2.719	0.014	0.000196
77	2.702	-0.003	0.000009
78	2.705	0	0
79	2.700	-0.005	0.000025
80	2.720	0.015	0.000025
81	2.710	0.005	0.000025
82	2.716	0.011	0.000121
83	2.699	-0.006	0.000036
84	2.700	-0.005	0.000025
85	2.713	0.008	0.000064
86	2.698	-0.007	0.000049
87	2.707	0.002	0.000004
88	2.701	-0.004	0.000016

Table 4.58: *Quality Loss Attributes to Deviations of the Core Cable Diameter from its Specified Target Value (after Improvement)*

S/N	y	(y-T)	$(y\text{-}T)^2$
89	2.719	0.014	0.000196
90	2.711	0.006	0.000036
91	2.719	0.014	0.000196
92	2.710	0.005	0.000025
93	2.723	0.018	0.000324
94	2.712	0.007	0.000049
95	2.696	-0.009	0.000081
96	2.703	-0.002	0.000004
97	2.720	0.015	0.000225
98	2.699	-0.006	0.000036
99	2.709	0.004	0.000016
100	2.713	0.008	0.000064

Substituting values in Table 4.58 in Equation (4.11)

Substituting the cable diameter values after the Improvement in Equation (4.11)

$$\text{MSD} = \frac{1}{n}\sum(yi - T)^2 = \text{MSD} = 1/100[0.008508] = 0.00008508$$

$$L\ (2.715) = [30]\ [0.00008508] / (0.035)^2 \qquad = ₦2.08 \text{ per coil}$$

Actually, this quality level (₦) is the loss attributable to deviations of the cable diameter from its specified target value. Considering yearly production, assuming the organization worked for 300 days in a year and the daily production capacity is maintained on the average of 810 coils per day (see Table 4.52), then the estimated annual loss amounts to 2.08 x 300 x 810 = ₦505,440. ₦ 505,440 now becomes the projected overall loss and also an opportunity for improvement attributable to the deviations on the cable from its target diameter value per annum after the experimental design. However, the economic impact analysis was also applied to the initial diameter measurements, but now with the tightened tolerance limit to estimate the amount of loss incurred due to deviations from the target. The comparative results of the analysis depict a remarkable improvement. Drawing comparison from column three and seven of Table 4.57 and same columns in Table 4.58, we notice a whole lot of positive deviations in Table 4.57 than in Table 4.58, which is an indication there was more usage of insulation material input 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 on the annual loss estimation after improvement is computed with the formular:

Decrease in annual loss estimation= Orignal loss estimation-New estimated loss (4.12)

$$\%\text{Decrease in annual loss estimation} = \frac{Decrease\ in\ Cost}{Original\ Cost} * 100 \quad (4.13)$$

Decrease = 1,783,620-505,440 = 1,278,180

$$\%\text{Decrease} = \frac{1,278,180}{1,783,620} * 100 = 72\%$$

Table 4.59: *Quality Improvement by Tightening Tolerance*

	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 4.59, contains the value of the existing and the newly designed engineering tolerance interval for the extrusion process. The noticeable decrement between the two is seen as T±0.185 to T±0.032, which is about 82.7% reduction from the initial tolerance limit. The second row of the fifth column in Table 4.59, the expected quality loss per unit coil for 1.0(mm) single core cable is ₦7.34, and in the third row of the same fifth column with the tightened tolerance the expected quality loss per coil reduced to ₦2.08. Judging the level of improvement attained using the original engineering tolerance as shown in column six of

Table 4.53 is at ₦1,783,620, and with the tightened tolerance is a reduced cost of ₦505,440. Lastly, the estimated net improvement due to the new design per annum, considering the earlier estimated production throughput from the process is ₦1,278,180 as depicted in the third row of the last column of Table 4.59. At the end of the improvement projects, the height of the improvement attained was assessed using the annual production data and defect history records from the case organisation. Records on 1.0s cables produced from 2013 to Dec. 2017 are as shown in the Table 4.60.

Table 4.60: *Records on 1.0s (mm) Cables Produced from 2013- Dec.2017*
Source: Cutix Cable PLC Anuka Production Plant

Monthly production	*Quantity produced* (*m*) (2013)	*Quantity produced* (*m*) (2014)	*Quantity produced* (*m*) (2015)	*Quantity produced* (*m*) (2016)	*Quantity produced* (*m*) (2017)
Jan	459,245	579,927	722,558	410,631	1,174,004
Feb.	572,724	115,666	465,009	600,637	677,368
March	573,393	*	895,685	749,572	862,593
April	547,612	*	838,339	1,026,326	712,619
May	550,454	*	334,866	841,004	592,185
June	656,202	*	878,437	732,712	667,204
July	225,191	*	893,041	589,568	619,697
Aug.	649,335	689,840	818,403	*	701,229
Sept.	451,158	605,923	406,139	*	472,119
Oct.	706,199	564,649	900,909	*	514,811
Nov.	615,612	689,882	369,894	*	653,524
Dec	466,573	481,130	771,873	*	446,178
$\sum$	6,473,678	3,727,017	7,523,280	4,950,450	8,093,531

From the tabulated report on Table 4.60 2017 production year has the largest number of produced quantity of cables 8,093,531metres, followed by 2015, 2013, 2016 and 2014 with the least production quantity. Records on the number of 1.0s (mm) cables rejected due to the categorised defect features in the organisation is as shown in Table 4.61.

Table 4.61: *Quantity of 1.0s (mm) Cables Rejected from 2013- Dec.2017*

S/N	*Defects* (m)	2013	2014	2015	2016	2017	
1	*ITF*	5,672.44	3,995.092	9,025.110	8,743.098	4508.019	
2	*ISF*	4,697.44	4,877.495	5,460.999	10,710.054	3,577.102	
3	*LCD*	*	*	1,680.111	*	*	
4	*WL*	*	*	*	*	105.000	
5	*NL*	*	*	945.000	*	840.00	
6	*TPs*	420.000	*	*	210.000	735.000	
7	*ICD*	*	882.403	*	*	420.000	
	Total (m)	10,789.88	9,754.99	17,111.22	19,663.35	10,185.120	

Source: Cutix Cable PLC Anuka Production Plant

At the project termination stage as shown in Table 4.61, the quantity of non-conformed cables rejected due to Insulation Surface Flaws was reduced by 23.85% from the entitlement value of 4697.44 of 2013 period.

4.8 Development of a Generic Graphical User Interface Support System

A graphical user interface was developed to take the burden of numerous and complex mathematical calculations away from manufacturers. The developed graphical user interface was based on MATLAB toolbox which is a programming language of a higher level with interactive development environment. The design environment of this program is based on the Simulink of MATLAB that provides the drawing function and the graphical user interface development environment (GUIDE). The developed graphical user interface (GUI) was tested through real case study and satisfactorily results were obtained. The results showed that developed graphical user interface was functional, effective, flexible and beneficial in solving some of the real life problems that characterize cable manufacturing organizations.

4.8.1 General Consideration in Generic User Interface Support Systems

Designing a good user interface is critical to the success of a system. The developed GUI system was designed to be accessible to people of all levels of knowledge, and with instant feedback mechanism. In the development of the tool, a MATLAB code that defines all component properties and behaviors was created and used in building the tool. This application framework was used to construct elegant and powerful applications displaying interactive reports and data visualizations. The tool interface was simply created in such a way that the user's objectives could be achieved easily. In designing the software, some considerations were made paramount and was adopted; the end user's experience, simplicity, software usability, flexibility and responsive. These considerations were adopted to ensure that the developed tool contains the following features:

- It is user friendly and can be used by anyone that doesn't have a comprehensive knowledge of the technical details behind it.
- It is simple with no ambiguity over the way the interface operates both in terms of visual hierarchy and content.
- The User Interface has the capacity for updates thus changes can be made without causing a conflict of interest.
- The interface was designed to move swiftly in pace with the user,

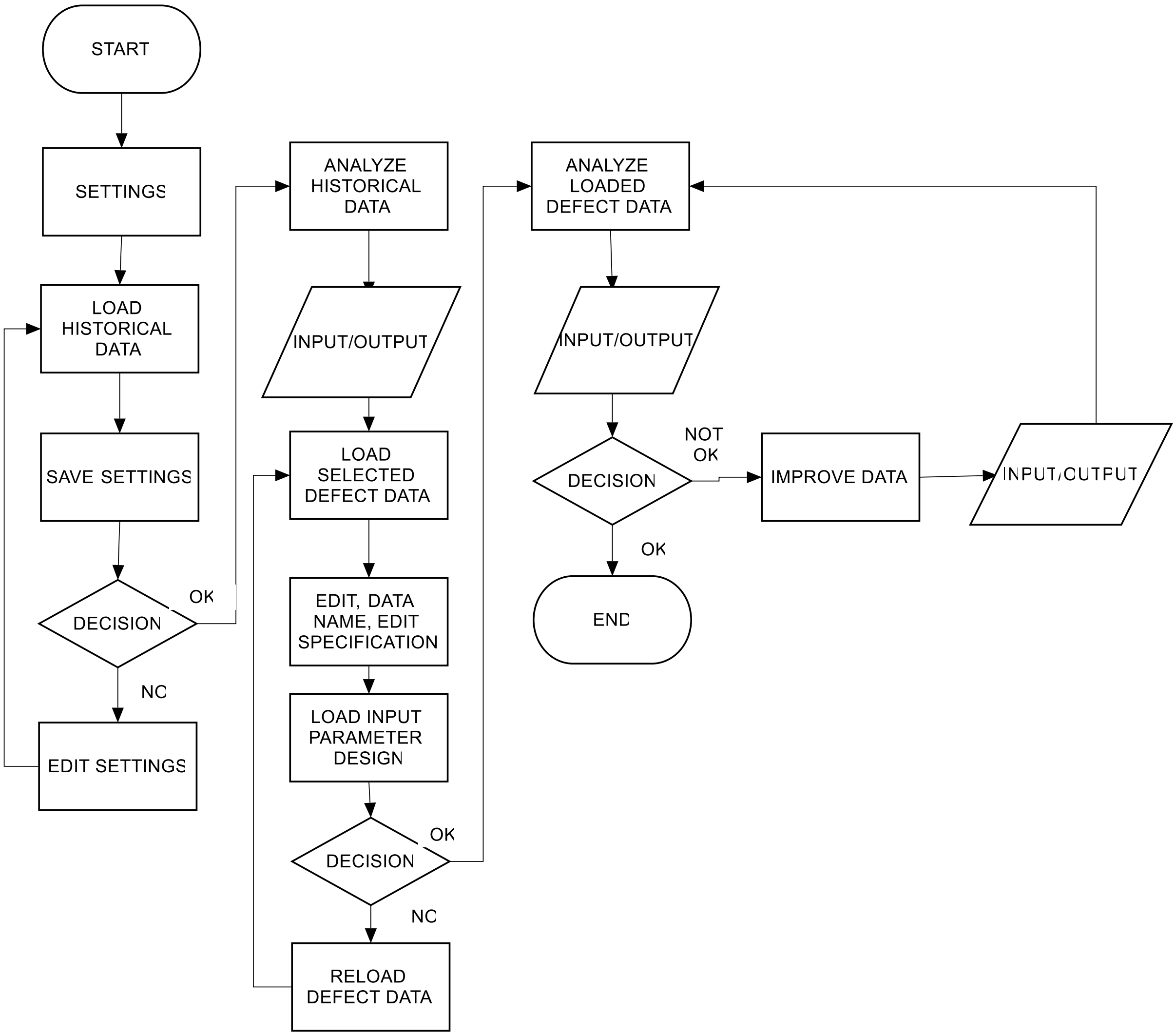
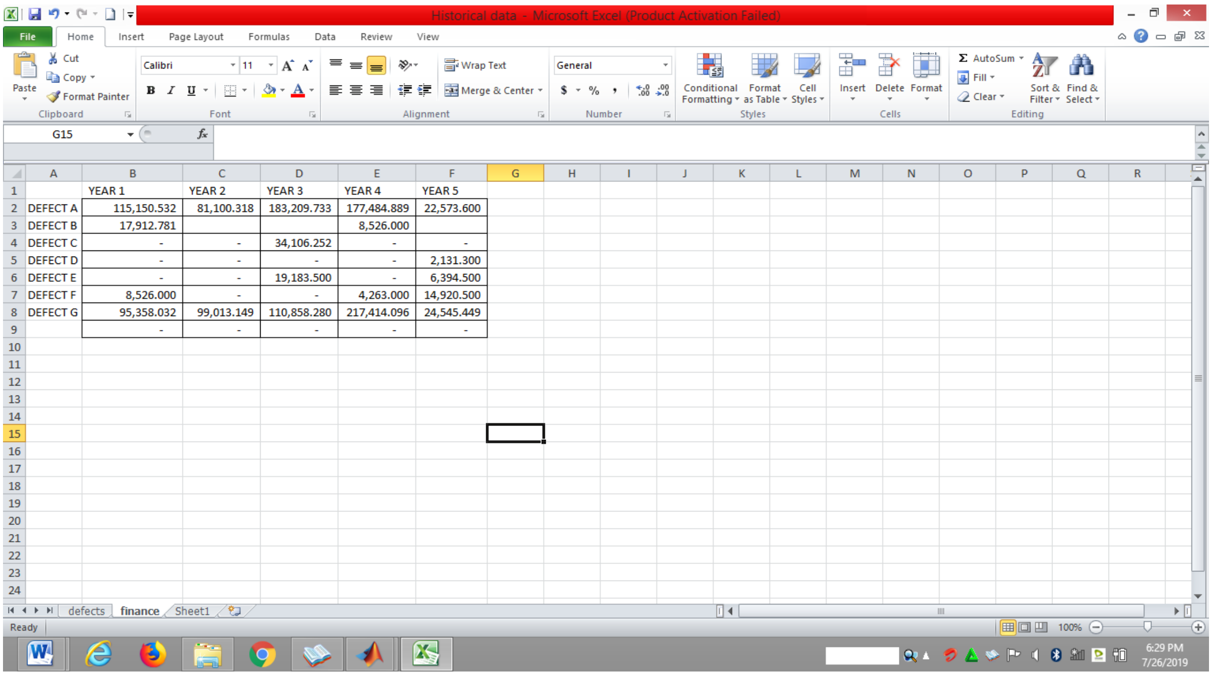


Figure 4.62. General Graphical Overview of the Generic User Support System

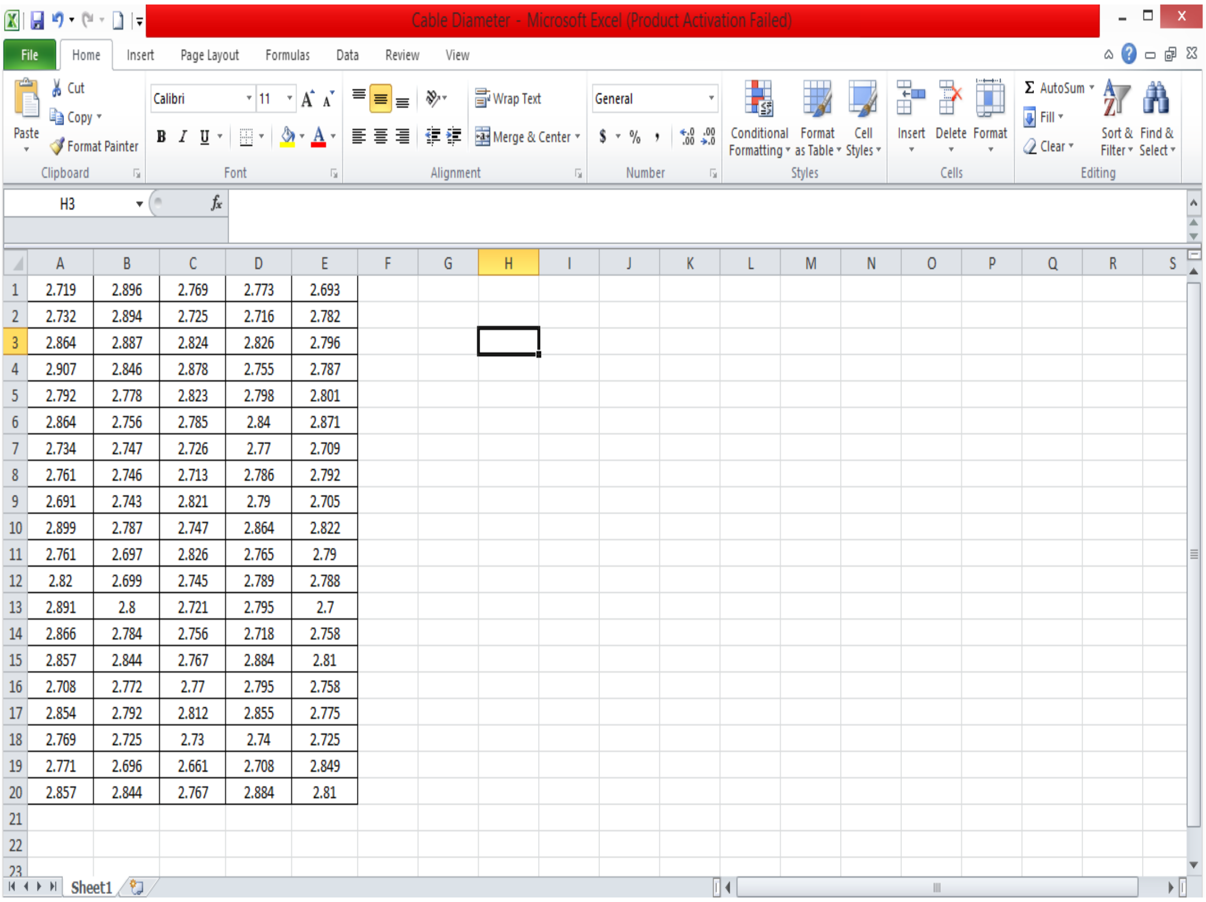
4.8.2 Data presentation

In order to standardize the procedures of the user interface support system, the required input data have to be prepared in a specific format before the user interface support system can be utilized. The system requires many user-friendly input files, containing financial cost of defect, cable diameter measurements, and Insulation thickness measurements. An example of the exact required input data required is shown in figure 4.63, 4.64 and 4.65.



	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
DEFECT A	115,150.532	81,100.318	183,209.733	177,484.889	22,573.600
DEFECT B	17,912.781			8,526.000	
DEFECT C	-	-	34,106.252	-	-
DEFECT D	-	-	-	-	2,131.300
DEFECT E	-	-	19,183.500	-	6,394.500
DEFECT F	8,526.000	-	-	4,263.000	14,920.500
DEFECT G	95,358.032	99,013.149	110,858.280	217,414.096	24,545.449
	-	-	-	-	-

Figure 4.63 Required Input Format for the Historical data



	A	B	C	D	E
1	2.719	2.896	2.769	2.773	2.693
2	2.732	2.894	2.725	2.716	2.782
3	2.864	2.887	2.824	2.826	2.796
4	2.907	2.846	2.878	2.755	2.787
5	2.792	2.778	2.823	2.798	2.801
6	2.864	2.756	2.785	2.84	2.871
7	2.734	2.747	2.726	2.77	2.709
8	2.761	2.746	2.713	2.786	2.792
9	2.691	2.743	2.821	2.79	2.705
10	2.899	2.787	2.747	2.864	2.822
11	2.761	2.697	2.826	2.765	2.79
12	2.82	2.699	2.745	2.789	2.788
13	2.891	2.8	2.721	2.795	2.7
14	2.866	2.784	2.756	2.718	2.758
15	2.857	2.844	2.767	2.884	2.81
16	2.708	2.772	2.77	2.795	2.758
17	2.854	2.792	2.812	2.855	2.775
18	2.769	2.725	2.73	2.74	2.725
19	2.771	2.696	2.661	2.708	2.849
20	2.857	2.844	2.767	2.884	2.81

Figure 4.64 Required Input Format for the Cable Diameter Measurements

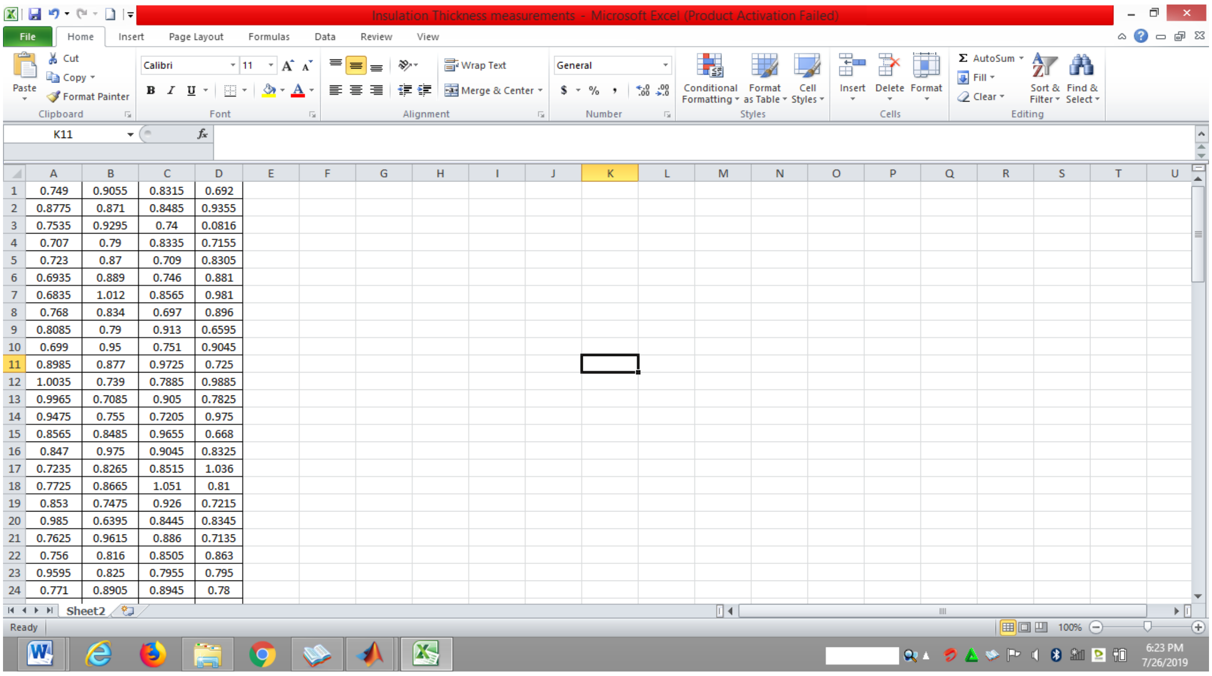


Figure 4.65 Required Input Format for Cable Insulation Thickness Measurements

4.8.3 System Walk Through

After having prepared the required input data in the specified format as described in the previous section, the user interface support system can be utilized to recommend appropriate projects to embark on. Once the user interface support system is initialized, the user is presented with the "Home screen" shown in Figure 4.66.

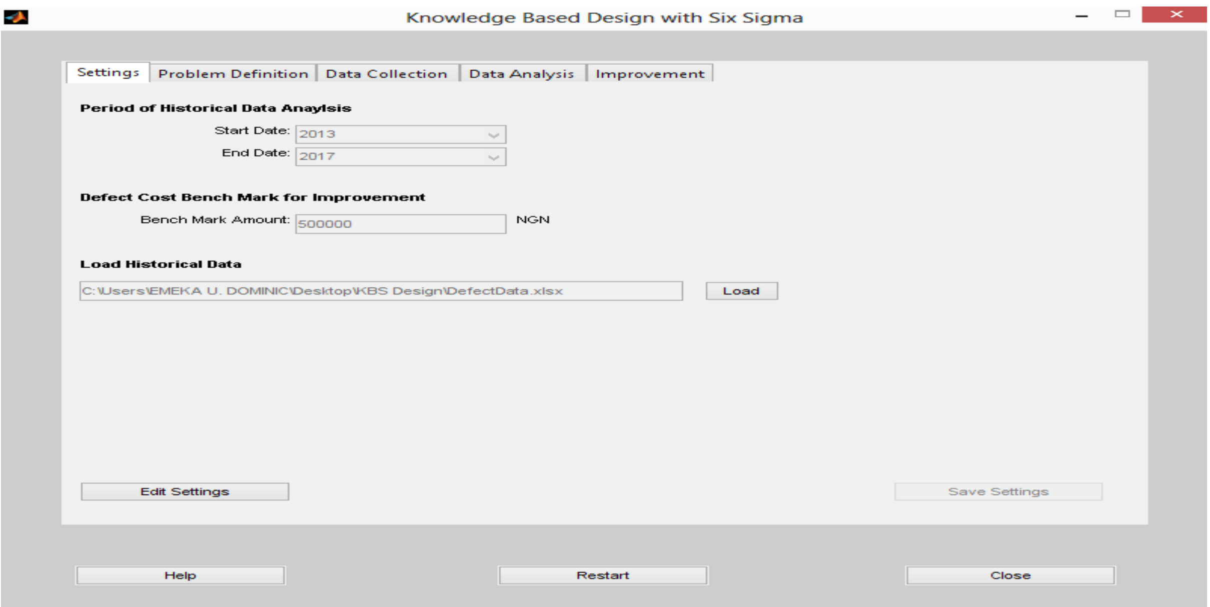


Figure 4.66: Home screen of the Graphical User Interface

The user can navigate on the app by clicking on any of the Icons on the toolbar. The icons at the home screen are characterized with unique responsibilities. The settings icon is for setting the software according to user's specification. From figure 4.66 the icons at the top rank of the home screen consists of the problem definition Icon, data collection icon, data analysis icon and l the Improvement icon. At the bottom of the home screen, we have the help icon, the restart icon and the close icon. The help icon contains all the necessary instructions needed to run the application. One can restart the programme by clicking on the restart button, and the application can as well be closed by just hitting the close button. To use the tool, the user's first click on settings having read the instructions as contained in the help to adjust some of the setting like the period of investigation and benchmark settings. The already prepared historical data is loaded and saved.

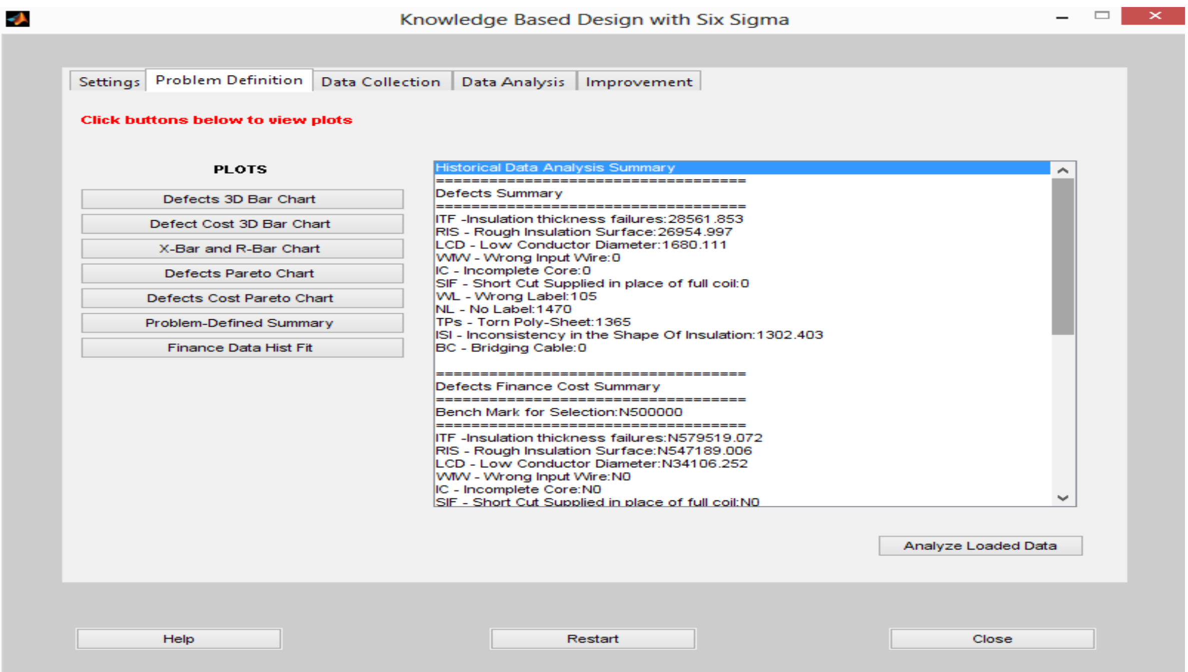


Figure 4.67 An Overview of the Problem definition and Defect Stratification.

Different plots such as the Pareto, 3D bar chart etc. are displayed on this page. Here defects are stratified based on the input benchmark.

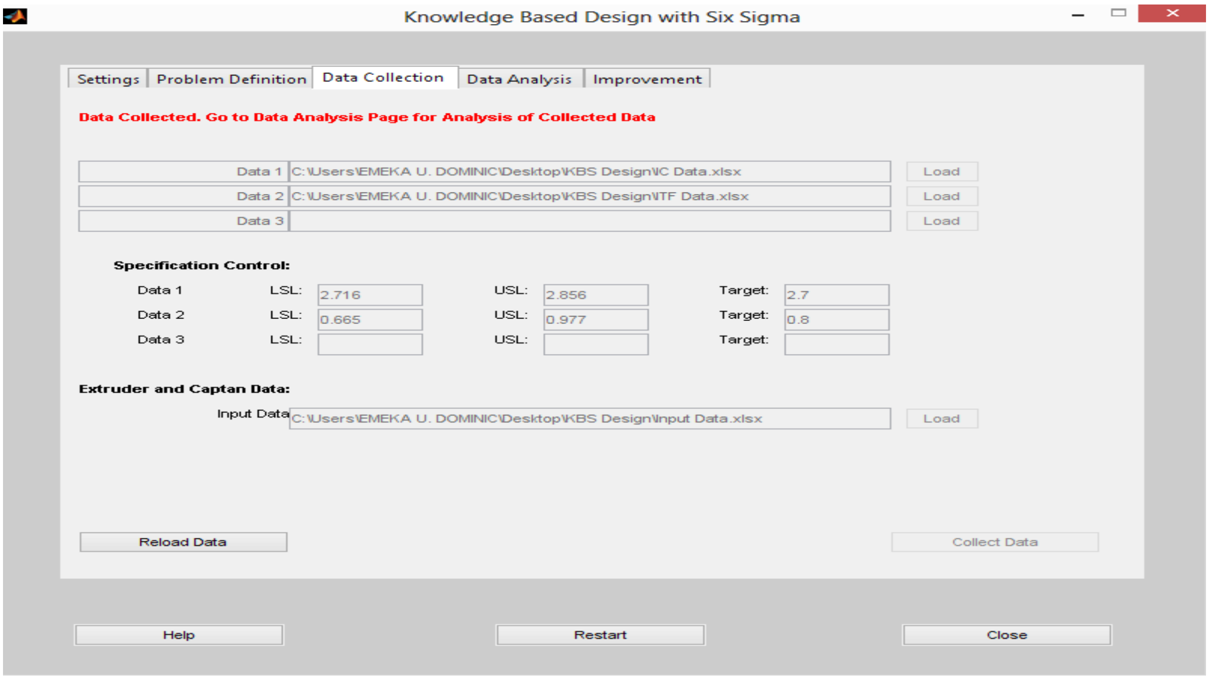


Figure 4.68 An Overview of the Specified System Specification and Data upload.

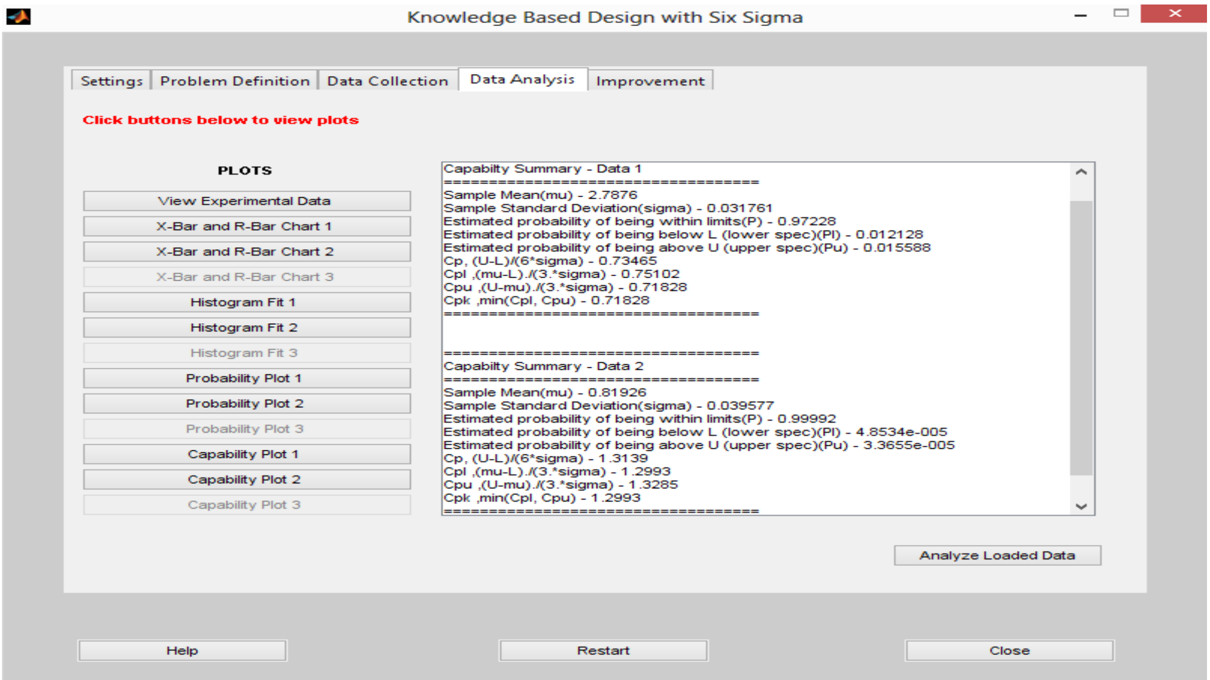


Figure 4.69 An Overview on the Data analysis and Capability Summary.

Capability summary and necessary plots are displayed at this interface as shown in the uploaded screen shot of figure 4.69. The capability index formulations that was used to run the analysis that are displayed as outputs in the software are found in the processs capability section of the chapter three, and figure 4,70 describes how capability analysis are being run in the software.

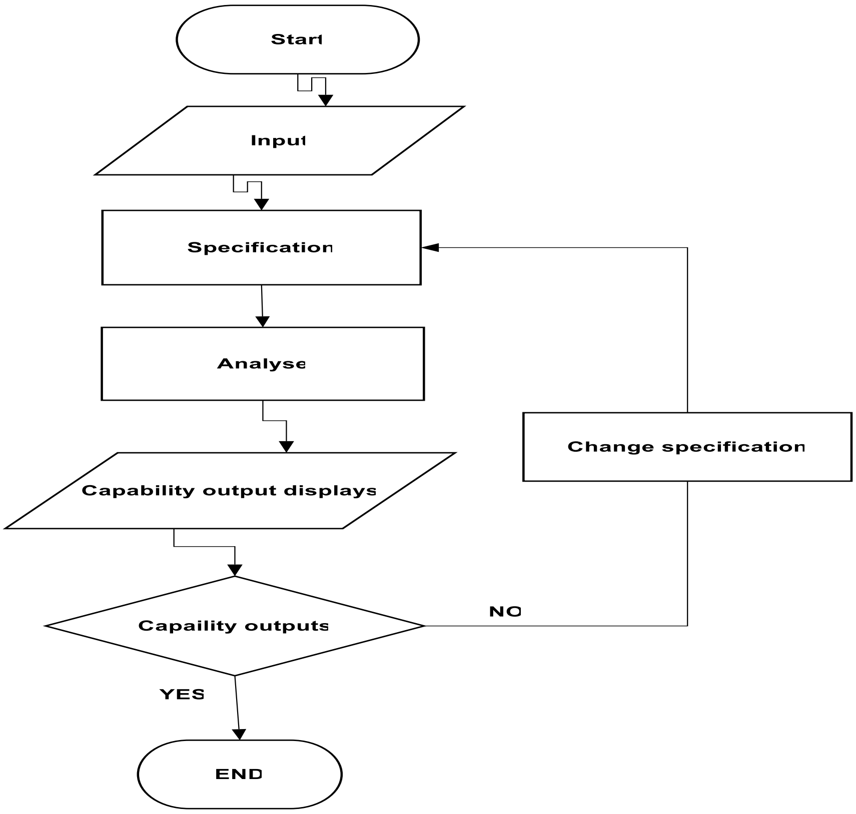


Figure 4.70: Design flowchart of the capability index studies

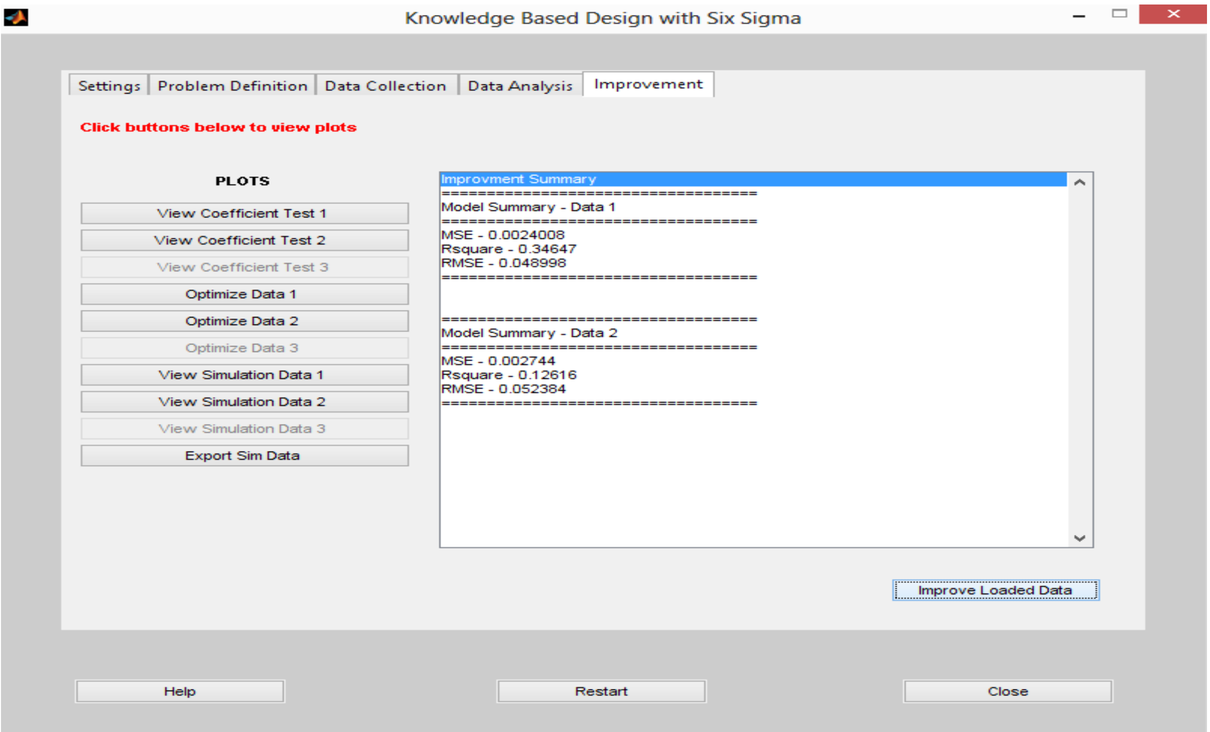


Figure 4.71. Screen Shot View of the Improvement Page/Summary.

Improvement test results in terms of model evaluation metrics, prediction plots and simulation data are displayed on the improvement interface as shown in figure 4.71. The simulated data can be viewed , and exported to Microsoft word or powerpoint file by clicking on the designated dialogue box.The software simulation was developed using multiple regression equation in order to develop a generic model for predicting uniform cable dimension in any typical cable manufacturing organization. The simulation program made use of first and second order models as shown in equation (4.1) & (4.2).

$$C_D = \beta_0 + \beta_{1C} + \beta_2 x_E + \varepsilon \quad 4.1$$

$$C_D = \beta_0 + \beta_1 x_C + \beta_2 x_E + \beta_{12CE} + \beta_{11} x_C^2 + \beta_{22} x_E^2 + \varepsilon \quad 4.2$$

where C_D = cable dimension, E = extruder speed, C = Capstan speed, β_0…. βn = constants, e = statistical error.

The second-order model is used in cases when the first order model is not suitable.The simulation program runs in a generic fashion in such a way that models are determined with respect to the input variables. Figure 4.72 illustrates the simulation procedure of the software.

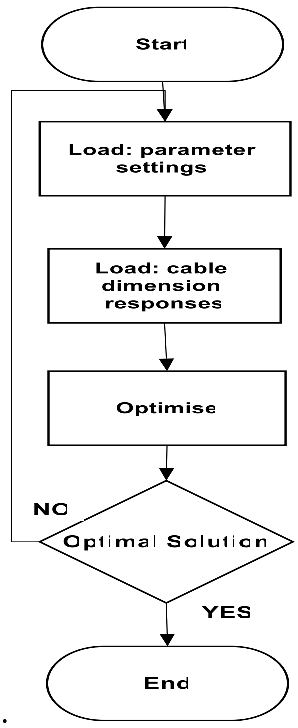


Figure 4.72: Flowchart of the Simulation and optimization operation of the Software

CHAPTER FIVE

CONCLUSION, RECOMMENDATION AND CONTRIBUTION TO KNOWLEDGE

5.1 **Summary of Findings**

This research explored the innate potentials within these two powerful disciplines, knowledge management (KM) and Six Sigma approach, to monitor the changing distribution of process capabilities in a cable manufacturing organization. The proposed Six Sigma-DMAIC-KM integrated approach has been validated in a cable manufacturing company in order to enhance the organizational performance. The improvements of project performance and application impacts of the new 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 (for both the cable diameter and Insulation thickness).

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. A hierarchy of decision model for producing cable with improved Insulation thickness and Improved Insulation Surface flaws was mapped and used in prioritizing defect judgments. An extrusion model of the form:

$CD_{\textbf{preheated PVC}} = 1.81243 + -0.00126332*A + 0.00156569*B,$

$CD_{\textbf{non-preheated PVC}} = 1.67344 + -0.0013576*A + 0.00176569*B$

was developed for predicting the cable dimension. Appropriate engineering specification was designed and tightened for the process from (T±0.185) to (T±0.032) such that a Six sigma process can easily be captured. The completion of the study resulted to peak improvement in the capability performance, for the cable diameter, using the newly-designed engineering tolerance, Cp increased from 0.22 to 1.43, Cpk increased from 0.3 to 1.23, CR decreased from 447.43% to 69.96%, ZU improved from -0.88 to 3.68, and ZL now moved from 2.22 to 4.89. DPMO reduced from 810,000 to 10, thus improving the Sigma level from the value of 0.6 to 5.2. On the insulation thickness using the newly-derived engineering tolerance, Cp, value increased from 0.45 to 0.90, Cpk increased from -0.035 to 0.09, ZU increased from -0.11 to 0.28, and ZL from 2.79 to 5.17. CR reduced from 223% to 110%, and total rejection rate was reduced from 54.64% to 38.97%. A significant reduction in DPMO from 570,000 to 420,000 was achieved, thus improving the Sigma level from 1.3 to 1.7.

The economic impact assessment for the cable diameter project, using quality loss function approach, has shown that the quality loss attributed to every single 1.0s (mm) coil produced has reduced from the initial cost of ₦7.34 to ₦2.08. The percentage decrease in annual loss is estimated at about 72%, an indication that annual loss before the improvement was reduced from ₦ 1,783,620 to ₦505,440 after the process improvement. On the other hand, the net annual improvement due to redesigning the tolerance now becomes ₦1,278,180. The quantity of non-conformed 1.0s (mm) cable rejected due to Insulation Surface flaws was reduced by 38.22% from the acceptable defect quantity, and about 5.6% reduction when compared with the entitlement value in the previous years. A Generic knowledge based Management tool was developed from the project that will support replication of new projects in cable manufacturing without necessarily involving an external consultant. An appropriate recommendation arising from the result of this study has been contemplated. In conclusion, Process performance can be improved and well sustained, using the synergetic support of Six Sigma-DMAIC and Knowledge Management strategies.

5.2 Achievement of Research Aim

The purpose of this research was to incorporate Knowledge Management strategy within a Six Sigma-DMAIC's framework to enhance process performance in cable manufacturing. The aim has been achieved. In chapter 4, the developed synergetic solution of Six Sigma and Knowledge Management was used to enhance process performance in cable manufacturing. A generic knowledge-based tool has been developed to aid easy replication of improvement study in cable manufacturing.

5.3 Contributions to Knowledge

A unique form of Knowledge Management (KM) and Six Sigma-DMAIC integration tactics has been introduced into the body of Six Sigma and Knowledge Management literature, and how it can be deployed to solve organization specific problems. Secondly, a Generic User Interface Support System tool, with ease of replication to enhance cable manufacturing, using Knowledge Management and Six-Sigma-DMAIC has been introduced, and successfully applied to the Anuka Cable Plant of the Cutix Cable Plc.

5.4 Recommendation for Further Research

In this study, the proposed solution was used to improve process performance in cable manufacturing. Relevant recommendations from the study has been highlighted at the Entire Process Review section at the control phase. However, it will be useful to apply this solution in service sector organizations and also in other manufacturing sector that are keen to improve their process performance and retain knowledge garnered from their improvement studies.

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APPENDIX A

Attribute Agreement Analysis Worksheet

Samples: 10 Appraisers: 3

Replicates: 2 Total runs: 60

Attribute Agreement Analysis for Response

Date of study: APRIL -2017

Reported by: CHUKWUEBUKA U-DOMINIC

Name of product: CUTIX CABLE

Misc:

Within Appraisers

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
JERRY	10	9	90.00	(55.50, 99.75)
WILLIAMS	10	9	90.00	(55.50, 99.75)
CHISOM	10	9	90.00	(55.50, 99.75)

Matched: Appraiser agrees with him/herself across trials.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
JERRY	BAD	0.797980	0.316228	2.52343	0.0058
	GOOD	0.797980	0.316228	2.52343	0.0058
WILLIAMS	BAD	0.797980	0.316228	2.52343	0.0058
	GOOD	0.797980	0.316228	2.52343	0.0058
CHISOM	BAD	0.797980	0.316228	2.52343	0.0058
	GOOD	0.797980	0.316228	2.52343	0.0058

Each Appraiser vs Standard

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
JERRY	10	9	90.00	(55.50, 99.75)
WILLIAMS	10	9	90.00	(55.50, 99.75)

CHISOM 10 9 90.00 (55.50, 99.75)

Matched: Appraiser's assessment across trials agrees with the known standard.

Assessment Disagreement

Appraiser	# GOOD / BAD	Percent	# BAD / GOOD	Percent	# Mixed	Percent
JERRY	0	0.00	0	0.00	1	10.00
WILLIAMS	0	0.00	0	0.00	1	10.00
CHISOM	0	0.00	0	0.00	1	10.00

GOOD / BAD: Assessments across trials = GOOD / standard = BAD.

BAD / GOOD: Assessments across trials = BAD / standard = GOOD.

Mixed: Assessments across trials are not identical.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
JERRY	BAD	0.898990	0.223607	4.02041	0.0000
	GOOD	0.898990	0.223607	4.02041	0.0000
WILLIAMS	BAD	0.898990	0.223607	4.02041	0.0000
	GOOD	0.898990	0.223607	4.02041	0.0000
CHISOM	BAD	0.898990	0.223607	4.02041	0.0000
	GOOD	0.898990	0.223607	4.02041	0.0000

Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
10	8	80.00	(44.39, 97.48)

Matched: All appraisers' assessments agree with each other.

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
BAD	0.824916	0.0816497	10.1031	0.0000
GOOD	0.824916	0.0816497	10.1031	0.0000

All Appraisers vs Standard

Assessment Agreement

Inspected # Matched Percent 95% CI

10 8 80.00 (44.39, 97.48)

Matched: All appraisers' assessments agree with the known standard.

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
BAD	0.898990	0.129099	6.96355	0.0000
GOOD	0.898990	0.129099	6.96355	0.0000

APPENDIX B

Gage R&R Study - ANOVA Method

Gage R&R for Core diameter

Gage name: CORE DIAMETER GAGE R & R STUDY
Date of study: APRIL 2017
Reported by: CHUKWUEBUKA U-DOMINIC
Tolerance:
Misc:

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Parts	4	0.220455	0.0551136	6618.05	0.000
Operators	2	0.000022	0.0000110	1.32	0.319
Parts * Operators	8	0.000067	0.0000083	19.72	0.000
Repeatability	30	0.000013	0.0000004		
Total	44	0.220556			

α to remove interaction term = 0.05

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0000032	0.05
Repeatability	0.0000004	0.01
Reproducibility	0.0000028	0.05
Operators	0.0000002	0.00
Operators*Parts	0.0000026	0.04
Part-To-Part	0.0061228	99.95
Total Variation	0.0061260	100.00

Process tolerance = 0.37

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.0017992	0.010795	2.30	2.92
Repeatability	0.0006498	0.003899	0.83	1.05
Reproducibility	0.0016777	0.010066	2.14	2.72
Operators	0.0004238	0.002543	0.54	0.69
Operators*Parts	0.0016233	0.009740	2.07	2.63
Part-To-Part	0.0782484	0.469490	99.97	126.89
Total Variation	0.0782691	0.469615	100.00	126.92

Number of Distinct Categories = 61

APPENDIX C

Table of Control Chart Constants

X-bar Chart Constants | for sigma estimate | R Chart Constants | S Chart Constants

Sample Size = m	A_2	A_3	d_2	D_3	D_4	B_3	B_4
2	1.880	2.659	1.128	0	3.267	0	3.267
3	1.023	1.954	1.693	0	2.574	0	2.568
4	0.729	1.628	2.059	0	2.282	0	2.266
5	0.577	1.427	2.326	0	2.114	0	2.089
6	0.483	1.287	2.534	0	2.004	0.030	1.970
7	0.419	1.182	2.704	0.076	1.924	0.118	1.882
8	0.373	1.099	2.847	0.136	1.864	0.185	1.815
9	0.337	1.032	2.970	0.184	1.816	0.239	1.761
10	0.308	0.975	3.078	0.223	1.777	0.284	1.716
11	0.285	0.927	3.173	0.256	1.744	0.321	1.679
12	0.266	0.886	3.258	0.283	1.717	0.354	1.646
13	0.249	0.850	3.336	0.307	1.693	0.382	1.618
14	0.235	0.817	3.407	0.328	1.672	0.406	1.594
15	0.223	0.789	3.472	0.347	1.653	0.428	1.572
16	0.212	0.763	3.532	0.363	1.637	0.448	1.552
17	0.203	0.739	3.588	0.378	1.622	0.466	1.534
18	0.194	0.718	3.640	0.391	1.608	0.482	1.518
19	0.187	0.698	3.689	0.403	1.597	0.497	1.503
20	0.180	0.680	3.735	0.415	1.585	0.510	1.490
21	0.173	0.663	3.778	0.425	1.575	0.523	1.477
22	0.167	0.647	3.819	0.434	1.566	0.534	1.466
23	0.162	0.633	3.858	0.443	1.557	0.545	1.455
24	0.157	0.619	3.895	0.451	1.548	0.555	1.445
25	0.153	0.606	3.931	0.459	1.541	0.565	1.435

APPENDIX D

Areas under the Standard Normal Curve

STANDARD NORMAL DISTRIBUTION: Table Values Represent AREA to the LEFT of the Z score.

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
-3.9	.00005	.00005	.00004	.00004	.00004	.00004	.00004	.00004	.00003	.00003
-3.8	.00007	.00007	.00007	.00006	.00006	.00006	.00006	.00005	.00005	.00005
-3.7	.00011	.00010	.00010	.00010	.00009	.00009	.00008	.00008	.00008	.00008
-3.6	.00016	.00015	.00015	.00014	.00014	.00013	.00013	.00012	.00012	.00011
-3.5	.00023	.00022	.00022	.00021	.00020	.00019	.00019	.00018	.00017	.00017
-3.4	.00034	.00032	.00031	.00030	.00029	.00028	.00027	.00026	.00025	.00024
-3.3	.00048	.00047	.00045	.00043	.00042	.00040	.00039	.00038	.00036	.00035
-3.2	.00069	.00066	.00064	.00062	.00060	.00058	.00056	.00054	.00052	.00050
-3.1	.00097	.00094	.00090	.00087	.00084	.00082	.00079	.00076	.00074	.00071
-3.0	.00135	.00131	.00126	.00122	.00118	.00114	.00111	.00107	.00104	.00100
-2.9	.00187	.00181	.00175	.00169	.00164	.00159	.00154	.00149	.00144	.00139
-2.8	.00256	.00248	.00240	.00233	.00226	.00219	.00212	.00205	.00199	.00193
-2.7	.00347	.00336	.00326	.00317	.00307	.00298	.00289	.00280	.00272	.00264
-2.6	.00466	.00453	.00440	.00427	.00415	.00402	.00391	.00379	.00368	.00357
-2.5	.00621	.00604	.00587	.00570	.00554	.00539	.00523	.00508	.00494	.00480
-2.4	.00820	.00798	.00776	.00755	.00734	.00714	.00695	.00676	.00657	.00639
-2.3	.01072	.01044	.01017	.00990	.00964	.00939	.00914	.00889	.00866	.00842
-2.2	.01390	.01355	.01321	.01287	.01255	.01222	.01191	.01160	.01130	.01101
-2.1	.01786	.01743	.01700	.01659	.01618	.01578	.01539	.01500	.01463	.01426
-2.0	.02275	.02222	.02169	.02118	.02068	.02018	.01970	.01923	.01876	.01831
-1.9	.02872	.02807	.02743	.02680	.02619	.02559	.02500	.02442	.02385	.02330
-1.8	.03593	.03515	.03438	.03362	.03288	.03216	.03144	.03074	.03005	.02938
-1.7	.04457	.04363	.04272	.04182	.04093	.04006	.03920	.03836	.03754	.03673
-1.6	.05480	.05370	.05262	.05155	.05050	.04947	.04846	.04746	.04648	.04551
-1.5	.06681	.06552	.06426	.06301	.06178	.06057	.05938	.05821	.05705	.05592
-1.4	.08076	.07927	.07780	.07636	.07493	.07353	.07215	.07078	.06944	.06811
-1.3	.09680	.09510	.09342	.09176	.09012	.08851	.08691	.08534	.08379	.08226
-1.2	.11507	.11314	.11123	.10935	.10749	.10565	.10383	.10204	.10027	.09853
-1.1	.13567	.13350	.13136	.12924	.12714	.12507	.12302	.12100	.11900	.11702
-1.0	.15866	.15625	.15386	.15151	.14917	.14686	.14457	.14231	.14007	.13786
-0.9	.18406	.18141	.17879	.17619	.17361	.17106	.16853	.16602	.16354	.16109
-0.8	.21186	.20897	.20611	.20327	.20045	.19766	.19489	.19215	.18943	.18673
-0.7	.24196	.23885	.23576	.23270	.22965	.22663	.22363	.22065	.21770	.21476
-0.6	.27425	.27093	.26763	.26435	.26109	.25785	.25463	.25143	.24825	.24510
-0.5	.30854	.30503	.30153	.29806	.29460	.29116	.28774	.28434	.28096	.27760
-0.4	.34458	.34090	.33724	.33360	.32997	.32636	.32276	.31918	.31561	.31207
-0.3	.38209	.37828	.37448	.37070	.36693	.36317	.35942	.35569	.35197	.34827
-0.2	.42074	.41683	.41294	.40905	.40517	.40129	.39743	.39358	.38974	.38591
-0.1	.46017	.45620	.45224	.44828	.44433	.44038	.43644	.43251	.42858	.42465
-0.0	.50000	.49601	.49202	.48803	.48405	.48006	.47608	.47210	.46812	.46414

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APPENDIX D2

Area under Standard Normal Curve

STANDARD NORMAL DISTRIBUTION: Table Values Represent AREA to the LEFT of the Z score.

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.50000	.50399	.50798	.51197	.51595	.51994	.52392	.52790	.53188	.53586
0.1	.53983	.54380	.54776	.55172	.55567	.55962	.56356	.56749	.57142	.57535
0.2	.57926	.58317	.58706	.59095	.59483	.59871	.60257	.60642	.61026	.61409
0.3	.61791	.62172	.62552	.62930	.63307	.63683	.64058	.64431	.64803	.65173
0.4	.65542	.65910	.66276	.66640	.67003	.67364	.67724	.68082	.68439	.68793
0.5	.69146	.69497	.69847	.70194	.70540	.70884	.71226	.71566	.71904	.72240
0.6	.72575	.72907	.73237	.73565	.73891	.74215	.74537	.74857	.75175	.75490
0.7	.75804	.76115	.76424	.76730	.77035	.77337	.77637	.77935	.78230	.78524
0.8	.78814	.79103	.79389	.79673	.79955	.80234	.80511	.80785	.81057	.81327
0.9	.81594	.81859	.82121	.82381	.82639	.82894	.83147	.83398	.83646	.83891
1.0	.84134	.84375	.84614	.84849	.85083	.85314	.85543	.85769	.85993	.86214
1.1	.86433	.86650	.86864	.87076	.87286	.87493	.87698	.87900	.88100	.88298
1.2	.88493	.88686	.88877	.89065	.89251	.89435	.89617	.89796	.89973	.90147
1.3	.90320	.90490	.90658	.90824	.90988	.91149	.91309	.91466	.91621	.91774
1.4	.91924	.92073	.92220	.92364	.92507	.92647	.92785	.92922	.93056	.93189
1.5	.93319	.93448	.93574	.93699	.93822	.93943	.94062	.94179	.94295	.94408
1.6	.94520	.94630	.94738	.94845	.94950	.95053	.95154	.95254	.95352	.95449
1.7	.95543	.95637	.95728	.95818	.95907	.95994	.96080	.96164	.96246	.96327
1.8	.96407	.96485	.96562	.96638	.96712	.96784	.96856	.96926	.96995	.97062
1.9	.97128	.97193	.97257	.97320	.97381	.97441	.97500	.97558	.97615	.97670
2.0	.97725	.97778	.97831	.97882	.97932	.97982	.98030	.98077	.98124	.98169
2.1	.98214	.98257	.98300	.98341	.98382	.98422	.98461	.98500	.98537	.98574
2.2	.98610	.98645	.98679	.98713	.98745	.98778	.98809	.98840	.98870	.98899
2.3	.98928	.98956	.98983	.99010	.99036	.99061	.99086	.99111	.99134	.99158

2.4	.99180	.99202	.99224	.99245	.99266	.99286	.99305	.99324	.99343	.99361
2.5	.99379	.99396	.99413	.99430	.99446	.99461	.99477	.99492	.99506	.99520
2.6	.99534	.99547	.99560	.99573	.99585	.99598	.99609	.99621	.99632	.99643
2.7	.99653	.99664	.99674	.99683	.99693	.99702	.99711	.99720	.99728	.99736
2.8	.99744	.99752	.99760	.99767	.99774	.99781	.99788	.99795	.99801	.99807
2.9	.99813	.99819	.99825	.99831	.99836	.99841	.99846	.99851	.99856	.99861
3.0	.99865	.99869	.99874	.99878	.99882	.99886	.99889	.99893	.99896	.99900
3.1	.99903	.99906	.99910	.99913	.99916	.99918	.99921	.99924	.99926	.99929
3.2	.99931	.99934	.99936	.99938	.99940	.99942	.99944	.99946	.99948	.99950
3.3	.99952	.99953	.99955	.99957	.99958	.99960	.99961	.99962	.99964	.99965
3.4	.99966	.99968	.99969	.99970	.99971	.99972	.99973	.99974	.99975	.99976
3.5	.99977	.99978	.99978	.99979	.99980	.99981	.99981	.99982	.99983	.99983
3.6	.99984	.99985	.99985	.99986	.99986	.99987	.99987	.99988	.99988	.99989
3.7	.99989	.99990	.99990	.99990	.99991	.99991	.99992	.99992	.99992	.99992
3.8	.99993	.99993	.99993	.99994	.99994	.99994	.99994	.99995	.99995	.99995
3.9	.99995	.99995	.99996	.99996	.99996	.99996	.99996	.99996	.99997	.99997

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APPENDIX E

Abridged "6-sigma" Conversion Table Note: Yield refers to percent of output that is good

Yield	Sigma	Defects per 1,000,000	Defects per 100,000	Defects per 10,000	Defects per 1,000	Defects per 100
99.99966%	6.0	3.4	0.34	0.034	0.0034	0.00034
99.9995%	5.9	5	0.5	0.05	0.005	0.0005
99.9992%	5.8	8	0.8	0.08	0.008	0.0008
99.9990%	5.7	10	1	0.1	0.01	0.001
99.9980%	5.6	20	2	0.2	0.02	0.002
99.9970%	5.5	30	3	0.3	0.03	0.003
99.9960%	5.4	40	4	0.4	0.04	0.004
99.9930%	5.3	70	7	0.7	0.07	0.007
99.9900%	5.2	100	10	1.0	0.1	0.01
99.9850%	5.1	150	15	1.5	0.15	0.015
99.9770%	5.0	230	23	2.3	0.23	0.023
99.9670%	4.9	330	33	3.3	0.33	0.033
99.9520%	4.8	480	48	4.8	0.48	0.048
99.9320%	4.7	680	68	6.8	0.68	0.068
99.9040%	4.6	960	96	9.6	0.96	0.096
99.8650%	4.5	1,350	135	13.5	1.35	0.135
99.8140%	4.4	1,860	186	18.6	1.86	0.186
99.7450%	4.3	2,550	255	25.5	2.55	0.255
99.6540%	4.2	3,460	346	34.6	3.46	0.346
99.5340%	4.1	4,660	466	46.6	4.66	0.466
99.3790%	4.0	6,210	621	62.1	6.21	0.621
99.1810%	3.9	8,190	819	81.9	8.19	0.819
98.930%	3.8	10,700	1,070	107	10.7	1.07
98.610%	3.7	13,900	1,390	139	13.9	1.39
98.220%	3.6	17,800	1,780	178	17.8	1.78
97.730%	3.5	22,700	2,270	227	22.7	2.27
97.130%	3.4	28,700	2,870	287	28.7	2.87
96.410%	3.3	35,900	3,590	359	35.9	3.59
95.540%	3.2	44,600	4,460	446	44.6	4.46
94.520%	3.1	54,800	5,480	548	54.8	5.48
93.320%	3.0	66,800	6,680	668	66.8	6.68
91.920%	2.9	80,800	8,080	808	80.8	8.08
90.320%	2.8	96,800	9,680	968	96.8	9.68
88.50%	2.7	115,000	11,500	1,150	115	11.5
86.50%	2.6	135,000	13,500	1,350	135	13.5
84.20%	2.5	158,000	15,800	1,580	158	15.8
81.60%	2.4	184,000	18,400	1,840	184	18.4
78.80%	2.3	212,000	21,200	2,120	212	21.2
75.80%	2.2	242,000	24,200	2,420	242	24.2
72.60%	2.1	274,000	27,400	2,740	274	27.4
69.20%	2.0	308,000	30,800	3,080	308	30.8
65.60%	1.9	344,000	34,400	3,440	344	34.4
61.80%	1.8	382,000	38,200	3,820	382	38.2
58.00%	1.7	420,000	42,000	4,200	420	42
54.00%	1.6	460,000	46,000	4,600	460	46
50%	1.5	500,000	50,000	5,000	500	50
46%	1.4	540,000	54,000	5,400	540	54
43%	1.3	570,000	57,000	5,700	570	57
39%	1.2	610,000	61,000	6,100	610	61
35%	1.1	650,000	65,000	6,500	650	65
31%	1.0	690,000	69,000	6,900	690	69
28%	0.9	720,000	72,000	7,200	720	72
25%	0.8	750,000	75,000	7,500	750	75
22%	0.7	780,000	78,000	7,800	780	78
19%	0.6	810,000	81,000	8,100	810	81
16%	0.5	840,000	84,000	8,400	840	84
14%	0.4	860,000	86,000	8,600	860	86
12%	0.3	880,000	88,000	8,800	880	88
10%	0.2	900,000	90,000	9,000	900	90
8%	0.1	920,000	92,000	9,200	920	92

Abridged Sigma Table:Retrieved online from http://www.sixsigmacertificationcourse.com/abridged-sigma-table/

APPENDIX F

Analytical Hierarchial Process (AHP)

1. Model the problem as a hierarchy containing the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives. In doing this, participants explore the aspects of the problem at levels from general to detailed, then express it in the multileveled way that the AHP requires. As they work to build the hierarchy, they increase their understanding of the problem, of its context, and of each other's thoughts and feelings about both.
2. Establish priorities among the elements of the hierarchy by making a series of judgments based on pairwise comparisons of the elements
3. Synthesize these judgments to yield a set of overall priorities for the hierarchy.
4. Check the consistency of the judgments.
5. Come to a final decision based on the results of this process.

The AHP is a very flexible and powerful tool because the scores and, therefore, the final ranking are obtained on the basis of the pairwise relative evaluations of both the criteria and options provided by the user. The equations and functions for the preference analysis, according to Cabala (2010), are as follows:

$[a_{ij}]$, where I, j = 1, 2, …, n. (1)

$a_{ij} = 1$ for i = j, (2)

$a_{ij} = \frac{1}{aji}$ for $i \neq j$. (3)

Using the scale in Table 3.3, a reciprocal matrix $[a_{ij}]$ is created, where a_{ij} is the expert's evaluation expressing the preference of the i-th element in relation to the j-th. The eigen vector W matching the maximum eigenvalue λ_{max} of the pairwise comparison matrix A is the final expression of the preferences between the investigated elements. Determining the eigenvector now leads to solution to matrix A's characteristic functions as follows:

$$F(\lambda) = |A - \lambda I| = \begin{vmatrix} a_{11}-\lambda & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22}-\lambda & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n1} & a_{n1} & a_{nn}-\lambda \end{vmatrix} \quad (4)$$

and its respective characteristic equation $f(\lambda) = |A - \lambda I| = 0$ is presented in the form of the polynomial $c_0\lambda^n + c_1\lambda^{n-1} + \dots + c_{n-1}\lambda + c_n = 0$

The eigenvectors of matrix **A** are each column and non-zero vector Xi, for which the following equality occurs:

$$(\mathbf{A}-\lambda_i)X_i = 0 \quad (5)$$

Assume $X_i = \mathbf{w}$ for λ_{max}, eigenvector is in the solution to the following equation;

$$\mathbf{Aw} = \lambda_{max}\mathbf{w}. \quad (6)$$

$$b_{ij} = \frac{aij}{\sum_{i=1}^{n} aij} . \quad (7)$$

Eigenvector w = [w_i]

$$w_i = \frac{\sum_{j=1}^{n} bij}{n}. \quad (8)$$

Then the maximum eigenvector;

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n} \frac{(Aw)i}{wi} . \quad (9)$$

The equation for the components values of the eigenvector using the geometric averaging method looks as follows:

$$w_i = \frac{\left(\prod_{j=1}^{n} aij\right)^{\frac{1}{n}}}{\sum_{i=1}^{n}\left(\prod_{j}^{n} aij\right)^{\frac{1}{n}}} \quad (10)$$

Table: 1. ***The Fundamental Scale for Pairwise Comparisons***

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgment slightly favour one over the other.
5	Much more important	Experience and judgment strongly favour one over the other.
7	Very much more important	Experience and judgment very strongly favour one over the other; its importance is demonstrated in practice.
9	Absolutely more important	The evidence favoring one over the other is of the highest possible validity
2, 4, 6, 8	Intermediate values	When compromise is needed

Source: Adapted from Saaty (1980)

Consistency equations

$$C.I = \lambda_{max} - n / n-1 \qquad (11)$$

$$\text{Lambda } (\lambda) = \frac{\sum \frac{W}{P}}{n} \qquad (12)$$

where p = principal priority, w = weighted sum, C.I = 0 for a perfectly consistent decision, but small values of inconsistency is tolerated if,

$$CR = {CI}/{RI} < 0.1 \qquad (13)$$

where RI is the random index and is the average value of CI for random matrices. Appendix (**G**) contains a table for R.I values for m ≤ 15

$$GP = S_{Cp} * C_P \qquad (14)$$

where S_{Cp} = sub criteria priorities, and C_P = criteria priorities.

Insulation Thickness (AHP Computations)

Table 1: Main Criteria comparison table for the Improved Cable Insulation Thickness

Name		Criteria		More Important	Intensity
I	J	A	B	A or B	(1-9)
1	2	Measurement	Material	B	3
1	3		Machine	B	3
1	4		Man	B	3
1	5		Method	B	3
2	3	Material	Machine	A	3
2	4		Man	A	3
2	5		Method	B	2
3	4	Machine	Man	A	3
3	5		Method	A	2
4	5	Man	Method	B	3

Table 1: Pairwise comparison matrix with judgments for the main criteria

Criteria	Measurement	Material	Machine	Man	Method
Measurement	1	0.333	0.333	0.333	0.333
Material	3	1	3	3	0.5
Machine	3	0.333	1	3	0.5
Man	3	0.333	0.333	1	0.333
Method	3	2	2	3	1

Table 2: Normalized matrix for the principal Eigen vector for the main criteria

Criteria	Material	Machine	Man	Method	Measurement	Principal Priority vector
Measurement	0.076923	0.083271	0.049955	0.032227	0.124906	0.073456
Material	0.230769	0.250063	0.450045	0.290332	0.187547	0.281751
Machine	0.230769	0.083271	0.150015	0.290332	0.187547	0.188387
Man	0.230769	0.083271	0.049955	0.096777	0.124906	0.117136

Method	0.230769	0.500125	0.30003	0.290332	0.375094	0.33927

Table 3: Criteria weighing

Criteria	Measurement	Material	Machine	Man	Method	Weighted Sum
Measurement	0.073456	0.093823	0.062733	0.039006	0.112977	0.381995
Material	0.220368	0.281751	0.565161	0.351408	0.169635	1.588323
Machine	0.220368	0.093823	0.188387	0.351408	0.169635	1.023621
Man	0.220368	0.093823	0.062733	0.117136	0.112977	0.607037
Method	0.220368	0.563502	0.376774	0.351408	0.33927	1.851322

For the consistency check at the criteria level 1: Lambda (λ) = 5.382073, C.I = 0.095518, C.R = 0.088 < 0.1 for n= 5; R.I = 1.1086 (acceptable)

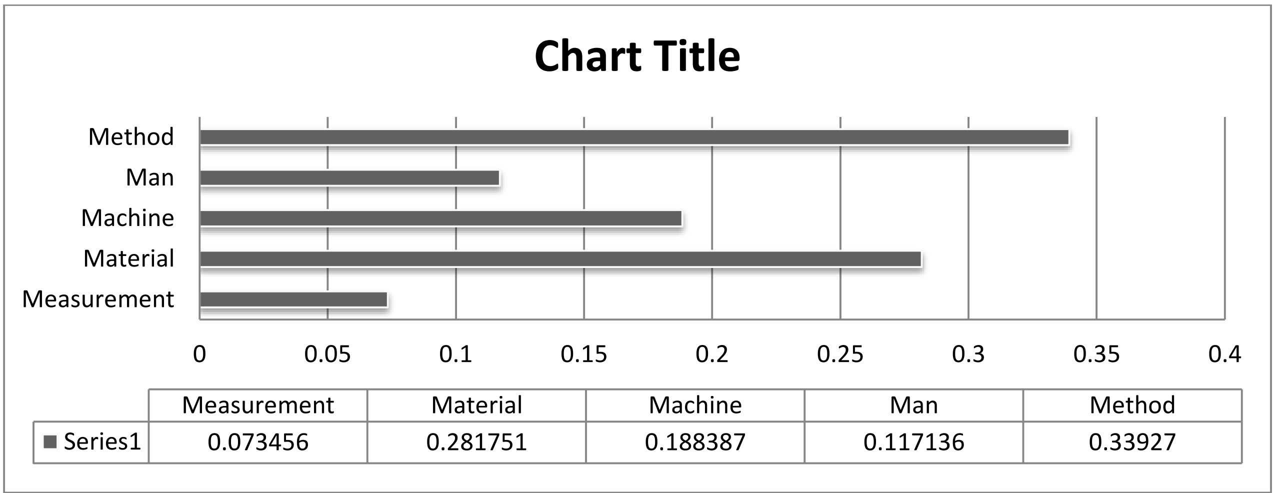


Fig 1: Graphical representation of criteria and their prioritized judgments.

Table 4: material- Sub criteria comparison table for the improved cable Insulation thickness

Name		Criteria		More Important	Intensity
I	j	A	B	A or B	(1-9)
1	2	Poorly annealed conductor	Un-annealed conductor		
1	3		Over-dimensioned tip		
2	3	Un-annealed conductor	Over dimensioned tip		

Table 5: Pairwise comparison matrix with judgments for the material- Sub criteria

Material	Poorly annealed conductor	Un-annealed conductor	Over dimensioned tip PVC
Poorly annealed conductor	1	0.2[1/5]	0.333[1/3]
Un-annealed conductor	5	1	3
Over dimensioned tip PVC	3	0.333[1/3]	1

Table 6: Normalized matrix for the principal Eigen vector for the material factors

Material	Poorly annealed conductor	Un-annealed conductor	Over dimensioned tip PVC	Principal Priority vector
Poorly annealed conductor	0.111111	0.130463	0.076852	0.106142
Un-annealed conductor	0.555556	0.652316	0.692361	0.633411
Over dimensioned tip PVC	0.333333	0.217221	0.230787	0.260447

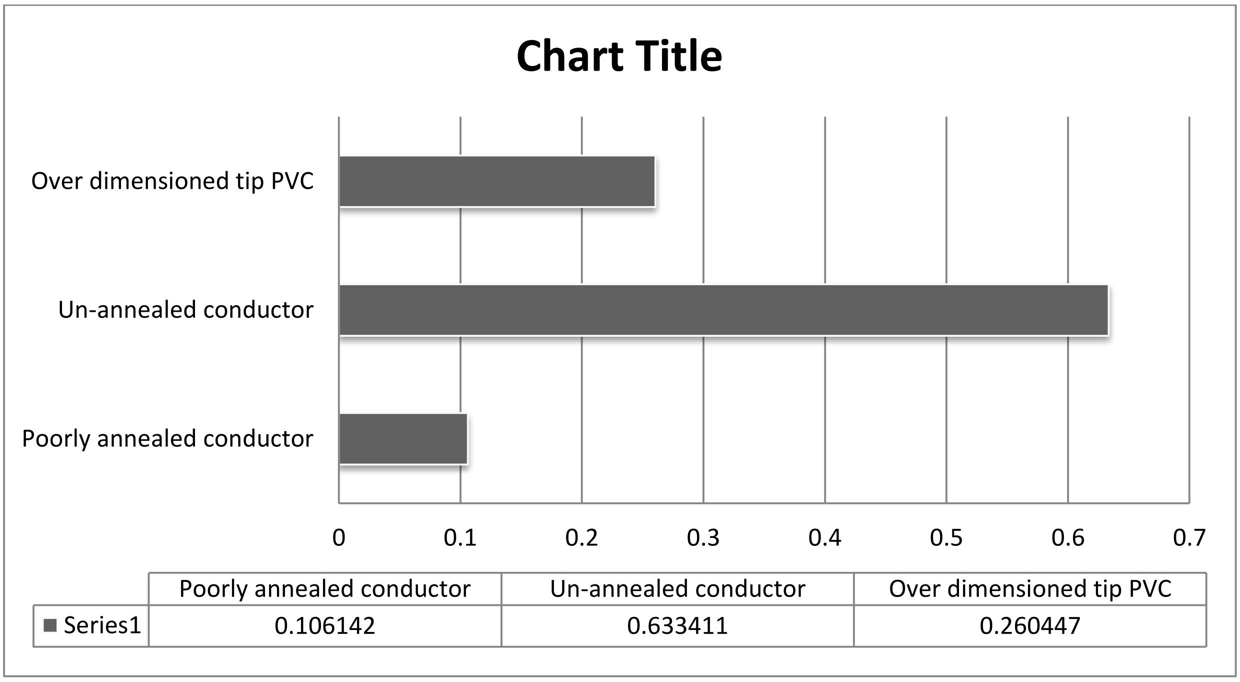


Fig 2. Graphical representation of Material-subgroup prioritization vector for the improved insulation thickness

Table 7: Calculated weighted sum for material-sub criteria and the global priorities

Material	Poorly annealed conductor	Un-annealed conductor	Over dimensioned tip PVC	Weighted sum	Global Priority vector
Poorly annealed conductor	0.106142	0.126682	0.086729	0.319553	0.03
Un-annealed conductor	0.53071	0.633411	0.781341	1.945462	0.178
Over dimensioned tip PVC	0.318426	0.210926	0.260447	0.789799	0.073

Table 8: Machine- Sub criteria comparison table for the Improved Cable Insulation thickness

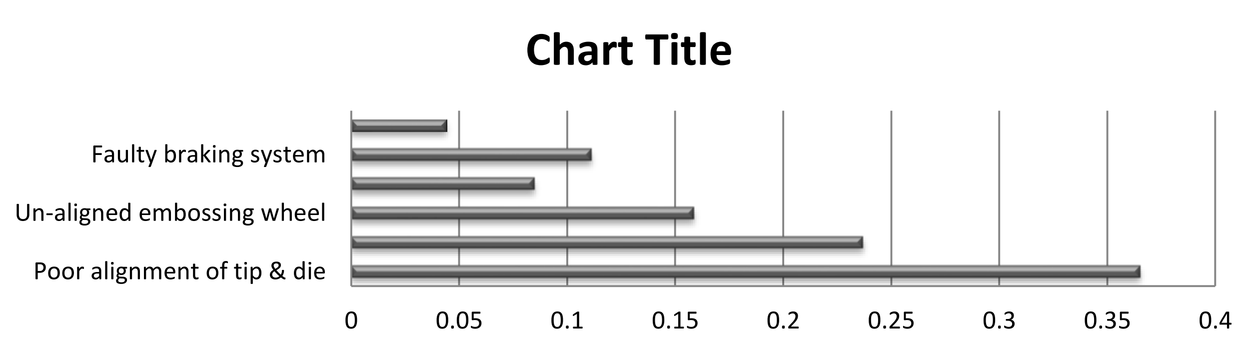
Name		Criteria		More Important	Intensity
I	j	A	B	A or B	(1-9)
1	2	Poor alignment of tip & die	Worn-out centering bolt	A	2
1	3		Un-aligned embossing wheel	A	3
1	4		Faulty heating system	A	3
1	5		Faulty braking system	A	5
1	6		Unsteady wire guard	A	7
2	3	Worn-out centering bolt	Un-aligned embossing wheel	A	3
2	4		Faulty heating system	A	3
2	5		Faulty braking system	A	3
2	6		Unsteady wire guard	A	3
3	4	Un-aligned embossing wheel	Faulty heating system	A	3
3	5		Faulty braking system	A	3
3	6		Unsteady wire guard	A	3
4	5	Faulty heating system	Faulty braking system	B	2
4	6		Unsteady wire guard	A	3
5	6	Faulty braking system	Unsteady wire guard	A	5

Table 9: Pairwise comparison matrix with judgments for the Machine-Sub criteria

Machine	Poor alignment of tip & die	Worn-out centering bolt	Un-aligned embossing wheel	Faulty heating system	Faulty braking system	Unsteady wire guard
Poor alignment of tip & die	1	2	3	3	5	7
Worn-out centering bolt	0.5 [1/2]	1	3	3	3	3
Un-aligned embossing wheel	0.333 [1/3]	0.333[1/3]	1	3	3	3
Faulty heating system	0.333[1/3]	0.333[1/3]	0.333[1/3]	1	0.5[1/2]	3
Faulty braking system	0.2[1/5]	0.333[1/3]	0.333[1/3]	2	1	5
Unsteady wire guard	0.1428[1/7]	0.333[1/3]	0.333[1/3]	0.333[1/3]	0.2[1/5]	1

Table 10: Normalized matrix for the principal Eigen vector for the Machine-Sub criteria

Machine	Poor alignment of tip & die	Worn-out centering bolt	Un-aligned embossing wheel	Faulty heating system	Faulty braking system	Unsteady wire guard	Principal Priority vector
Poor alignment of tip & die	0.398597	0.461681	0.375047	0.24325	0.393701	0.318182	0.365076
Worn-out centering bolt	0.199298	0.23084	0.375047	0.24325	0.23622	0.136364	0.236837
Un-aligned embossing wheel	0.132733	0.07687	0.125016	0.24325	0.23622	0.136364	0.158409
Faulty heating system	0.132733	0.07687	0.04163	0.081083	0.03937	0.136364	0.084675
SFaulty braking system	0.079719	0.07687	0.04163	0.162167	0.07874	0.227273	0.111066
Unsteady wire guard	0.05692	0.07687	0.04163	0.027001	0.015748	0.045455	0.043937



	Poor alignment of tip & die	Worn-out centering bolt	Un-aligned embossing wheel	Faulty heating system	Faulty braking system	Unsteady wire guard
Series1	0.365076	0.236837	0.158409	0.084675	0.111066	0.043937

Fig. 3. Graphical representation of Machine-subgroup prioritization vector for the improved insulation thickness

Table 11: Calculated weighted sum for Machine-Sub criteria and the global priorities

Machine	Poor alignment of tip & die	Worn-out centering bolt	Un-aligned embossing wheel	Faulty heating system	Faulty braking system	Unsteady wire guard	Weighted sum	Global Priority
Poor alignment of tip & die	0.365076	0.473674	0.475227	0.254025	0.55533	0.307559	2.430891	0.068
Worn-out centering bolt	0.182538	0.236837	0.475227	0.254025	0.333198	0.131811	1.613636	0.044
Un-aligned embossing wheel	0.12157	0.078867	0.158409	0.254025	0.333198	0.131811	1.07788	0.029
Faulty heating system	0.12157	0.078867	0.05275	0.084675	0.055533	0.131811	0.525206	0.016
Faulty braking system	0.073015	0.078867	0.05275	0.16935	0.111066	0.219685	0.704733	0.021
Unsteady wire guard	0.052133	0.078867	0.05275	0.028197	0.022213	0.043937	0.278097	0.008

Table 12: Man-Sub criteria comparison table for the improved cable Insulation thickness

Name		Criteria		More Important	Intensity
I	j	A	B	A or B	(1-9)
1	2	Inadequate centering skill	Improper fitting of the tip	A	3
1	3		Operator’s fatigue	B	3
2	3	Improper fitting of the tip	Operator’s fatigue	B	5

Table 13: Pairwise comparison matrix with judgments for the Man- Sub criteria

Man	Inadequate centering skill	Improper fitting of the tip	Operator's fatigue
Inadequate centering skill	1	3	0.333
Improper fitting of the tip	0.333	1	0.2
Operator's fatigue	3	5	1

Table 13: Normalized matrix for the principal Eigen vector for the Man-Sub criteria

Man	Inadequate centering skill	Improper fitting of the tip	Operator's fatigue	Principal Priority vector
Inadequate centering skill	0.230787	0.333333	0.217221	0.260447
Improper fitting of the tip	0.076852	0.111111	0.130463	0.106142
Operator's fatigue	0.692361	0.555556	0.652316	0.633411

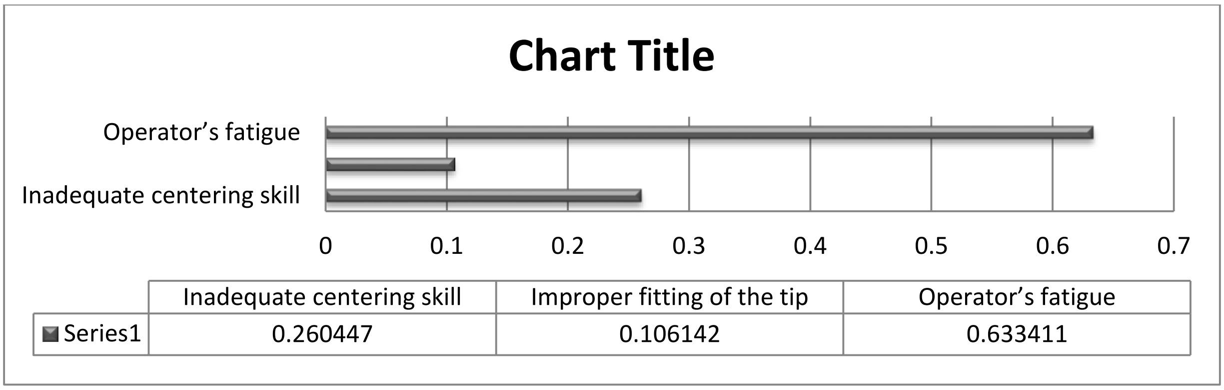


Figure 4. graphical representation of Man-subgroup prioritization vector for the improved insulation thickness.

Table 14: Calculated weighted sum for Man-Sub criteria and the global priorities

Man	Inadequate centering skill	Improper fitting of the tip	Operator's fatigue	Weighted Sum	Global Priority vector
Inadequate centering skill	0.26044	0.318426	0.210926	0.789792	0.03
Improper fitting of the tip	0.086727	0.106142	0.126682	0.319551	0.012
Operator's fatigue	0.78132	0.53071	0.633411	1.945441	0.074

Table 15: Method-Sub criteria comparison table for the improved cable Insulation thickness

Name		Criteria		More Important	Intensity
I	j	A	B	A or B	(1-9)
1	2	Improper control setting	Work target	A	5
1	3		Poor monitoring	A	2
2	3	Work Target	Poor monitoring	B	5

Table 16: Pairwise comparison matrix with judgments for the Method- Sub criteria

Method	Improper control setting	Work Target	Poor monitoring
Improper control setting	1	5	2
Work Target	0.2	1	0.2
Poor monitoring	0.5	5	1

Table 17: Normalized matrix for the principal Eigen vector for the Method-Sub criteria

Method	Improper control setting	Work Target	Poor monitoring	Principal Priority vector
Improper control setting	0.230787	0.333333	0.217221	0.260447
Work Target	0.076852	0.111111	0.130463	0.106142
Poor monitoring	0.692361	0.555556	0.652316	0.633411

Figure 5: Graphical representation of Method-subgroup prioritization vector for the improved insulation thickness

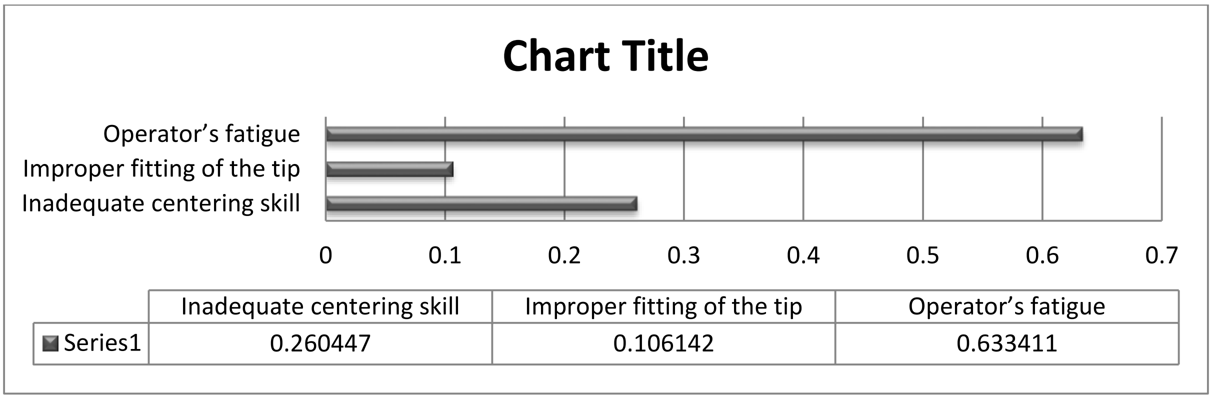


Table: 18: Calculated weighted sum for Method-Sub criteria and the global priorities

Method	Improper control setting	Work Target	Poor monitoring	Weighted Sum	Global Priority vector
Improper control setting	0.26044	0.318426	0.210926	0.789792	0.089
Work Target	0.086727	0.106142	0.126682	0.319551	0.036
Poor monitoring	0.78132	0.53071	0.633411	1.945441	0.215

APPENDIX G

Insulation Surface Flaws

Table 1**:** Main Criteria Comparison Table for the Cable Insulation Surface Flaws

Name		Criteria		More Important	Intensity
i	j	A	B	A or B	(1-9)
1	2	Measurement	Material	B	7
1	3		Machine	B	3
1	4		Man	B	3
1	5		Method	B	3
2	3	Material	Machine	A	3
2	4		Man	A	5
2	5		Method	A	5
3	4	Machine	Man	A	3
3	5		Method	A	5
4	5	Man	Method	A	3

Table 2: Pairwise comparison matrix with judgments for the main criteria

Criteria	Measurement	Material	Machine	Man	Method
Measurement	1	0.1428 [1/7]	0.333 [1/3]	0.333 [1/3]	0.333 [1/3
Material	7	1	3	5	5
Machine	3	0.333 [1/3]	1	3	5
Man	3	0.2 [1/5]	0.333 [1/3	]1	3
Method	3	0.2 [1/5]	0.2 [1/5]	0.333 [1/3]	1

Table 3: Normalized matrix for the principal Eigen vector for the main criteria

Criteria	Material	Machine	Man	Method	Measurement	Principal Priority vector
Measurement	0.058824	0.076128	0.068434	0.034451	0.023233	0.052214
Material	0.411765	0.533106	0.616523	0.517277	0.348845	0.485503
Machine	0.176471	0.177524	0.205508	0.310366	0.348845	0.243743
Man	0.176471	0.106621	0.068434	0.103455	0.209307	0.132858
Method	0.176471	0.106621	0.041102	0.034451	0.069769	0.085683

Table 4: Consistency Indices for the Improved Cable Insulation Smoothness Sub criteria.

AHP indices	λ_{max}	C.1	N	R.I	C.R	Decision
Material	6.5356	0.10712	6	1.2479	0.085	Acceptable
Machine	7.75068	0.12511	7	1.3417	0.093	Acceptable
Man	3.06508	0.032543	3	0.5245	0.062	Acceptable
Method	2.000	0	2	0	0	Acceptable

Table 5: Criteria weighing

Criteria	Measurement	Material	Machine	Man	Method	Weighted Sum
Measurement	0.052214	0.06933	0.081166	0.044242	0.028532	0.275484
Material	0.365498	0.485503	0.731229	0.66429	0.428415	2.674935
Machine	0.156642	0.161672	0.243743	0.398574	0.428415	1.389046
Man	0.156642	0.097101	0.081166	0.132858	0.257049	0.724816
Method	0.156642	0.097101	0.048749	0.044242	0.085683	0.432416

Table 6: Material comparison table for the Cable Insulation Surface Flaws

Name		Criteria		More Important	Intensity
i	j	A	B	A or B	(1-9)
1	2	Bunched PVC	Pores on the PVC	A	3
1	3		Presence of moisture	B	3
1	4		Poorly welded joint	B	7
1	5		Impurities on PVC	B	5
1	6		water on the input conductor	B	3
2	3	Pores on the PVC	Presence of moisture	B	3
2	4		Poorly welded joint	B	5
2	5		Impurities on PVC	B	5
2	6		water on the input conductor	B	3
3	4	Presence of moisture	Poorly welded joint	B	5
3	5		Impurities on PVC	B	3
3	6		water on the input conductor	B	3
4	5	Poorly welded joint	Impurities on PVC	A	3
4	6		water on the input conductor	A	5
5	6	Impurities on PVC	water on the input conductor	A	3

Table 7: Pairwise comparison matrix with judgments for the Material-Sub criteria

Material	Bunched PVC	Pores on the PVC	Moisture on PVC	Poorly welded joint	Impurities on PVC	Water on input conductor
Bunched PVC	1	3	0.333 [1/3]	0.1428 [1/7]	0.2 [1/5]	0.333 [1/3]
Pores on the PVC	0.333 [1/3]	1	0.333 [1/3]	0.2 [1/5]	0.2 [1/5]	0.333 [1/3]
Moisture on PVC	3	3	1	0.2	0.333 [1/3]	0.333 [1/3]
Poorly welded joint	7	5	5	1	3	5
Impurities on PVC	5	5	3	0.333 [1/3]	1	3
Water on input conductor	3	3	3	0.2 [1/5]	0.333 [1/3]	1

Table 8: Normalized matrix for the principal Eigen vector for the Material-Sub criteria

Material	Bunched PVC	Pores on the PVC	Moisture on PVC	Poorly welded joint	Impurities on PVC	Water on input conductor	Principal Priority vector
Bunched PVC	0.051725	0.15	0.026290857	0.068793	0.039479	0.033303	0.061598
Pores on the PVC	0.017224	0.05	0.026290857	0.096348	0.039479	0.033303	0.043774
Moisture on PVC	0.155175	0.15	0.078951524	0.096348	0.065732	0.033303	0.096585
Poorly welded joint	0.362075	0.25	0.394757619	0.481742	0.592183	0.50005	0.430135
Impurities on PVC	0.258625	0.25	0.236854571	0.16042	0.197394	0.30003	0.233887
Water on input conductor	0.155175	0.15	0.236854571	0.096348	0.065732	0.10001	0.13402

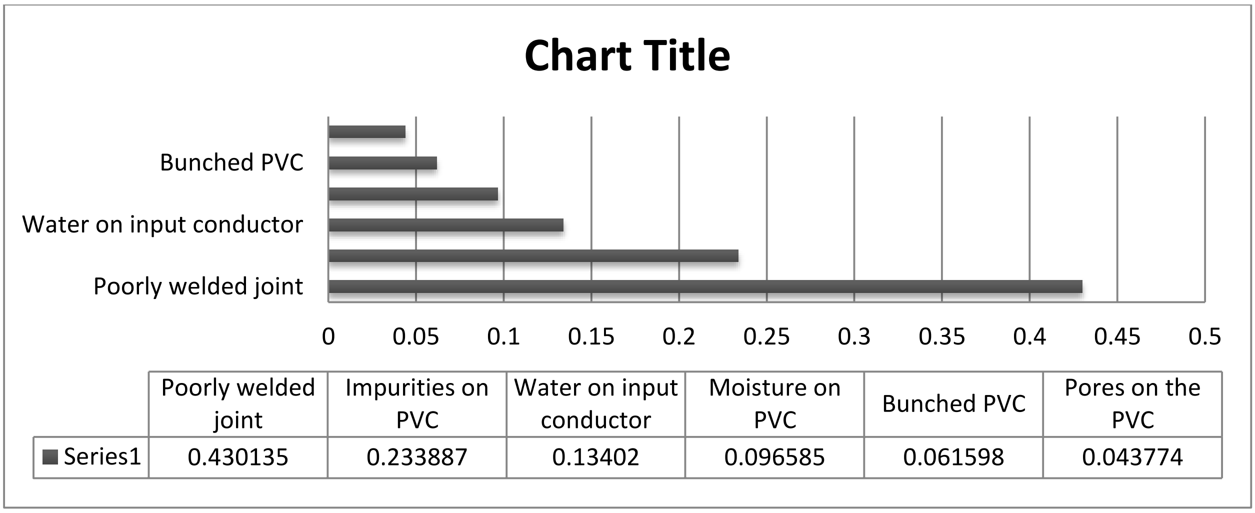


Figure 1: Graphical representation of Material-subgroup prioritization vector for the improved cable Insulation Surface Flaws

Table 9: Calculated weighted sum for Material-Sub criteria and the Global Eigen vectors

Material	Bunched PVC	Pores on the PVC	Moisture on PVC	Poorly welded joint	Impurities on PVC	Water on input conductor	Weighted sum	Global Eigen vector
Bunched PVC	0.061598	0.131322	0.032162805	0.061423	0.046777	0.044629	0.377912143	0.029906014
Pores on the PVC	0.020512	0.043774	0.032162805	0.086027	0.046777	0.044629	0.273881999	0.021252408
Moisture on PVC	0.184794	0.131322	0.096585	0.086027	0.077884	0.044629	0.621241031	0.046892307
Poorly welded joint	0.431186	0.21887	0.482925	0.430135	0.701661	0.6701	2.934877	0.208831833
Impurities on PVC	0.30799	0.21887	0.289755	0.143235	0.233887	0.40206	1.595796955	0.11355284
Water on input conductor	0.184794	0.131322	0.289755	0.086027	0.077884	0.13402	0.903802371	0.065067112

Table 10: Machine comparison table for the Cable Insulation Surface Flaws

Name		Criteria		More Important	Intensity
I	j	A	B	A or B	(1-9)
1	2	Poor tip tolerance	Faulty water pump	A	3
1	3		Unsteady wire guard	A	5
1	4		Faulty heating system	B	3
1	5		Faulty braking system	A	3
1	6		Shifting embosser	B	5
1	7		Water trough design not ok.	B	3
2	3	Faulty water pump	Unsteady wire guard	A	5
2	4		Faulty heating system	B	3
2	5		Faulty braking system	B	3
2	6		Shifting embosser	B	7
2	7		Water trough design not ok.	B	5
3	4	Unsteady wire guard	Faulty heating system	B	7
3	5		Faulty braking system	B	3
3	6		Shifting embosser	B	7
3	7		Water trough design not ok.	B	5
4	5	Faulty heating system	Faulty braking system	A	3
4	6		Shifting embosser	B	3
4	7		Water trough design not ok.	B	3
5	6	Shifting embosser	Shifting embosser	B	5
5	7		Water trough design not ok.	B	5
6	7	Shifting embosser	Water trough design not ok	A	3

Table 11: Pairwise comparison matrix with judgments for the machine criteria

Machine	Poor tip tolerance	Faulty water pump	Unsteady wire guard	Faulty heating system	Faulty braking system	Shifting embosser	Water trough designed not ok.
Poor tip tolerance	1	3	5	0.333[1/3]	3	0.2[1/5]	0.333[1/3]
Faulty water pump	0.333[1/3]	1	5	0.333[1/3]	0.333[1/3]	0.1428[1/7]	0.2[1/5]
Unsteady wire guard	0.2[1/5]	0.2[1/5]	1	0.1428[1/7]	0.333[1/3]	0.1428[1/7]	0.2[1/5]
Faulty heating system	3	3	7	1	3	0.333[1/3]	0.333[1/3]
Faulty braking system	0.333[1/3]	3	3	0.333[1/3]	1	0.2[1/5]	0.2[1/5]
Shifting embosser	5	7	7	3	5	1	3
Water trough designed not ok.	3	5	5	3	5	0.333[1/3]	1

Table 12: Normalized matrix for the principal Eigen vector for the machine factors

Machine	Poor tip tolerance	Faulty water pump	Unsteady wire guard	Faulty heating system	Faulty braking system	Shifting embosser	Water trough designed not ok.	Principal Priority vector
Poor tip tolerance	0.077724	0.135135	0.151515	0.0409	0.169818	0.085048	0.063236	0.10334
Faulty water pump	0.025882	0.045045	0.151515	0.0409	0.01885	0.060725	0.037979	0.054414
Unsteady wire guard	0.015545	0.009009	0.030303	0.017539	0.01885	0.060725	0.037979	0.027136
Faulty heating system	0.233173	0.135135	0.212121	0.122823	0.169818	0.141606	0.063236	0.153987
Faulty braking system	0.025882	0.135135	0.090909	0.0409	0.056606	0.085048	0.037979	0.067494
Shifting embosser	0.388621	0.315315	0.212121	0.368469	0.28303	0.425242	0.569692	0.36607
Water trough designed not ok.	0.233173	0.225225	0.151515	0.368469	0.28303	0.141606	0.189897	0.227559

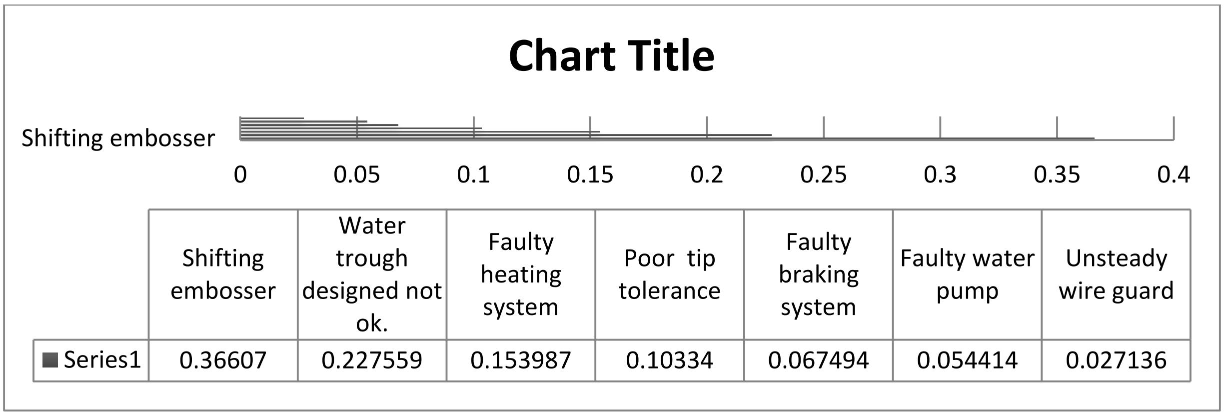


Figure 2: graphical representation of Machine-subgroup prioritization vector for the improved cable Insulation Surface Flaws

Table 13: Calculated weighted sum for the Machine criteria and the global priorities

Machine	Poor tip tolerance	Faulty water pump	Unsteady wire guard	Faulty heating system	Faulty braking system	Shifting embosser	Water trough designed not ok.	Weighted sum	Global Eigen vector
Poor tip tolerance	0.1033	0.1632	0.1357	0.0513	0.2025	0.0732	0.0758	0.80501	0.0251884
Faulty water pump	0.0344	0.0544	0.1357	0.0513	0.0225	0.0523	0.0455	0.39605	0.01326303
Unsteady wire guard	0.0207	0.0109	0.0271	0.0219	0.0225	0.0523	0.0455	0.20094	0.00661421
Faulty heating system	0.3100	0.1632	0.1899	0.1539	0.2025	0.1219	0.0758	1.21736	0.03753325
Faulty braking system	0.0344	0.1632	0.0814	0.0513	0.0675	0.0732	0.0455	0.51656	0.01645119
Shifting embosser	0.5167	0.3809	0.18995	0.4619	0.3375	0.36607	0.6827	2.93573	0.089227
Water trough designed not ok.	0.3100	0.2721	0.1357	0.46196	0.3375	0.12190	0.22756	1.86666	0.05546591

Table 14: Man- sub criteria comparison table for the Cable Insulation surface flaws

Name		Criteria		More Important	Intensity
i	j	A	B	A or B	(1-9)
i	j	Poor flushing of the extruder barrel	Poorly cleaned breaker plate		
i	j		Poor alignment of the embossing wheel		
i	j	Poorly cleaned breaker plate	Poor alignment of the embossing wheel.		

Table 15: Pairwise comparison matrix with judgments for the man- Sub criteria

Man	Poor flushing of the extruder barrel	Poorly cleaned breaker plate	Poor alignment of the embossing wheel
Poor flushing of the extruder barrel	1	7	3
Poorly cleaned breaker plate	0.1428[1/7]	1	0.2[1/5]
Poor alignment of the embossing wheel	0.333[1/3]	5	1

Table 16: Normalized matrix for the principal Eigen vector for the man-Sub criteria

Man	Poor flushing of the extruder barrel	Poorly cleaned breaker plate	Poor alignment of the embossing wheel	Principal Priority vector
Poor flushing of the extruder barrel	0.677599	0.538462	0.714286	0.643449
Poorly cleaned breaker plate	0.096761	0.076923	0.047619	0.073768
Poor alignment of the embossing wheel	0.22564	0.384615	0.238095	0.282784

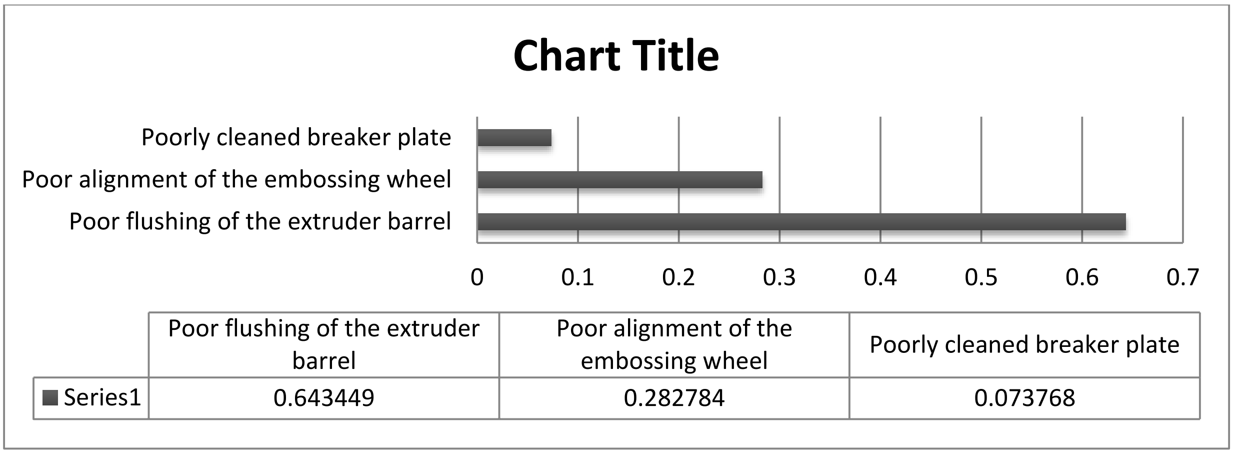


Figure 3: graphical representation of Man-subgroup prioritization vector for the improved cable Insulation Surface Flaw.

Table 17: Calculated weighted sum for the man-Sub criteria and the global priorities

Man	Poor flushing of the extruder barrel	Poorly cleaned breaker plate	Poor alignment of the embossing wheel	Weighted sum	Global Eigen vector
Poor flushing of the extruder barrel	0.643449	0.516376	0.848352	2.008177	0.085487
Poor flushing of the extruder barrel	0.091885	0.073768	0.056557	0.222209	0.009801
Poorly cleaned breaker plate	0.214269	0.36884	0.282784	0.865893	0.03757

Table 18: Method- sub criteria comparison table for the cable Insulation surface flaws

Name		Criteria		More Important	Intensity
i	j	A	B	A or B	(1-9)
i	j	Poor monitoring system	Improper speed setting	B	3

Table 19: Pairwise comparison matrix with judgments for the method- Sub criteria on Insulation Surface flaws.

Method	Poor monitoring system	Improper speed setting	
Poor monitoring system	1	0.333[1/3]	
Improper speed setting	3	1	
Prioritization			
Method	Poor monitoring system	Improper speed setting	Principal Priority vector
Poor monitoring system	0.25	0.249812	0.249906
Improper speed setting	0.75	0.750188	0.750094

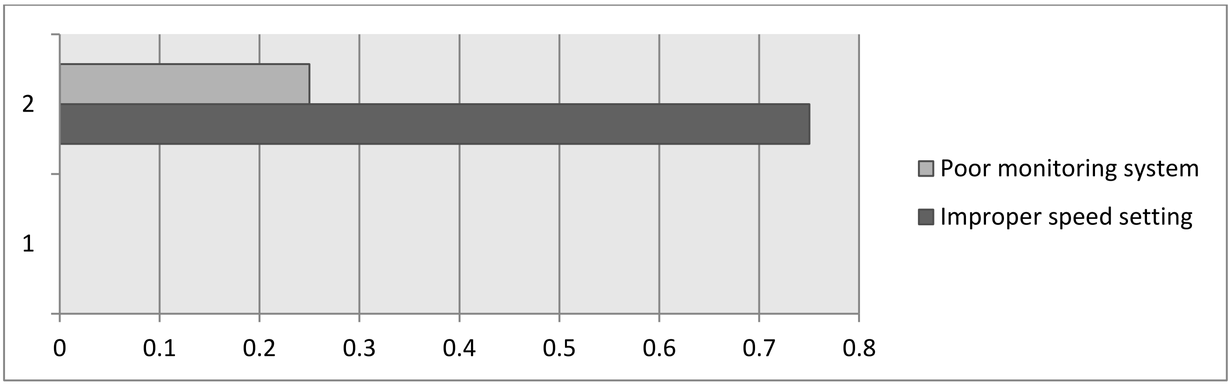


Figure 4: graphical representation of Method-subgroup prioritization vector for the improved cable Insulation Surface Flaws.

Table 20: Normalized matrix for the principal Eigen vector for the Method-Sub criteria for Insulation Surface flaws.

Method	Poor monitoring system	Improper speed setting	Weighted sum	Global Eigen vector
Poor monitoring system	0.249906	0.249781	0.499687	0.0214127
Improper speed setting	0.749718	0.750094	1.499812	0.0642703

APPENDIX H

Table 1 RI (n) various from Alonso & Lamata, 2006

S/N	M	RI
1	2	0
2	3	0.5245
3	4	0.8815
4	5	1.1086
5	6	1.2479
6	7	1.3417
7	8	1.4056
8	9	1.4499
9	10	1.4854
10	11	1.5141
11	12	1.5365
12	13	1.5551
13	14	1.5713
14	15	1.5838

APPENDIX I

Questionnaire on Defect solutions

What are the potential solutions to removing the following identified defects that are found in the cable extrusion line such as:

1. **Un-aligned embossing wheel**
2. **Worn-out centering bolts**
3. **Faulty heating system**
4. **Poorly annealed copper conductor**
5. **Over-dimensioned tip**
6. **Faulty measuring tools**
7. **Inadequate centering skills**
8. **Faulty tensioning system**
9. **Operator's fatigue**
10. **Poor monitoring system**
11. **Presence of water on the input**
12. **Pores on the PVC**
13. **Improper speed setting**
14. **Poor flushing of the extrusion barrel**
15. **Water trough design not ok.**
16. **Poor tip tolerance**
17. **Poorly welded joint**
18. **Management problems/ lack of motivation**

APPENDIX J

Table of Two-way ANOVA with replication

Anova: Two-Factor With Replication						
SUMMARY	375	400	425	450	Total	
Count	5	5	5	5	20	
Sum	13.67	12.99	12.89	12.63	52.18	
Average	2.734	2.598	2.578	2.526	2.609	
Variance	0.00078	0.00317	0.00437	0.00193	0.008367	
900						
Count	5	5	5	5	20	
Sum	13.71	13.74	13.48	13.16	54.09	
Average	2.742	2.748	2.696	2.632	2.7045	
Variance	0.00497	0.00237	0.00023	0.00177	0.004237	
925						
Count	5	5	5	5	20	
Sum	14.3	13.84	13.74	13.46	55.34	
Average	2.86	2.768	2.748	2.692	2.767	
Variance	0.0024	0.00107	0.00137	0.00457	0.005833	
950						
Count	5	5	5	5	20	
Sum	14.37	14.22	14.01	13.76	56.36	
Average	2.874	2.844	2.802	2.752	2.818	
Variance	0.00243	0.00428	0.00537	0.00162	0.005101	

APPENDIX K

Taguchi Design

Taguchi Analysis: Preheated PVC, Non-Preheated PV versus Capstan Speed (r, Extruder Speed (

Linear Model Analysis: SN ratios versus Capstan Speed (rpm), Extruder Speed (rpm)

Estimated Model Coefficients for SN ratios

Term	Coef	SE Coef	T	P
Constant	38.1261	2.045	18.646	0.000
Capstan 375	-1.1958	3.542	-0.338	0.743
Capstan 400	0.1518	3.542	0.043	0.967
Capstan 425	1.8452	3.542	0.521	0.615
Extruder 875	-3.6889	3.542	-1.042	0.325
Extruder 900	7.3574	3.542	2.077	0.068
Extruder 925	-2.5621	3.542	-0.723	0.488

S = 8.179   R-Sq = 35.0%   R-Sq(adj) = 0.0%

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Capstan Speed (rpm)	3	22.00	22.00	7.333	0.11	0.952
Extruder Speed (rpm)	3	302.11	302.11	100.704	1.51	0.278
Residual Error	9	602.05	602.05	66.894		
Total	15	926.16				

Unusual Observations for SN ratios

Observation	SN ratios	Fit	SE Fit	Residual	St Resid
2	27.109	44.288	5.410	-17.179	-2.80 R

R denotes an observation with a large standardized residual.

Linear Model Analysis: Means versus Capstan Speed (rpm), Extruder Speed (rpm)

Estimated Model Coefficients for Means

Term	Coef	SE Coef	T	P
Constant	2.73781	0.007460	366.994	0.000
Capstan 375	0.06969	0.012921	5.393	0.000
Capstan 400	0.01094	0.012921	0.846	0.419
Capstan 425	-0.01031	0.012921	-0.798	0.445
Extruder 875	-0.09656	0.012921	-7.473	0.000
Extruder 900	-0.03781	0.012921	-2.926	0.017
Extruder 925	0.04469	0.012921	3.458	0.007

S = 0.02984   R-Sq = 93.9%   R-Sq(adj) = 89.8%

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P

Capstan Speed (rpm)	3	0.040105	0.040105	0.013368	15.01	0.001
Extruder Speed (rpm)	3	0.083180	0.083180	0.027727	31.14	0.000
Residual Error	9	0.008014	0.008014	0.000890		
Total	15	0.131298				

Unusual Observations for Means

Observation	Means	Fit	SE Fit	Residual	St Resid
6	2.765	2.711	0.020	0.054	2.42 R

Response Table for Signal to Noise Ratios
Nominal is best (10×Log10(Ybar^2/s^2))

Level	Capstan Speed (rpm)	Extruder Speed (rpm)
1	36.93	34.44
2	38.28	45.48
3	39.97	35.56
4	37.32	37.02
Delta	3.04	11.05
Rank	2	1

Response Table for Means

Level	Capstan Speed (rpm)	Extruder Speed (rpm)
1	2.808	2.641
2	2.749	2.700
3	2.728	2.782
4	2.668	2.827
Delta	0.140	0.186
Rank	2	1

Predicted values

S/N Ratio	Mean
35.7159	2.79344

Factor levels for predictions

Capstan Speed (rpm)	Extruder Speed (rpm)
400	925

APPENDIX L

Optimization

RESPONSE 1

Table 1: 1Two-sided Confidence = 95%

Response	Predicted Mean	Predicted Median	Observed	Std Dev	n	SE Pred	95% PI low	Data Mean	95% PI high
Preheated PVC	2.72462	2.72462		0.0391344	1	0.0406117	2.63413		2.8151
Non preheated PVC	2.72	2.72		0.0320428	1	0.0332524	2.64591		2.79409

Table 2: Build Information

File Version	11.1.1.0		
Study Type	Response Surface	Subtype	Randomized
Design Type	Central Composite	Runs	13
Design Model	Quadratic	Blocks	No Blocks
Build Time (ms)	85.00		

Table 3: Responses

Response	Name	Units	Observations	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Transform	Model
R1	Preheated PVC	mm	13	Polynomial	2.6	2.92	2.72	0.0770	1.12	None	Linear
R2	Non preheated PVC	mm	13	Polynomial	2.59	2.88	2.72	0.0682	1.11	None	Linear

Table: 4: Factors

Factor	Name	Units	Type	Minimum	Maximum	Coded Low	Coded High	Mean	Std. Dev.
A	Capstan speed	rpm	Numeric	359.47	465.53	-1 ↔ 375.00	+1 ↔ 450.00	412.50	30.62
B	Extruder speed	rpm	Numeric	859.47	965.53	-1 ↔ 875.00	+1 ↔ 950.00	912.50	30.62

Table 5: Sequential Model Sum of Squares [Type I]

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	96.51	1	96.51			
Linear vs Mean	**0.0558**	**2**	**0.0279**	**18.22**	**0.0005**	**Suggested**
2FI vs Linear	0.0001	1	0.0001	0.0592	0.8133	
Quadratic vs 2FI	0.0009	2	0.0005	0.2306	0.7998	
Cubic vs Quadratic	0.0074	2	0.0037	2.72	0.1585	Aliased
Residual	0.0068	5	0.0014			
Total	96.58	13	7.43			

Table 6: Lack of Fit Tests

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Linear	**0.0130**	**6**	**0.0022**	**3.73**	**0.1115**	**Suggested**
2FI	0.0129	5	0.0026	4.45	0.0867	
Quadratic	0.0120	3	0.0040	6.87	0.0468	
Cubic	0.0045	1	0.0045	7.78	0.0493	Aliased
Pure Error	0.0023	4	0.0006			

Table 7: Model Summary Statistics

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	**0.0391**	**0.7847**	**0.7416**	**0.5666**	**0.0308**	**Suggested**
2FI	0.0411	0.7861	0.7148	0.2174	0.0557	
Quadratic	0.0452	0.7993	0.6559	-0.2462	0.0886	
Cubic	0.0370	0.9039	0.7694	-3.1115	0.2924	Aliased

Focus on the model maximizing the **Adjusted R^2** and the **Predicted R^2**.

Table 8: Fit Statistics

Std. Dev.	0.0391		**R^2**	0.7847
Mean	2.72		**Adjusted R^2**	0.7416
C.V. %	1.44		**Predicted R^2**	0.5666
			Adeq Precision	12.4602

Table: 9 Coefficients in Terms of Coded Factors

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	2.72	1	0.0109	2.70	2.75	
A-Capstan speed	-0.0509	1	0.0138	-0.0817	-0.0201	1.0000
B-Extrruder speed	0.0662	1	0.0138	0.0354	0.0970	1.0000

RESPONSE 2

Table 10: Sequential Model Sum of Squares [Type I]

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	96.18	1	96.18			
Linear vs Mean	**0.0455**	**2**	**0.0228**	**22.17**	**0.0002**	**Suggested**
2FI vs Linear	0.0001	1	0.0001	0.0885	0.7728	
Quadratic vs 2FI	0.0008	2	0.0004	0.3142	0.7402	
Cubic vs Quadratic	0.0062	2	0.0031	4.99	0.0643	Aliased
Residual	0.0031	5	0.0006			
Total	96.24	13	7.40			

Table 11: Lack of Fit Tests

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Linear	**0.0087**	**6**	**0.0014**	**3.61**	**0.1172**	**Suggested**
2FI	0.0086	5	0.0017	4.28	0.0918	
Quadratic	0.0077	3	0.0026	6.44	0.0519	
Cubic	0.0015	1	0.0015	3.78	0.1237	Aliased
Pure Error	0.0016	4	0.0004			

Table 12: Model Summary Statistics

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	**0.0320**	**0.8160**	**0.7792**	**0.6327**	**0.0205**	**Suggested**
2FI	0.0336	0.8178	0.7571	0.3515	0.0362	
Quadratic	0.0365	0.8328	0.7134	-0.0299	0.0575	
Cubic	0.0249	0.9442	0.8661	-0.7796	0.0993	Aliased

Focus on the model maximizing the **Adjusted R^2** and the **Predicted R^2**.

Table 13: Fit Statistics

Std. Dev.	0.0320		**R^2**	0.8160
Mean	2.72		**Adjusted R^2**	0.7792
C.V. %	1.18		**Predicted R^2**	0.6327
			Adeq Precision	13.7840

Table 14: Coefficients in Terms of Coded Factors

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	2.72	1	0.0089	2.70	2.74	
A-Capstan speed	-0.0474	1	0.0113	-0.0726	-0.0221	1.0000
B-Extrruder speed	0.0587	1	0.0113	0.0335	0.0840	1.0000

Table 15: Final Equation in Terms of Coded Factors

Non preheated PVC	=
+2.72	
-0.0474	A
+0.0587	B

Table 16: Final Equation in Terms of Actual Factors

Non preheated PVC	=
+1.81243	
-0.001263	Capstan speed
+0.001566	Extruder speed

Table 17:

Run Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residuals	Externally Studentized Residuals	Cook's Distance	Influence on Fitted Value DFFITS	Standard Order
1	2.72	2.72	-0.0046	0.077	-0.123	-0.117	0.000	-0.034	12
2	2.73	2.72	0.0054	0.077	0.143	0.136	0.001	0.039	10
3	2.60	2.61	-0.0075	0.327	-0.233	-0.222	0.009	-0.155	2
4	2.77	2.74	0.0301	0.327	0.937	0.931	0.142	0.649	4
5	2.70	2.72	-0.0246	0.077	-0.655	-0.635	0.012	-0.183	13
6	2.68	2.72	-0.0446	0.077	-1.187	-1.214	0.039	-0.351	11
7	2.65	2.63	0.0190	0.327	0.593	0.572	0.057	0.399	7
8	2.74	2.72	0.0154	0.077	0.409	0.391	0.005	0.113	9
9	2.73	2.71	0.0207	0.327	0.644	0.624	0.067	0.435	1
10	2.66	2.65	0.0074	0.327	0.230	0.219	0.009	0.152	6
11	2.77	2.82	-0.0483	0.327	-1.503	-1.621	0.366	-1.129	8
12	2.92	2.84	0.0783	0.327	2.438	3.630	0.962 (1)	2.530 (1)	3
13	2.75	2.80	-0.0466	0.327	-1.452	-1.550	0.341	-1.081	5

Table 18:

Run Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residuals	Externally Studentized Residuals	Cook's Distance	Influence on Fitted Value DFFITS	Standard Order
1	2.73	2.72	0.0100	0.077	0.325	0.310	0.003	0.089	12
2	2.72	2.72	0.0000	0.077	0.000	0.000	0.000	0.000	10
3	2.59	2.61	-0.0239	0.327	-0.910	-0.901	0.134	-0.628	2
4	2.75	2.73	0.0187	0.327	0.710	0.691	0.082	0.482	4
5	2.68	2.72	-0.0400	0.077	-1.299	-1.352	0.047	-0.390	13
6	2.70	2.72	-0.0200	0.077	-0.650	-0.630	0.012	-0.182	11
7	2.65	2.64	0.0130	0.327	0.496	0.476	0.040	0.332	7
8	2.72	2.72	0.0000	0.077	0.000	0.000	0.000	0.000	9
9	2.74	2.71	0.0313	0.327	1.192	1.221	0.230	0.851	1
10	2.68	2.65	0.0270	0.327	1.027	1.030	0.171	0.718	6
11	2.77	2.80	-0.0330	0.327	-1.257	-1.299	0.256	-0.905	8
12	2.88	2.83	0.0539	0.327	2.051	2.556	0.681	1.781 (1)	3
13	2.75	2.79	-0.0370	0.327	-1.407	-1.491	0.321	-1.039	5

APPENDIX: M

Factors for Tolerance Intervals

Values of *k* for Two-Sided Intervals									
Confidence	**0.90**			**0.95**			**0.99**		
Percent Coverage	0.90	0.95	0.99	0.90	0.95	0.99	0.90	0.95	0.99
2	15.978	18.800	24.1	32.019	37.674	48.4	160.19	188.49	242.30
3	5.847	6.919	8.97	8.380	9.916	12.8	18.930	22.401	29.05
4	4.166	4.943	6.44	5.369	6.370	8.29	9.398	11.150	14.52
5	3.949	4.152	5.42	4.275	5.079	6.63	6.612	7.855	10.26
6	3.131	3.723	4.87	3.712	4.414	5.77	5.337	6.345	8.30
7	2.902	3.452	4.52	3.369	4.007	5.24	4.613	5.488	7.18
8	2.743	3.264	4.27	3.136	3.732	4.89	4.147	4.936	6.46
9	2.626	3.125	4.09	2.967	3.532	4.63	3.822	4.550	5.96
10	2.535	3.018	3.95	2.839	3.379	4.43	3.582	4.265	5.59
11	2.463	2.933	3.84	2.737	3.259	4.27	3.397	4.045	5.30
12	2.404	2.863	3.75	2.655	3.162	4.15	3.250	3.870	5.07
13	2.355	2.805	3.68	2.587	3.081	4.04	3.130	3.727	4.89
14	2.314	2.756	3.61	2.529	3.012	3.95	3.029	3.608	4.73
15	2.278	2.713	3.56	2.480	2.954	3.87	2.945	3.507	4.60
16	2.246	2.676	3.51	2.437	2.903	3.81	2.872	3.421	4.49
17	2.219	2.643	3.47	2.400	2.858	3.75	2.808	3.345	4.39
18	2.194	2.614	3.43	2.366	2.819	3.70	2.753	3.279	4.30
19	2.172	2.588	3.39	2.337	2.784	3.65	2.703	3.221	4.23
20	2.152	2.564	3.36	2.310	2.752	3.61	2.659	3.168	4.16
21	2.135	2.543	3.34	2.286	2.723	3.57	2.620	3.121	4.10
22	2.118	2.524	3.31	2.264	2.697	3.54	2.584	3.078	4.04
23	2.103	2.506	3.29	2.244	2.673	3.51	2.551	3.040	3.99
24	2.089	2.489	3.27	2.225	2.651	3.48	2.522	3.004	3.94
25	2.077	2.474	3.25	2.208	2.631	3.45	2.494	2.972	3.90
30	2.025	2.413	3.17	2.140	2.529	3.35	2.385	2.841	3.73
40	1.959	2.334	3.06	2.052	2.445	3.21	2.247	2.677	3.51
50	1.916	2.284	3.00	1.996	2.379	3.12	2.162	2.576	3.38
60	1.887	2.248	2.95	1.958	2.333	3.06	2.103	2.506	3.29
70	1.865	2.222	2.92	1.929	2.299	3.02	2.060	2.454	3.22
80	1.848	2.202	2.89	1.907	2.272	2.98	2.026	2.414	3.17
90	1.834	2.185	2.87	1.889	2.251	2.95	1.999	2.382	3.13
10	1.822	2.172	2.85	1.874	2.233	2.93	1.977	2.355	3.09

Factor for Tolerance Interval. Retrieved online from:

http://www.bessegato.com.br/UFJF/resources/tolerance_table.pdf

APPENDIX N

Table 1: Average time = 3532/76 = 46.47 sec

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
1	50	3.53	12.461
2	60	13.53	183.061
3	39	-7.47	55.801
4	50	3.53	12.461
5	70	23.53	553.661
6	30	-16.47	271.261
7	31	-15.47	239.321
8	49	2.53	6.401
9	36	-10.47	109.621
10	50	3.53	12.461
11	40	-6.47	41.861
12	41	-5.47	29.921
13	40	-6.47	41.861
14	39	-7.47	55.801
15	60	13.53	183.061
16	45	-1.47	2.161
17	50	3.53	12.461
18	33	-13.47	181.441
19	70	23.53	553.661
20	49	2.53	6.401
21	49	2.53	6.401
22	48	1.53	2.341
23	45	-1.47	2.161
24	31	-15.47	239.321
25	60	13.53	183.061
26	51	4.53	20.521

No.	Time (t)	(t_i-t)	(t_i-t)^2
27	49	2.53	6.401
28	52	5.53	30.581
29	50	3.53	12.461
30	30	-16.47	271.261
31	41	-5.47	29.921
32	40	-6.47	41.861
33	30	-16.47	271.261
34	60	13.53	183.0609
35	55	8.53	72.761
36	70	23.53	553.661
37	63	16.53	273.241
38	58	11.53	132.941
39	45	-1.47	2.161
40	40	-6.47	41.861
41	40	-6.47	41.861
42	33	-13.47	181.441
43	33	-13.47	181.441
44	45	-1.47	2.161
45	30	-16.47	271.261
46	30	-16.47	271.261
47	32	-14.47	209.381
48	46	-0.47	0.2209
49	40	-6.47	41.861
50	50	3.53	12.461
51	48	1.53	2.341
52	51	4.53	20.521
53	50	3.53	12.461
54	50	3.53	12.461

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
55	50	3.53	12.461
56	39	-7.47	55.801
57	62	15.53	241.181
58	68	21.53	463.541
59	45	-1.47	2.161
60	43	-3.47	12.041
61	54	7.53	56.701
62	45	-1.47	2.161
63	39	-7.47	55.801
64	40	-6.47	41.861
65	49	2.53	6.401
66	30	-16.47	271.261
67	44	-2.47	6.101
68	60	13.53	183.061
69	52	5.53	30.581
70	50	3.53	12.461
71	48	1.53	2.341
72	55	8.53	72.761
73	58	11.53	132.941
74	55	8.53	72.761
75	39	-7.47	55.801
76	30	-16.47	271.261

$\sum t$ = 2176

Average time = 2278/50 = 45.56 sec

$S_x = [\sum [((t_i - t)^2)] /n]^{0.5} = [\frac{6114.601}{50}]^{0.5} = 11.058$

Lower limit = t- 2Sx = 45.56 – 2(11.058) = 23.444

Upper limit = t + 2Sx = 45.56 +2(11.058) = 67.676

Any data points not in the range 23.444 ≤ t_i≤ 67.676 will be discarded. This includes data points 5, 19 & 36. We now recalculate the average and sample variance, as follows

t = (2278-70-70-70) / 47 = 44 and Sx = S_x = $[\sum [((t_i - t)^2)] /n]^{0.5} = [\frac{4322.659}{47}]^{0.5}$ = 9.590

The new upper and lower limit:

Lower limit = 44- 2(9.590) = 24.82

Upper limit = 44 + 2(9.590) = 63.18

Any data points not in the range 24.82≤ t_i≤ 63.18 will be discarded. At this point, there is no longer any out-of-range data. However, we still need to determine the required number of data points in the sample

$N = [\frac{2\ x\ 9.590}{0.05\ x\ 44}]^2 = 76$

$\sum t$ = 3532

Average time = 3532/76 = 46.47 sec

Table 2 : Element 2

No.	Time (t)	(t_i-t)	$(t_i-t)^2$
1	322	-71.92	5172.48
2	305	-88.92	7906.76
3	374	-19.92	396.80
4	540	146.08	21339.36
5	491	97.08	9424.52
6	525	131.08	17181.96
7	442	48.08	2311.68
8	311	-82.92	6875.72
9	322	-71.92	5172.48
10	365	-28.92	836.36
11	442	48.08	2311.68

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
12	312	-81.92	6710.88
13	547	153.08	23433.48
14	345	-48.92	2393.16
15	381	-12.92	166.92
16	317	-76.92	5916.68
17	417	23.08	532.68
18	405	11.08	122.76
19	400	6.08	36.96
20	373	-20.92	437.64
21	422	28.08	788.48
22	480	86.08	7409.76
23	343	-50.92	2592.84
24	308	-85.92	7382.24
25	401	7.08	50.12
26	379	-14.92	222.60
27	380	-13.92	193.76
28	375	-18.92	357.96
29	483	89.08	7935.24
30	429	35.08	1230.60
31	369	-24.92	621.00
32	414	20.08	403.20
33	541	147.08	21632.52
34	393	-0.92	0.84
35	381	-12.92	166.92
36	369	-24.92	621.00
37	421	27.08	733.32
38	333	-60.92	3711.24
39	300	-93.92	8820.96

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
40	303	-90.92	8266.44
41	420	26.08	680.16
42	364	-26.92	724.68
No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
43	363	-30.92	956.04
44	411	17.08	291.72
45	424	30.08	904.80
46	424	30.08	904.80
47	353	-40.92	1674.44
48	341	-52.92	2800.52
49	427	33.08	1094.28
50	409	15.08	227.40

Table 3: Element 3 (Passing the wire through the die and tying with the existing line).

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
1	190	-6.12	37.454
2	187	0.88	0.774
3	182	-4.12	16.974
4	189	2.88	8.294
5	180	-6.12	37.454
6	187	0.88	0.774
7	182	-4.12	16.974
8	176	-10.12	102.414
9	181	-5.12	26.214
10	182	-4.12	16.974
11	182	-4.12	16.974
12	189	2.88	8.294
13	185	-1.12	1.254
14	189	2.88	8.294

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
15	189	2.88	8.294
16	186	-0.12	0.014
17	186	-0.12	0.014
18	186	-0.12	0.014
19	186	-0.12	0.014
20	188	1.88	3.534
21	188	1.88	3.534
22	180	-6.12	37.454
23	179	-7.12	50.694
24	184	-2.12	4.494
25	188	1.88	3.534
26	189	2.88	8.294
27	192	5.88	34.574
28	181	-5.12	26.214
29	202	15.88	252.17
30	189	2.88	8.294
31	187	0.88	0.774
32	183	-3.12	9.734
33	183	-3.12	9.734
34	212	25.88	669.774
35	176	-10.12	102.414
36	187	0.88	0.774
37	190	3.88	15.054
38	179	-7.12	50.694
39	189	2.88	8.294
40	185	-1.12	1.254

Table 4: Element 4 (Opening of the Crosshead)

No.	Time (t)	(t_i-t)	(t_i-t)^2
1	122	-3.15	9.922
2	139	13.85	191.822
3	136	10.85	117.722
4	140	14.85	220.522
5	136	10.85	117.722
6	129	3.85	14.822
7	125	-0.15	0.022
8	129	3.85	14.822
9	149	23.85	568.822
10	118	-7.15	51.122
11	114	-11.15	124.322
12	132	6.85	46.922
13	118	-7.15	51.122
14	127	1.5	2.25
15	132	6.85	46.922
16	129	3.85	14.822
17	131	5.85	34.222
18	122	-3.15	9.922
19	116	-9.15	83.722
20	119	-6.15	37.822
21	129	3.85	14.822
22	115	-10.15	103.022
23	120	-5.15	26.522
24	121	-4.15	17.222
25	125	-0.15	0.022
26	132	6.85	46.922
27	131	5.85	34.222

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
28	122	-3.15	9.922
29	127	1.85	3.422
30	117	-8.15	66.422
31	110	-15.15	229.522
32	121	-4.15	17.222
33	119	-6.15	37.822
34	114	-11.15	124.322
35	124	-1.15	1.322
36	120	-5.15	26.522
37	122	-3.15	9.922
38	125	-0.15	0.022
39	130	4.85	23.522
40	119	-6.15	37.822

Table 5: Element 6 124.88

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
1	122	-2.88	8.294
2	139	14.12	199.374
3	136	11.12	123.654
4	140	15.12	228.614
5	136	11.12	123.654
6	129	4.12	16.974
7	125	0.12	0.014
8	129	4.12	16.974
9	149	24.12	581.774
10	118	-6.88	47.334
11	114	-10.88	118.374
12	132	7.12	50.694
13	118	-6.88	47.334

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
14	127	2.12	4.494
15	132	7.12	50.694
16	129	4.12	16.974
17	131	6.12	37.454
18	122	-2.88	8.294
19	116	-8.88	78.854
20	119	-5.88	34.574
21	129	4.12	16.974
22	115	-9.88	97.614
23	120	-4.88	23.814
24	121	-3.88	15.054
25	125	0.12	0.014
26	132	7.12	50.694
27	131	6.12	37.454
28	122	-2.88	8.294
29	127	2.12	4.494
30	117	-7.88	62.094
31	110	-14.88	221.414
32	121	-3.88	15.054
33	119	-5.88	34.574
34	114	-10.88	118.374
35	124	-0.88	0.774
36	120	-4.88	23.814
37	122	-2.88	8.294
38	125	0.12	0.014
39	130	5.12	26.214
40	119	-5.88	34.574
41	129	4.12	16.974

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
42	119	-5.88	34.574
43	122	-2.88	8.294
44	129	4.12	16.974
45	128	3.12	9.734
46	116	-8.88	78.854
47	124	-0.88	0.774
48	127	2.12	4.494
49	123	-1.88	3.534
50	121	-3.88	15.054

Table 7: Element 7

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
1	461	-20.32	412.902
2	477	-4.32	18.662
3	484	2.68	7.182
4	489	7.68	58.982
5	467	-14.32	205.062
6	491	9.68	93.702
7	490	8.68	75.342
8	494	12.68	160.782
9	484	2.68	7.182
10	488	6.68	44.622
11	481	-0.32	0.102
12	489	7.68	58.982
13	502	20.68	427.662
14	497	15.68	245.862
15	464	-17.32	299.982
16	471	-10.32	106.502
17	484	2.68	7.182

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
18	482	0.68	0.462
19	487	5.68	32.262
20	486	4.68	21.902
21	488	6.68	44.622
22	492	10.68	114.062
23	466	-15.32	234.702
24	481	-0.32	0.102
25	481	-0.32	0.102
26	479	-2.32	5.382
27	481	-0.32	0.102
28	472	-9.32	86.862
29	478	-3.32	11.022
30	461	-20.32	412.902
31	507	25.68	659.462
32	477	-4.32	18.662
33	512	30.68	941.262
34	491	9.68	93.702
35	489	7.68	58.982
36	490	8.68	75.342
37	484	2.68	7.182
38	482	0.68	0.462
39	485	3.68	13.542
40	486	4.68	21.902
41	474	-7.32	53.582
42	486	4.68	21.902
43	472	-9.32	86.862
44	481	-0.32	0.102
45	488	6.68	44.622

No.	Time (t)	(t_i-t)	(t_i-t)^2
46	424	-57.32	3285.582
47	490	8.68	75.342
48	436	-45.32	2053.902
49	488	6.68	44.622
50	485	3.68	13.542

Table 8: Element 8 (481.22)

No.	Time (t)	(t_i-t)	(t_i-t)^2
1	461	-20.22	408.84
2	477	-4.22	17.808
3	484	2.78	7.728
4	489	7.78	60.528
5	467	-14.22	202.208
6	491	9.78	95.648
7	490	8.78	77.088
8	494	12.78	163.328
9	484	2.78	7.728
10	488	6.78	45.968
11	481	-0.22	0.048
12	489	7.78	60.528
13	502	20.78	431.808
14	497	15.78	249.008
15	464	-17.22	296.528
16	471	-10.22	104.448
17	484	2.78	7.728
18	482	0.78	0.608
19	487	5.78	33.408
20	486	4.78	22.848
21	488	6.78	45.968

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
22	492	10.78	116.208
23	466	-15.22	231.648
24	481	-0.22	0.048
25	481	-0.22	0.048
26	479	-2.22	4.928
27	481	-0.22	0.048
28	472	-9.22	85.008
29	478	-3.22	10.368
30	461	-20.22	408.848
31	507	25.78	664.608
32	477	-4.22	17.808
33	512	30.78	947.408
34	491	9.78	95.648
35	489	7.78	60.528
36	490	8.78	77.088
37	484	2.78	7.728
38	482	0.78	0.608
39	485	3.78	14.288
40	486	4.78	22.848
41	474	-7.22	52.128
42	486	4.78	22.848
43	472	-9.22	85.008
44	481	-0.22	0.048
45	488	6.78	45.968
46	424	-57.22	3274.128
47	490	8.78	77.088
48	436	-45.22	2044.848
49	488	6.78	45.968

No.	Time (t)	(t_i-t)	$(t_i-t)^2$
50	485	3.78	14.288
51	469	-12.22	149.328
52	479	-2.22	4.928
53	488	6.78	45.968
54	481	-0.22	0.048
55	452	-29.22	853.808
56	499	17.78	316.128
57	492	10.78	116.208
58	487	5.78	33.408
59	479	-2.22	4.928
60	468	-13.22	174.768
61	464	-17.22	296.528
62	481	-0.22	0.048
63	488	6.78	45.968
64	495	13.78	189.888

Table 9 Element 6

No.	Time (t)	(t_i-t)	$(t_i-t)^2$
1	276	-0.38	0.144
2	260	-16.38	268.304
3	259	-17.38	302.064
4	321	44.62	1990.944
5	268	-8.38	70.224
6	267	-9.38	87.984
7	269	-7.38	54.464
8	277	0.62	0.384
9	288	11.62	135.024
10	268	-8.38	70.224
11	299	22.62	511.664

No.	Time (t)	(t_i-t)	$(t_i-t)^2$
12	273	-3.38	11.424
13	271	-5.38	28.944
14	265	-11.38	129.504
15	267	-9.38	87.984
16	277	0.62	0.384
17	279	2.62	6.864
18	272	-4.38	19.184
19	284	7.62	58.064
20	285	8.62	74.304
21	269	-7.38	54.464
22	271	-5.38	28.944
23	280	3.62	13.104
24	283	6.62	43.824
25	278	1.62	2.624
26	266	-10.38	107.744
27	281	4.62	21.344
28	282	5.62	31.584
29	275	-1.38	1.904
30	262	-14.38	206.784
31	275	-1.38	1.904
32	268	-8.38	70.224
33	266	-10.38	107.744
34	261	-15.38	236.544
35	268	-8.38	70.224
36	271	-5.38	28.944
37	276	-0.38	0.144
38	279	2.62	6.864
39	300	23.62	557.904

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
40	266	-10.38	107.734
41	276	-0.38	0.144
42	278	1.62	2.624
43	260	-16.38	268.304
44	279	2.62	6.864
45	266	-10.38	107.744
46	289	12.62	159.264
47	309	32.62	1064.064
48	301	24.62	606.144
49	290	13.62	185.504
50	269	-7.38	54.464

Table 10: 277.21

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
1	276	-1.21	1.464
2	260	-17.21	296.184
3	259	-18.21	331.604
4	321	43.79	1917.564
5	268	-9.21	84.824
6	267	-10.21	104.244
7	269	-8.21	67.404
8	277	-0.21	0.044
9	288	10.79	116.424
10	268	-9.21	84.824
11	299	21.79	474.804
12	273	-4.21	17.724
13	271	-6.21	38.564
14	265	-12.21	149.084
15	267	-10.21	104.244

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
16	277	-0.21	0.044
17	279	1.79	3.204
18	272	-5.21	27.144
19	284	6.79	46.104
20	285	7.79	60.684
21	269	-8.21	67.404
22	271	-6.21	38.564
23	280	2.79	7.784
24	283	5.79	33.524
25	278	0.79	0.624
26	266	-11.21	125.664
27	281	3.79	14.364
28	282	4.79	22.944
29	275	-2.21	4.884
30	262	-15.21	231.344
31	275	-2.21	4.884
32	268	-9.21	84.824
33	266	-11.21	125.664
34	261	-16.21	262.764
35	268	-9.21	84.824
36	271	-6.21	38.564
37	276	-1.21	1.464
38	279	1.79	3.204
39	300	22.79	519.384
40	266	-11.21	125.664
41	276	-1.21	1.464
42	278	0.79	0.624
43	260	-17.21	296.184

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
44	279	1.79	3.204
45	266	-11.21	125.664
46	289	11.79	139.004
47	309	31.79	1010.604
48	301	23.79	565.964
49	290	12.79	163.584
50	269	-8.21	67.404
51	274	-3.21	10.304
52	271	-6.21	38.564
53	290	12.79	163.584
54	271	-6.21	38.564
55	274	-3.21	10.304
56	288	10.79	116.424
57	281	3.79	14.364
58	299	21.79	474.804
59	279	1.79	3.204
60	287	9.79	95.844

Table 11: Element 7 (loading the reel at the payoff section and tying with the existing wire) (303.84)

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
1	302	-1.84	3.3856
2	298	-5.84	34.1056
3	295	-8.84	78.1456
4	304	0.16	0.0256
5	309	5.16	26.6256
6	311	7.16	51.2656
7	297	-6.84	46.7856
8	308	4.16	17.3056
9	312	8.16	66.5856

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
10	301	-2.84	8.0656
11	325	21.16	447.7456
12	312	8.16	66.5856
13	301	-2.84	8.0656
14	280	-23.84	568.3456
15	305	1.16	1.3456
16	315	11.16	124.5456
17	291	-12.84	164.8656
18	309	5.16	26.6256
19	303	-0.84	0.7056
20	301	-2.84	8.0656
21	310	6.16	37.9456
22	301	-2.84	8.0656
23	301	-2.84	8.0656
24	311	7.16	51.2656
25	309	5.16	26.6256
26	310	6.16	37.9456
27	307	3.16	9.9856
28	306	2.16	4.6656
29	305	1.16	1.3456
30	297	-6.84	46.7856
31	309	5.16	26.6256
32	293	-10.84	117.5056
33	280	-23.84	568.3456
34	299	-4.84	23.4256
35	317	13.16	173.1856
36	306	2.16	4.6656
37	301	-2.84	8.0656

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
38	301	-2.84	8.0656
39	309	5.16	26.6256
40	308	4.16	17.3056
41	299	-4.84	23.4256
42	311	7.16	51.2656
43	308	4.16	17.3056
44	306	2.16	4.6656
45	306	2.16	4.6656
46	307	3.16	9.9856
47	287	-16.84	283.5856
48	290	-13.84	191.5456
49	313	9.16	83.9056
50	306	2.16	4.6656

Table 12: Element 8: (Primary centering while flushing the barrel)

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
1	587	-3.82	14.5924
2	613	22.18	491.9524
3	609	18.18	330.5124
4	611	20.18	407.2324
5	591	0.18	0.0324
6	582	-8.82	77.7924
7	621	30.18	910.8324
8	589	-1.82	3.3124
9	612	21.18	448.5924
10	582	-8.82	77.7924
11	601	10.18	103.6324
12	597	6.18	38.1924
13	617	26.18	685.3924

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
14	578	-12.82	164.3524
15	510	-80.82	6531.872
16	607	16.18	261.7924
17	602	11.18	124.9924
18	618	27.18	738.7524
19	589	-1.82	3.3124
20	599	8.18	66.9124
21	594	3.18	10.1124
22	592	1.18	1.3924
23	588	-2.82	7.9524
24	606	15.18	230.4324
25	459	-131.82	17376.51
26	594	3.18	10.1124
27	603	12.18	148.3524
28	621	30.18	910.8324
29	597	6.18	38.1924
30	586	-4.82	23.2324
31	602	11.18	124.9924
32	612	21.18	448.5924
33	595	4.18	17.4724
34	499	-91.82	8430.912
35	605	14.18	201.0724
36	612	21.18	448.5924
37	607	16.18	261.7924
38	613	22.18	491.9524
39	489	-101.82	10367.31
40	618	27.18	738.7524
41	590	-0.82	0.6724

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
42	593	2.18	4.7524
43	631	40.18	1614.432
44	498	-92.82	8615.552
45	604	13.18	173.7124
46	609	18.18	330.5124
47	570	-20.82	433.4724
48	611	20.18	407.2324
49	607	16.18	261.7924
50	621	30.18	910.8324

Table 13: Element

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
1	587	-7.43	55.2049
2	613	18.57	344.8449
3	609	14.57	212.2849
4	611	16.57	274.5649
5	591	-3.43	11.7649
6	582	-12.43	154.5049
7	621	26.57	705.9649
8	589	-5.43	29.4849
9	612	17.57	308.7049
10	582	-12.43	154.5049
11	601	6.57	43.1649
12	597	2.57	6.6049
13	617	22.57	509.4049
14	578	-16.43	269.9449
15	510	-84.43	7128.425
16	607	12.57	158.0049
17	602	7.57	57.3049

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
18	618	23.57	555.5449
19	589	-5.43	29.4849
20	599	4.57	20.8849
21	594	-0.43	0.1849
22	592	-2.43	5.9049
23	588	-6.43	41.3449
24	606	11.57	133.8649
25	459	-135.43	18341.28
26	594	-0.43	0.1849
27	603	8.57	73.4449
28	621	26.57	705.9649
29	597	2.57	6.6049
30	586	-8.43	71.0649
31	602	7.57	57.3049
32	612	17.57	308.7049
33	595	0.57	0.3249
34	499	-95.43	9106.885
35	605	10.57	111.7249
36	612	17.57	308.7049
37	607	12.57	158.0049
38	613	18.57	344.8449
39	489	-105.43	11115.48
40	618	23.57	555.5449
41	590	-4.43	19.6249
42	593	-1.43	2.0449
43	631	36.57	1337.365
44	498	-96.43	9298.745
45	604	9.57	91.5849

No.	Time (t)	(t_i-t)	$(t_i-t)^2$
46	609	14.57	212.2849
47	570	-24.43	596.8249
48	611	16.57	274.5649
49	607	12.57	158.0049
50	621	26.57	705.9649
51	617	22.57	509.4049
52	604	9.57	91.5849
53	591	-3.43	11.7649
54	578	-16.43	269.9449
55	610	15.57	242.4249
56	619	24.57	603.6849
57	488	-106.43	11327.34
58	608	13.57	184.1449
59	606	11.57	133.8649
60	601	6.57	43.1649
61	614	19.57	382.9849
62	631	36.57	1337.365
63	607	12.57	158.0049
64	616	21.57	465.2649
65	498	-96.43	9298.745
66	594	-0.43	0.1849
67	612	17.57	308.7049
68	611	16.57	274.5649
69	591	-3.43	11.7649
70	627	32.57	1060.805
71	630	35.57	1265.225
72	662	67.57	4565.705
73	609	14.57	212.2849

No.	Time (t)	(t_i-t)	(t_i-t)^2
74	599	4.57	20.8849
75	592	-2.43	5.9049
76	621	26.57	705.9649

Table 14: Element 9 (Start line at low speeds and continues with centering)

No.	Time (t)	(t_i-t)	(t_i-t)^2
1	515	10.06	101.2036
2	410	-94.94	9013.604
3	488	-16.94	286.9636
4	610	105.06	11037.6
5	500	-4.94	24.4036
6	509	4.06	16.4836
7	519	14.06	197.6836
8	511	6.06	36.7236
9	389	-115.94	13442.08
10	513	8.06	64.9636
11	519	14.06	197.6836
12	370	-134.94	18208.8
13	502	-2.94	8.6436
14	522	17.06	291.0436
15	500	-4.94	24.4036
16	489	-15.94	254.0836
17	541	36.06	1300.324
18	519	14.06	197.6836
19	521	16.06	257.9236
20	501	-3.94	15.5236
21	530	25.06	628.0036
22	482	-22.94	526.2436
23	503	-1.94	3.7636

No.	Time (t)	(t_i-t)	(t_i-t)^2
24	509	4.06	16.4836
25	522	17.06	291.0436
26	508	3.06	9.3636
27	473	-31.94	1020.164
28	511	6.06	36.7236
29	502	-2.94	8.6436
30	514	9.06	82.0836
31	512	7.06	49.8436
32	501	-3.94	15.5236
33	511	6.06	36.7236
34	542	37.06	1373.444
35	520	15.06	226.8036
36	513	8.06	64.9636
37	515	10.06	101.2036
38	509	4.06	16.4836
39	503	-1.94	3.7636
40	492	-12.94	167.4436
41	499	-5.94	35.2836
42	510	5.06	25.6036
43	509	4.06	16.4836
44	491	-13.94	194.3236
45	577	72.06	5192.644
46	524	19.06	363.2836
47	504	-0.94	0.8836
48	497	-7.94	63.0436
49	499	-5.94	35.2836
50	517	12.06	145.4436

Table 15: Element

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
1	515	1.68	2.8224
2	410	-103.32	10675.02
3	488	-25.32	641.1024
4	610	96.68	9347.022
5	500	-13.32	177.4224
6	509	-4.32	18.6624
7	519	5.68	32.2624
8	511	-2.32	5.3824
9	389	-124.32	15455.46
10	513	-0.32	0.1024
11	519	5.68	32.2624
12	370	-143.32	20540.62
13	502	-11.32	128.1424
14	522	8.68	75.3424
15	500	-13.32	177.4224
16	489	-24.32	591.4624
17	541	27.68	766.1824
18	519	5.68	32.2624
19	521	7.68	58.9824
20	501	-12.32	151.7824
21	530	16.68	278.2224
22	482	-31.32	980.9424
23	503	-10.32	106.5024
24	509	-4.32	18.6624
25	522	8.68	75.3424
26	508	-5.32	28.3024
27	473	-40.32	1625.702

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
28	511	-2.32	5.3824
29	502	-11.32	128.1424
30	514	0.68	0.4624
31	512	-1.32	1.7424
32	501	-12.32	151.7824
33	511	-2.32	5.3824
34	542	28.68	822.5424
35	520	6.68	44.6224
36	513	-0.32	0.1024
37	515	1.68	2.8224
38	509	-4.32	18.6624
39	503	-10.32	106.5024
40	492	-21.32	454.5424
41	499	-14.32	205.0624
42	510	-3.32	11.0224
43	509	-4.32	18.6624
44	491	-22.32	498.1824
45	577	63.68	4055.142
46	524	10.68	114.0624
47	504	-9.32	86.8624
48	497	-16.32	266.3424
49	499	-14.32	205.0624
50	517	3.68	13.5424
51	514	0.68	0.4624
52	495	-18.32	335.6224
53	554	40.68	1654.862
54	499	-14.32	205.0624
55	601	87.68	7687.782

No.	Time (t)	$(t_i\text{-}t)$	$(t_i\text{-}t)^2$
56	392	-121.32	14718.54
57	532	18.68	348.9424
58	489	-24.32	591.4624
59	602	88.68	7864.142
60	479	-34.32	1177.862
61	589	75.68	5727.462
62	492	-21.32	454.5424
63	533	19.68	387.3024
64	511	-2.32	5.3824
65	517	3.68	13.5424
66	521	7.68	58.9824
67	620	106.68	11380.62
68	503	-10.32	106.5024
69	548	34.68	1202.702
70	601	87.68	7687.782
71	519	5.68	32.2624
72	497	-16.32	266.3424
73	526	12.68	160.7824
74	612	98.68	9737.742
75	521	7.68	58.9824
76	499	-14.32	205.0624

APPENDIX O

Table: ILO Recommendation of Relaxation Allowances

(as the percent of Basic Time)

A. Constant allowances:	5
1. Personal allowance	4
2. Basic fatigue allowance	
B. Variable allowances:	
1. Standing allowance	2
2. Abnormal position allowance:	
a. Slightly awkward	0
b. Awkward (bending)	2
c. Very awkward (lying, stretching)	7
3. Use of force, or muscular energy (lifting, pulling, or pushing):	
Weight lifted, pounds:	
5	0
10	1
15	2
20	3
25	4
30	5
35	7
40	9
45	11
50	13
60	17
70	22
4. Bad light:	
a. Slightly below recommended	0
b. Well below	2
c. Quite inadequate	5
5. Atmospheric conditions (heat and humidity)- variable	0-100
6. Close attention:	
a. Fairly fine work	0
b. Fine or exacting	2
c. Very fine or very exacting	5
7. Noise level:	
a. Continuous	0
b. Intermittent - loud	2
c. Intermittent - very loud	5

Industrial Engineering lab (UTM): Retrieve online from

http://industrialengineeringlabutm.blogspot.com/2011/02/table-of-allowance.html

APPENDIX P

Test Results for I Chart of Subgroup Means of Cable Dimension

I-MR-R/S (Between/Within) Chart of Shift 1

I-MR-R/S Standard Deviations of Shift 1

Standard Deviations

Between 0.0000000
Within 0.0036113
Between/Within 0.0036113

* WARNING * If graph is updated with new data, the results above may no
* longer be correct.

I-MR-R/S (Between/Within) Chart of Shift 2

I-MR-R/S Standard Deviations of Shift 2

Standard Deviations

Between 0.0045014
Within 0.0068788
Between/Within 0.0082207

* WARNING * If graph is updated with new data, the results above may no
* longer be correct.

I-MR-R/S (Between/Within) Chart of Shift 3

I-MR-R/S Standard Deviations of Shift 3

Standard Deviations

Between 0.0025759
Within 0.0042132
Between/Within 0.0049383

* WARNING * If graph is updated with new data, the results above may no
* longer be correct.

I-MR-R/S (Between/Within) Chart of Shift 4

I-MR-R/S Standard Deviations of Shift 4

Standard Deviations

Between 0.0039838
Within 0.0049871
Between/Within 0.0063829

* WARNING * If graph is updated with new data, the results above may no
* longer be correct.

I-MR-R/S (Between/Within) Chart of Shift 5

I-MR-R/S Standard Deviations of Shift 5

Standard Deviations

Between 0.0000000
Within 0.0056750
Between/Within 0.0056750

* WARNING * If graph is updated with new data, the results above may no
* longer be correct.

I-MR-R/S (Between/Within) Chart of Shift 6

I-MR-R/S Standard Deviations of Shift 6

Standard Deviations

Between 0.0062028
Within 0.0041273
Between/Within 0.0074505

* WARNING * If graph is updated with new data, the results above may no
* longer be correct.

I-MR-R/S (Between/Within) Chart of Shift 7

I-MR-R/S Standard Deviations of Shift 7

Standard Deviations

Between 0.0042726
Within 0.0041273
Between/Within 0.0059405

* WARNING * If graph is updated with new data, the results above may no
* longer be correct.

I-MR-R/S (Between/Within) Chart of Shift 8

I-MR-R/S Standard Deviations of Shift 8

Standard Deviations

Between 0.0030873
Within 0.0053310
Between/Within 0.0061605

* WARNING * If graph is updated with new data, the results above may no
* longer be correct.

I-MR-R/S (Between/Within) Chart of Shift 9

I-MR-R/S Standard Deviations of Shift 9

Standard Deviations

Between 0.0000000
Within 0.0073947
Between/Within 0.0073947

* WARNING * If graph is updated with new data, the results above may no
* longer be correct.

APPENDIX Q

Generic Graphical User Interface Computational Analysis

```
%% Improving a Cable Design for Six Sigma Techniques
%
% The application is used to improve the Cable production
% using Design for Six Sigma Techniques.  The popular Define, Measure,
% Analyze, Improve, and Control (DMAIC) Six Sigma approach is followed.
%
%1. Setting Tab:
% - Click Load
% - Select Defects excel file from your PC
% - Click Save Settings
% - To make changes - Click Edit Settings, Make Changes, Click Save Settings
%
%2. Problem Definition Tab:
% - Click Analyze Loaded Data
% - Wait for the analysis to be completed
% - Click plot buttons to view plots
% - Check the panel to see the summary
%
%3. Data Collection Tab:
% - Load Data by clicking load button as enabled
% - Type data name
% - Edit LSL, USL and Target
% - Load Input Data
% - Click on Collect Data button
% - To make changes - Click on Reload data button, Make changes, Click on Collect Data button
%
%4. Data Analysis Tab:
% - Click Analyze Loaded Data
% - Wait for the analysis to be completed
% - Click plot buttons to view plots
% - Check the panel to see the summary
%
%5. Improvement Tab:
% - Click on Improve Loaded Data
% - Wait for the improvement to be completed
% - Click plot buttons to view plots
% - Check the panel to see the summary
%
% 6. Others
% - Help - Click Help button for guide
% - Restart - Click Restart button to start from beginning
% - Close - Click Close button to exit

%Initializing
check=findobj('Name','Knowledge Based Design with Six Sigma');

close(check);
clear;
%Figure
f = figure('Name','Knowledge Based Design with Six Sigma',...
    'NumberTitle','off',...
    'Position',[200 80 800 650],...
    'Resize','off',...
'MenuBar','none');
```

```
tabgp = uitabgroup(f,'Position',[.05 0.15 0.9 0.8]);
tab1 = uitab(tabgp,'Title','Settings','Tag','tab1');
tab2 = uitab(tabgp,'Title','Problem Definition','Tag','tab2');
tab3 = uitab(tabgp,'Title','Data Collection ','Tag','tab3');
tab4 = uitab(tabgp,'Title','Data Analysis ','Tag','tab4');
tab5 = uitab(tabgp,'Title','Improvement ','Tag','tab5');

%Control
 helpbtn = uicontrol(f,'Style','pushbutton','Position',[50 30 140 22],'String',...
    'Help', 'HorizontalAlignment','center','Callback',@help_callback,'Tag','helpbtn');
 closebtn = uicontrol(f,'Style','pushbutton','Position',[600 30 140 22],'String',...
    'Close', 'HorizontalAlignment','center','Callback',@close_callback,...
    'Tag','closebtn');
 restartbtn = uicontrol(f,'Style','pushbutton','Position',[330 30 140 22],'String',...
    'Restart', 'HorizontalAlignment','center','Callback',@restart_callback,...
    'Tag','restartbtn');

%% Setting Tab
%Historical Period
yrtxt = uicontrol(tab1,'Style','text','Position',[11 450 240 22],'String',...
    'Period of Historical Data Anaylsis', 'HorizontalAlignment','left',...
    'FontWeight','bold');
sdtxt = uicontrol(tab1,'Style','text','Position',[11 425 140 22],'String','Start Date:',...
    'HorizontalAlignment','right');
startdate = uicontrol(tab1,'Style','popupmenu','Position',[154 425 140 22],'String',...
    {'2010','2011','2012','2013','2014','2015','2016','2017','2018'},'Value',4,...
    'Backgroundcolor','white','Enable','off','Tag','startdate');
edtxt = uicontrol(tab1,'Style','text','Position',[11 400 140 22],'String','End Date:',...
    'HorizontalAlignment','right');
enddate = uicontrol(tab1,'Style','popupmenu','Position',[154 400 140 22],'String',...
    {'2010','2011','2012','2013','2014','2015','2016','2017','2018','2019'},'Value',8,...
    'Backgroundcolor','white','Enable','off','Tag','enddate');

%Bench Mark
bmtxt = uicontrol(tab1,'Style','text','Position',[11 350 240 22],'String',...
    'Defect Cost Bench Mark for Improvement', 'HorizontalAlignment','left',...
     'FontWeight','bold');
cbmtxt = uicontrol(tab1,'Style','text','Position',[11 325 140 22],'String',...
    'Bench Mark Amount:', 'HorizontalAlignment','right');
cbm = uicontrol(tab1,'Style','edit','Position',[154 325 140 22],'String','500000',...
    'HorizontalAlignment','left','Backgroundcolor','white','Enable','off','Tag','cbm');
ngntxt = uicontrol(tab1,'Style','text','Position',[300 325 50 22],'String',...
    'NGN', 'HorizontalAlignment','left');

%Load Historical Data
bmtxt = uicontrol(tab1,'Style','text','Position',[11 275 240 22],'String',...
    'Load Historical Data', 'HorizontalAlignment','left',...
     'FontWeight','bold');
 histedit = uicontrol(tab1,'Style','edit','Position',[11 250 400 22],'String',...
    'Load data', 'HorizontalAlignment','left','Backgroundcolor','white','Enable','off',...
    'Tag','histedit');
 histbtn = uicontrol(tab1,'Style','pushbutton','Position',[425 250 50 22],'String',...
    'Load', 'HorizontalAlignment','center','Callback',@hist_callback,'Tag','histbtn');

%Setting Control
 editsetbtn = uicontrol(tab1,'Style','pushbutton','Position',[11 25 140 22],'String',...
    'Edit Settings', 'HorizontalAlignment','center','Callback',@editset_callback,'Tag','editsetbtn');
 savesetbtn = uicontrol(tab1,'Style','pushbutton','Position',[550 25 140 22],'String',...
    'Save Settings', 'HorizontalAlignment','center','Callback',@saveset_callback,...
```

```
    'Enable','off','Tag','savesetbtn');
%% Define Problem Tab
defntxt = uicontrol(tab2,'Style','text','Position',[11 450 600 22],'String',...
    'No Historical Data Load, Click on Setting tab to Load',...
    'HorizontalAlignment','left','FontWeight','bold','Tag','defntxt','ForegroundColor','red');

defnlistbox = uicontrol(tab2,'Style','listbox','Position',[250 75 435 350],'Enable','off',...
    'HorizontalAlignment','left','Backgroundcolor','white','String','Defined Problem',...
    'Tag','defnlistbox');
 analyzebtn = uicontrol(tab2,'Style','pushbutton','Position',[550 25 140 22],'String',...
    'Analyze Loaded Data', 'HorizontalAlignment','center','Callback',@analyze_callback,...
    'Tag','analyzebtn','Enable','off');

 plottxt = uicontrol(tab2,'Style','text','Position',[11 400 220 22],'String',...
    'PLOTS ', 'HorizontalAlignment','center','Tag','plottxt','FontWeight','bold');
 plotdbtn = uicontrol(tab2,'Style','pushbutton','Position',[11 375 220 22],'String',...
    'Defects 3D Bar Chart ', 'HorizontalAlignment','center','Callback',@plotdbtn_callback,...
    'Tag','plotdbtn','Enable','off');

 plotfbtn = uicontrol(tab2,'Style','pushbutton','Position',[11 350 220 22],'String',...
    'Defect Cost 3D Bar Chart ', 'HorizontalAlignment','center','Callback',@plotfbtn_callback,...
    'Enable','off','Tag','plotfbtn');
plotxbtn = uicontrol(tab2,'Style','pushbutton','Position',[11 325 220 22],'String',...
    'X-Bar and R-Bar Chart ', 'HorizontalAlignment','center','Callback',@plotxbtn_callback,...
   'Enable','off','Tag','plotxbtn');
plotdpbtn = uicontrol(tab2,'Style','pushbutton','Position',[11 300 220 22],'String',...
    'Defects Pareto Chart ', 'HorizontalAlignment','center','Callback',@plotdpbtn_callback,...
    'Enable','off','Tag','plotdpbtn');
plotfpbtn = uicontrol(tab2,'Style','pushbutton','Position',[11 275 220 22],'String',...
    'Defects Cost Pareto Chart ', 'HorizontalAlignment','center','Callback',@plotfpbtn_callback,...
    'Enable','off','Tag','plotfpbtn');
defnresultbtn = uicontrol(tab2,'Style','pushbutton','Position',[11 250 220 22],'String',...
    'Problem-Defined Summary ', 'HorizontalAlignment','center','Callback',@defnresult_callback,...
    'Enable','off','Tag','defnresultbtn');
 histfitbtn = uicontrol(tab2,'Style','pushbutton','Position',[11 225 220 22],'String',...
    'Finance Data Hist Fit ', 'HorizontalAlignment','center','Callback',@histfitbtn_callback,...
    'Tag','histfitbtn','Enable','off');
%% Data Collection Tab
datatxt = uicontrol(tab3,'Style','text','Position',[11 450 600 22],'String',...
    'Load Problem Defined Data for Improvement -Maximum Data is Three',...
    'HorizontalAlignment','left','FontWeight','bold','Tag','datatxt','ForegroundColor','red');

% Load Data 1
datatxt1 = uicontrol(tab3,'Style','edit','Position',[11 400 140 22],'String',...
    'Data 1', 'HorizontalAlignment','right','Tag','datatxt1','Callback',...
    @datatxt1_callback,'Enable','off');
 dataedit1 = uicontrol(tab3,'Style','edit','Position',[151 400 400 22],'String',...
    '', 'HorizontalAlignment','left','Backgroundcolor','white','Enable','off',...
    'Tag','dataedit1');
 databtn1 = uicontrol(tab3,'Style','pushbutton','Position',[560 400 50 22],'String',...
    'Load','Enable','off', 'HorizontalAlignment','center','Callback',@databtn1_callback,'Tag','databtn1');

% Load Data 2
datatxt2 = uicontrol(tab3,'Style','edit','Position',[11 375 140 22],'String',...
    'Data 2', 'HorizontalAlignment','right','Tag','datatxt2','Callback',...
    @datatxt2_callback,'Enable','off');
 dataedit2 = uicontrol(tab3,'Style','edit','Position',[151 375 400 22],'String',...
    '', 'HorizontalAlignment','left','Backgroundcolor','white','Enable','off',...
    'Tag','dataedit2');
```

```
 databtn2 = uicontrol(tab3,'Style','pushbutton','Position',[560 375 50 22],'String',...
    'Load','Enable','off','HorizontalAlignment','center','Callback',@databtn2_callback,'Tag','databtn2');


% Load Data 3
datatxt3 = uicontrol(tab3,'Style','edit','Position',[11 350 140 22],'String',...
    'Data 3', 'HorizontalAlignment','right','Tag','datatxt3','Callback',...
    @datatxt3_callback,'Enable','off');
 dataedit3 = uicontrol(tab3,'Style','edit','Position',[151 350 400 22],'String',...
    '', 'HorizontalAlignment','left','Backgroundcolor','white','Enable','off',...
    'Tag','dataedit3');
 databtn3 = uicontrol(tab3,'Style','pushbutton','Position',[560 350 50 22],'String',...
    'Load','Enable','off', 'HorizontalAlignment','center','Callback',@databtn3_callback,'Tag','databtn3');
inputtxt = uicontrol(tab3,'Style','text','Position',[11 175 140 22],'String',...
    'Extruder and Captan Data:', 'FontWeight','bold','HorizontalAlignment','right');
datatxt4 = uicontrol(tab3,'Style','text','Position',[11 150 140 22],'String',...
    'Input Data', 'HorizontalAlignment','right','Tag','datatxt4');
 dataedit4 = uicontrol(tab3,'Style','edit','Position',[151 150 400 22],'String',...
    'Load Extruder and Captans Data', 'HorizontalAlignment','left','Backgroundcolor','white','Enable','off',...
    'Tag','dataedit4');
 databtn4 = uicontrol(tab3,'Style','pushbutton','Position',[560 150 50 22],'String',...
    'Load','Enable','off', 'HorizontalAlignment','center','Callback',@databtn4_callback,'Tag','databtn4');

%Specification
%data1 control
spectxt = uicontrol(tab3,'Style','text','Position',[11 300 140 22],'String',...
    'Specification Control:', 'FontWeight','bold','HorizontalAlignment','right');
spectxt1 = uicontrol(tab3,'Style','text','Position',[11 275 70 22],'String',...
    'Data 1', 'HorizontalAlignment','right','Tag','spectxt1');
uptxt1 = uicontrol(tab3,'Style','text','Position',[90 275 70 22],'String',...
    'LSL:', 'HorizontalAlignment','right');
lwtedit1 = uicontrol(tab3,'Style','edit','Position',[170 275 70 22],'String','',...
    'HorizontalAlignment','left','Backgroundcolor','white','Enable','off','Tag','lwtedit1');
uptxt2 = uicontrol(tab3,'Style','text','Position',[240 275 70 22],'String',...
    'USL:', 'HorizontalAlignment','right');
upedit2 = uicontrol(tab3,'Style','edit','Position',[320 275 70 22],'String','',...
    'HorizontalAlignment','left','Backgroundcolor','white','Enable','off','Tag','upedit2');
ttxt1 = uicontrol(tab3,'Style','text','Position',[400 275 70 22],'String',...
    'Target:', 'HorizontalAlignment','right');
tedit1 = uicontrol(tab3,'Style','edit','Position',[480 275 70 22],'String','',...
    'HorizontalAlignment','left','Backgroundcolor','white','Enable','off','Tag','tedit1');



%data2 control
spectxt2 = uicontrol(tab3,'Style','text','Position',[11 250 70 22],'String',...
    'Data 2', 'HorizontalAlignment','right','Tag','spectxt2');
uptxt12 = uicontrol(tab3,'Style','text','Position',[90 250 70 22],'String',...
    'LSL:', 'HorizontalAlignment','right');
lwtedit12 = uicontrol(tab3,'Style','edit','Position',[170 250 70 22],'String','',...
    'HorizontalAlignment','left','Backgroundcolor','white','Enable','off','Tag','lwtedit12');
uptxt22 = uicontrol(tab3,'Style','text','Position',[240 250 70 22],'String',...
    'USL:', 'HorizontalAlignment','right');
upedit22 = uicontrol(tab3,'Style','edit','Position',[320 250 70 22],'String','',...
    'HorizontalAlignment','left','Backgroundcolor','white','Enable','off','Tag','upedit22');
ttxt2 = uicontrol(tab3,'Style','text','Position',[400 250 70 22],'String',...
    'Target:', 'HorizontalAlignment','right');
tedit2 = uicontrol(tab3,'Style','edit','Position',[480 250 70 22],'String','',...
    'HorizontalAlignment','left','Backgroundcolor','white','Enable','off','Tag','tedit2');
```

```
%data3 control
spectxt3 = uicontrol(tab3,'Style','text','Position',[11 225 70 22],'String',...
    'Data 3', 'HorizontalAlignment','right','Tag','spectxt3');
uptxt13 = uicontrol(tab3,'Style','text','Position',[90 225 70 22],'String',...
    'LSL:', 'HorizontalAlignment','right');
lwtedit13 = uicontrol(tab3,'Style','edit','Position',[170 225 70 22],'String','',...
    'HorizontalAlignment','left','Backgroundcolor','white','Enable','off','Tag','lwtedit13');
uptxt23 = uicontrol(tab3,'Style','text','Position',[240 225 70 22],'String',...
    'USL:', 'HorizontalAlignment','right');
upedit23 = uicontrol(tab3,'Style','edit','Position',[320 225 70 22],'String','',...
    'HorizontalAlignment','left','Backgroundcolor','white','Enable','off','Tag','upedit23');
ttxt3 = uicontrol(tab3,'Style','text','Position',[400 225 70 22],'String',...
    'Target:', 'HorizontalAlignment','right');
tedit3 = uicontrol(tab3,'Style','edit','Position',[480 225 70 22],'String','',...
    'HorizontalAlignment','left','Backgroundcolor','white','Enable','off','Tag','tedit3');



% Data Collection Control
 reloaddatabtn = uicontrol(tab3,'Style','pushbutton','Position',[11 25 140 22],'String',...
    'Reload
Data','Enable','off','HorizontalAlignment','center','Callback',@reloaddata_callback,'Tag','reloaddatabtn');
 collectdatabtn = uicontrol(tab3,'Style','pushbutton','Position',[550 25 140 22],'String',...
    'Collect Data', 'HorizontalAlignment','center','Callback',@collectdata_callback,...
    'Enable','off','Tag','collectdatabtn');

%% Data Analysis Tab
anatxt = uicontrol(tab4,'Style','text','Position',[11 450 600 22],'String',...
    'No Data Loaded for Analysis, Click on Data Collection tab to Load',...
    'HorizontalAlignment','left','FontWeight','bold','Tag','anatxt','ForegroundColor','red');

analistbox = uicontrol(tab4,'Style','listbox','Position',[250 75 435 350],'Enable','off',...
    'HorizontalAlignment','left','Backgroundcolor','white','String','Data Analysis',...
    'Tag','analistbox');
 analyzebtn2 = uicontrol(tab4,'Style','pushbutton','Position',[550 25 140 22],'String',...
    'Analyze Loaded Data', 'HorizontalAlignment','center','Callback',@analyze2_callback,...
    'Tag','analyzebtn2','Enable','off');

 plottxt2 = uicontrol(tab4,'Style','text','Position',[11 400 220 22],'String',...
    'PLOTS ', 'HorizontalAlignment','center','Tag','plottxt2','FontWeight','bold');
 expbtn = uicontrol(tab4,'Style','pushbutton','Position',[11 375 220 22],'String',...
    'View Experimental Data ', 'HorizontalAlignment','center','Callback',@expbtn_callback,...
    'Tag','expbtn','Enable','off');

plotxbtn2 = uicontrol(tab4,'Style','pushbutton','Position',[11 350 220 22],'String',...
    'X-Bar and R-Bar Chart 1 ', 'HorizontalAlignment','center','Callback',@plotxbtn2_callback,...
    'Enable','off','Tag','plotxbtn2');
plotxbtn21 = uicontrol(tab4,'Style','pushbutton','Position',[11 325 220 22],'String',...
    'X-Bar and R-Bar Chart 2 ', 'HorizontalAlignment','center','Callback',@plotxbtn21_callback,...
   'Enable','off','Tag','plotxbtn21');
plotxbtn22 = uicontrol(tab4,'Style','pushbutton','Position',[11 300 220 22],'String',...
    'X-Bar and R-Bar Chart 3 ', 'HorizontalAlignment','center','Callback',@plotxbtn22_callback,...
    'Enable','off','Tag','plotxbtn22');
histfitbtn1 = uicontrol(tab4,'Style','pushbutton','Position',[11 275 220 22],'String',...
    'Histogram Fit 1 ', 'HorizontalAlignment','center','Callback',@histfitbtn1_callback,...
    'Enable','off','Tag','histfitbtn1');
```

```
histfitbtn2 = uicontrol(tab4,'Style','pushbutton','Position',[11 250 220 22],'String',...
    'Histogram Fit 2 ', 'HorizontalAlignment','center','Callback',@histfitbtn2_callback,...
    'Enable','off','Tag','histfitbtn2');
histfitbtn3 = uicontrol(tab4,'Style','pushbutton','Position',[11 225 220 22],'String',...
    'Histogram Fit 3 ', 'HorizontalAlignment','center','Callback',@histfitbtn3_callback,...
    'Enable','off','Tag','histfitbtn3');

probplotbtn1 = uicontrol(tab4,'Style','pushbutton','Position',[11 200 220 22],'String',...
    'Probability Plot 1 ', 'HorizontalAlignment','center','Callback',@probplotbtn1_callback,...
    'Enable','off','Tag','probplotbtn1');
probplotbtn2 = uicontrol(tab4,'Style','pushbutton','Position',[11 175 220 22],'String',...
    'Probability Plot 2 ', 'HorizontalAlignment','center','Callback',@probplotbtn2_callback,...
    'Enable','off','Tag','probplotbtn2');
probplotbtn3 = uicontrol(tab4,'Style','pushbutton','Position',[11 150 220 22],'String',...
    'Probability Plot 3 ', 'HorizontalAlignment','center','Callback',@probplotbtn3_callback,...
    'Enable','off','Tag','probplotbtn3');

capaplotbtn1 = uicontrol(tab4,'Style','pushbutton','Position',[11 125 220 22],'String',...
    'Capability Plot 1 ', 'HorizontalAlignment','center','Callback',@capaplotbtn1_callback,...
    'Enable','off','Tag','capaplotbtn1');
capaplotbtn2 = uicontrol(tab4,'Style','pushbutton','Position',[11 100 220 22],'String',...
    'Capability Plot 2 ', 'HorizontalAlignment','center','Callback',@capaplotbtn2_callback,...
    'Enable','off','Tag','capaplotbtn2');
capaplotbtn3 = uicontrol(tab4,'Style','pushbutton','Position',[11 75 220 22],'String',...
    'Capability Plot 3 ', 'HorizontalAlignment','center','Callback',@capaplotbtn3_callback,...
    'Enable','off','Tag','capaplotbtn3');
%% Improvement Tab
improvtxt = uicontrol(tab5,'Style','text','Position',[11 450 600 22],'String',...
    'No Data Loaded for Analysis, Click on Data Collection tab to Load',...
    'HorizontalAlignment','left','FontWeight','bold','Tag','improvtxt','ForegroundColor','red');

improvlistbox = uicontrol(tab5,'Style','listbox','Position',[250 75 435 350],'Enable','off',...
    'HorizontalAlignment','left','Backgroundcolor','white','String','Data Analysis',...
    'Tag','improvlistbox');
 improvbtn = uicontrol(tab5,'Style','pushbutton','Position',[550 25 140 22],'String',...
    'Improve Loaded Data', 'HorizontalAlignment','center','Callback',@improvbtn_callback,...
    'Tag','improvbtn','Enable','off');

 plottxt2 = uicontrol(tab5,'Style','text','Position',[11 400 220 22],'String',...
    'PLOTS ', 'HorizontalAlignment','center','Tag','plottxt2','FontWeight','bold');
 coeftestbtn = uicontrol(tab5,'Style','pushbutton','Position',[11 375 220 22],'String',...
    'View Coefficient Test 1 ', 'HorizontalAlignment','center','Callback',@coeftestbtn_callback,...
    'Tag','coeftestbtn','Enable','off');

coeftestbtn2 = uicontrol(tab5,'Style','pushbutton','Position',[11 350 220 22],'String',...
    'View Coefficient Test 2  ', 'HorizontalAlignment','center','Callback',@coeftestbtn2_callback,...
    'Enable','off','Tag','coeftestbtn2');
coeftestbtn3 = uicontrol(tab5,'Style','pushbutton','Position',[11 325 220 22],'String',...
    'View Coefficient Test 3 ', 'HorizontalAlignment','center','Callback',@coeftestbtn3_callback,...
   'Enable','off','Tag','coeftestbtn3');
predictbtn = uicontrol(tab5,'Style','pushbutton','Position',[11 300 220 22],'String',...
    'Optimize Data 1 ', 'HorizontalAlignment','center','Callback',@predictbtn_callback,...
    'Enable','off','Tag','predictbtn');
predictbtn2 = uicontrol(tab5,'Style','pushbutton','Position',[11 275 220 22],'String',...
    'Optimize Data 2 ', 'HorizontalAlignment','center','Callback',@predictbtn2_callback,...
    'Enable','off','Tag','predictbtn2');
predictbtn3 = uicontrol(tab5,'Style','pushbutton','Position',[11 250 220 22],'String',...
    'Optimize Data 3 ', 'HorizontalAlignment','center','Callback',@predictbtn3_callback,...
    'Enable','off','Tag','predictbtn3');
```

```
simdata1 = uicontrol(tab5,'Style','pushbutton','Position',[11 225 220 22],'String',...
    'View Simulation Data 1 ', 'HorizontalAlignment','center','Callback',@simdatabtn1_callback,...
    'Enable','off','Tag','simdatabtn1');

simdata2 = uicontrol(tab5,'Style','pushbutton','Position',[11 200 220 22],'String',...
    'View Simulation Data 2 ', 'HorizontalAlignment','center','Callback',@simdatabtn2_callback,...
    'Enable','off','Tag','simdatabtn2');
simdata3 = uicontrol(tab5,'Style','pushbutton','Position',[11 175 220 22],'String',...
    'View Simulation Data 3 ', 'HorizontalAlignment','center','Callback',@simdatabtn3_callback,...
    'Enable','off','Tag','simdatabtn3');
exportsimdata = uicontrol(tab5,'Style','pushbutton','Position',[11 150 220 22],'String',...
    'Export Sim Data ', 'HorizontalAlignment','center','Callback',@exportsimdata_callback,...
    'Enable','off','Tag','exportsimdata');

function help_callback(src,event)
htxt=help('cablekbsdesign');
f16=figure('Name','Knowledge Based Design with Six Sigma - Help',...
   'NumberTitle','off',...
    'Position',[200 50 600 700],...
    'Resize','off',...
'MenuBar','none');
helptxt = uicontrol(f16,'Style','text','Position',[50 50 500 620],'String','',...
    'HorizontalAlignment','left','Backgroundcolor','white','Enable','on','Tag','helptxt');
h2=findobj(f16,'Tag','helptxt');

      set(h2,'String',htxt);

function restart_callback(src,event)
cablekbsdesign;

function close_callback(src,event)
    fig=findobj('Type','figure');
close(fig);

%Edit Settings Button
function editset_callback(src,event)

b1=findobj('Tag','startdate');
b2=findobj('Tag','enddate');
b3=findobj('Tag','cbm');
b4=findobj('Tag','savesetbtn');
b5=findobj('Tag','editsetbtn');
set(b1,'Enable','on')
set(b2,'Enable','on')
set(b3,'Enable','on')
set(b4,'Enable','on')
set(b5,'Enable','off')

%Save Settings Button
function saveset_callback(src,event)
b1=findobj('Tag','startdate');
b2=findobj('Tag','enddate');
b3=findobj('Tag','cbm');
b4=findobj('Tag','savesetbtn');
b5=findobj('Tag','editsetbtn');
b6=findobj('Tag','analyzebtn');
b7=findobj('Tag','defntxt');
set(b1,'Enable','off')
set(b2,'Enable','off')
```

```
set(b3,'Enable','off')
set(b4,'Enable','off')
set(b5,'Enable','on')
set(b6,'Enable','on')
set(b7,'String',...
    'Click Analyze loaded Data button for historical data analysis and recommendation for improvement')

function reloaddata_callback(src,event)

b1=findobj('Tag','databtn1');
b2=findobj('Tag','databtn2');
b3=findobj('Tag','databtn3');
b4=findobj('Tag','collectdatabtn');
b5=findobj('Tag','datatxt');
b6=findobj('Tag','lwtedit1');
b7=findobj('Tag','lwtedit12');
b8=findobj('Tag','lwtedit13');
b9=findobj('Tag','upedit2');
b10=findobj('Tag','upedit22');
b11=findobj('Tag','upedit23');
b12=findobj('Tag','databtn4');
b13=findobj('Tag','tedit1');
b14=findobj('Tag','tedit2');
b15=findobj('Tag','tedit3');
b16=findobj('Tag','datatxt1');
b17=findobj('Tag','datatxt2');
b18=findobj('Tag','datatxt3');
set(b1,'Enable','on')
set(b2,'Enable','on')
set(b3,'Enable','on')
set(b4,'Enable','on')
set(b6,'Enable','on')
set(b7,'Enable','on')
set(b8,'Enable','on')
set(b9,'Enable','on')
set(b10,'Enable','on')
set(b11,'Enable','on')
set(b12,'Enable','on')
set(b13,'Enable','on')
set(b14,'Enable','on')
set(b15,'Enable','on')
set(b16,'Enable','on')
set(b17,'Enable','on')
set(b18,'Enable','on')
set(b5,'String','Load Problem Defined Data for Improvement -Maximum Data is Three')

%Collect Data Button
function collectdata_callback(src,event)

global bound1 bound2 bound3  defnprobs data1 data2 data3 data4 file1 ...
    file2 file3 file4 t1 t2 t3 dataname1 dataname2 dataname3
b1=findobj('Tag','databtn1');
b2=findobj('Tag','databtn2');
b3=findobj('Tag','databtn3');
b4=findobj('Tag','collectdatabtn');
b5=findobj('Tag','reloaddatabtn');
b6=findobj('Tag','datatxt');
b7=findobj('Tag','lwtedit1');
b8=findobj('Tag','lwtedit12');
```

```
b9=findobj('Tag','lwtedit13');
b10=findobj('Tag','upedit2');
b11=findobj('Tag','upedit22');
b12=findobj('Tag','upedit23');
b13=findobj('Tag','databtn4');
b14=findobj('Tag','tedit1');
b15=findobj('Tag','tedit2');
b16=findobj('Tag','tedit3');
b17=findobj('Tag','analyzebtn2');
b18=findobj('Tag','datatxt1');
b19=findobj('Tag','datatxt2');
b20=findobj('Tag','datatxt3');
set(b1,'Enable','off');
set(b2,'Enable','off');
set(b3,'Enable','off');
set(b4,'Enable','off');
set(b5,'Enable','on');
set(b7,'Enable','off');
set(b8,'Enable','off');
set(b9,'Enable','off');
set(b10,'Enable','off');
set(b11,'Enable','off');
set(b12,'Enable','off');
set(b13,'Enable','off');
set(b14,'Enable','off');
set(b15,'Enable','off');
set(b16,'Enable','off');
set(b17,'Enable','on');
set(b18,'Enable','off');
set(b19,'Enable','off');
set(b20,'Enable','off');
  m=length(defnprobs);

  if m==1
      data1=xlsread(file1,'Sheet1')
      usl1=str2num(get(b7,'String'));
      t1=str2num(get(b14,'String'));
      lsl1=str2num(get(b10,'String'));
      bound1=[usl1 lsl1];
       dataname1=get(b18,'String');
  elseif m==2

      data1=xlsread(file1,'Sheet1');
      data2=xlsread(file2,'Sheet1');
      usl1=str2num(get(b7,'String'));
      t1=str2num(get(b14,'String'));
      lsl1=str2num(get(b10,'String'));
      usl2=str2num(get(b8,'String'));
       t2=str2num(get(b15,'String'));
       lsl2=str2num(get(b11,'String'));
       bound1=[usl1 lsl1];
       bound2=[usl2 lsl2];
       dataname1=get(b18,'String');
         dataname2=get(b19,'String');
    elseif m==3

       data1=xlsread(file1,'Sheet1');
      data2=xlsread(file2,'Sheet1');
      data3=xlsread(file3,'Sheet1');
      usl1=str2num(get(b7,'String'));
```

```
       t1=str2num(get(b14,'String'));
       lsl1=str2num(get(b10,'String'));
       usl2=str2num(get(b8,'String'));
        t2=str2num(get(b15,'String'));
        lsl2=str2num(get(b11,'String'));
        usl3=str2num(get(b9,'String'));
        t3=str2num(get(b16,'String'));
        lsl3=str2num(get(b12,'String'));
        bound1=[usl1 lsl1];
        bound2=[usl2 lsl2];
        bound3=[usl3 lsl3];
        dataname1=get(b18,'String');
          dataname2=get(b19,'String');
          dataname3=get(b20,'String');
  elseif m>3

       data1=xlsread(file1,'Sheet1');
       data2=xlsread(file2,'Sheet1');
         data3=xlsread(file3,'Sheet1');
        usl1=str2num(get(b7,'String'));
       t1=str2num(get(b14,'String'));
       lsl1=str2num(get(b10,'String'));
       usl2=str2num(get(b8,'String'));
        t2=str2num(get(b15,'String'));
        lsl2=str2num(get(b11,'String'));
        usl3=str2num(get(b9,'String'));
        t3=str2num(get(b16,'String'));
        lsl3=str2num(get(b12,'String'));
        bound1=[usl1 lsl1];
        bound2=[usl2 lsl2];
        bound3=[usl3 lsl3];
         dataname1=get(b18,'String');
          dataname2=get(b19,'String');
          dataname3=get(b20,'String');
  else

       set(b6,'String','No Problem Defined so no data Collection')
  end
data4=xlsread(file4,'InputData');



set(b6,'String',...
    'Data Collected. Go to Data Analysis Page for Analysis of Collected Data');



function hist_callback(src,event)
global file;
b1=findobj('Tag','histedit');
 b2=findobj('Tag','savesetbtn');
%Load Defects Data
[FileName,PathName] = uigetfile('*.xls;*.xlsx','Load Historical Data');
file=[PathName,FileName];
set(b1,'String',file)
set(b2,'Enable','on')

function databtn1_callback(src,event)
global file1;
b1=findobj('Tag','dataedit1');
 b2=findobj('Tag','collectdatabtn');
```

```
 b3=findobj('Tag','upedit2');
 b4=findobj('Tag','lwtedit1');
 b5=findobj('Tag','tedit1');
%Load Defects Data 1
[FileName,PathName] = uigetfile('*.xls;*.xlsx','Data Collection');
file1=[PathName,FileName];
set(b1,'String',file1)
set(b2,'Enable','on')
set(b3,'Enable','on','String','2.856')
set(b4,'Enable','on','String','2.716')
set(b5,'Enable','on','String','2.7')

function databtn2_callback(src,event)
global file2;
b1=findobj('Tag','dataedit2');
 b2=findobj('Tag','collectdatabtn');
  b3=findobj('Tag','upedit22');
 b4=findobj('Tag','lwtedit12');
 b5=findobj('Tag','tedit2');
%Load Defects Data 2
[FileName,PathName] = uigetfile('*.xls;*.xlsx','Data Collection');
file2=[PathName,FileName];
set(b1,'String',file2)
set(b2,'Enable','on')
set(b3,'Enable','on','String','0.977')
set(b4,'Enable','on','String','0.665')
set(b5,'Enable','on','String','0.8')

function databtn3_callback(src,event)
global file3;
b1=findobj('Tag','dataedit3');
 b2=findobj('Tag','collectdatabtn');
 b3=findobj('Tag','upedit23');
 b4=findobj('Tag','lwtedit13');
 b5=findobj('Tag','tedit3');
%Load Defects Data 3
[FileName,PathName] = uigetfile('*.xls;*.xlsx','Data Collection');
file3=[PathName,FileName];
set(b1,'String',file3)
set(b2,'Enable','on')

function databtn4_callback(src,event)
global file4 PathName;
b1=findobj('Tag','dataedit4');
 b2=findobj('Tag','collectdatabtn');
%Load Defects Data 3
[FileName,PathName] = uigetfile('*.xls;*.xlsx','Data Collection');
file4=[PathName,FileName];
set(b1,'String',file4)
set(b2,'Enable','on')

function datatxt1_callback(src,event)
b1=findobj('Tag','spectxt1');
b2=findobj('Tag','datatxt1');
set(b1,'String',get(b2,'String'));

function datatxt2_callback(src,event)
b1=findobj('Tag','spectxt2');
b2=findobj('Tag','datatxt2');
```

```
set(b1,'String',get(b2,'String'));

function datatxt3_callback(src,event)
b1=findobj('Tag','spectxt3');
b2=findobj('Tag','datatxt3');
set(b1,'String',get(b2,'String'));

function analyze_callback(src,event)

%% Defining the Problem
% We have data for 1.0mm cable produced between 2013 to 2017 with so
% defects which led to rejects of cables produced. We also tried to
% identify the factors affecting defects in the cable production. We need to evaluate
% the current design and develop an alternative design that can achieve our
% target production with little or no defects.

global file costbm year defectdata financedata defects ...
    financedatatotal defectdatatotal defnprobs;



b3=findobj('Tag','defntxt');
set(b3,'String','Anaylzing Historical Data ........')
b1=findobj('Tag','cbm');
b2=findobj('Tag','histedit');
b4=findobj('Tag','startdate');
b5=findobj('Tag','enddate');
b6=findobj('Tag','defnlistbox');
b7=findobj('Tag','plotdbtn');
b8=findobj('Tag','plotfbtn');
b9=findobj('Tag','plotxbtn');
b10=findobj('Tag','plotdpbtn');
b11=findobj('Tag','plotfpbtn');
b12=findobj('Tag','defnresultbtn');
b13=findobj('Tag','databtn1');
b14=findobj('Tag','databtn2');
b15=findobj('Tag','databtn3');
b16=findobj('Tag','datatxt');
b17=findobj('Tag','datatxt1');
b18=findobj('Tag','datatxt2');
b19=findobj('Tag','datatxt3');
b20=findobj('Tag','reloaddatabtn');
b21=findobj('Tag','histfitbtn');
b22=findobj('Tag','spectxt1');
b23=findobj('Tag','spectxt2');
b24=findobj('Tag','spectxt3');
b25=findobj('Tag','databtn4');

set(b3,'Enable','on')
set(b25,'Enable','on')
defectdata=xlsread(file,'defects');
%Get finace data
financedata=xlsread(file,'finance');
financedatatotal=(sum(financedata'))';
defectdatatotal=(sum(defectdata'))';
defects={'ITF', 'RIS','LCD','WTW','IC','SIF','WL','NL','TPs','ISI','BC'};

projectdefects=defects';
```

```
%Bench Mark
costbm=str2num(get(b1,'String'));
%period
yr1=(get(b4,'value'));
yr2=(get(b5,'value'));
% yr1=sdv{1,1};
% yr2=edv{1,1};
if yr2-yr1==4
yearn=(yr1+2009):(yr2+2009);

    for i=1:length(yearn)
    year{i}=num2str(yearn(i));
    end
n=length(defects);
    for i=1:n
    data(i,1)={projectdefects(i)};
    data(i,2)={num2str(defectdatatotal(i))};
    data(i,3)={num2str(financedatatotal(i))};



    if financedatatotal(i)>=costbm
        data(i,4)={'High Cost Defects: Selected for Improvement'};
         recom{i,1}=('High Cost Defects: Selected for Improvement');
    elseif financedatatotal(i)==0;
        data(i,4)={'No Defects'};
         recom{i,1}=('No Defects');
    else
        data(i,4)={'Cost of Defects is Insignificant'};
         recom{i,1}=('Cost of Defects is Insignificant');
    end
end
  defnpi=find(financedatatotal>costbm);
  defnprobs=projectdefects(defnpi);

  m=length(defnprobs);
  if m==1
      set(b17,'Enable','on')
      set(b13,'Enable','on')

    elseif m==2
      set(b17,'Enable','on')
      set(b18,'Enable','on')
      set(b13,'Enable','on')
      set(b14,'Enable','on')
    elseif m==3
      set(b17,'Enable','on')
      set(b18,'Enable','on')
      set(b19,'Enable','on')
      set(b13,'Enable','on')
      set(b14,'Enable','on')
      set(b15,'Enable','on')

  elseif m>3
      set(b17,'Enable','on')
      set(b18,'Enable','on')
      set(b19,'Enable','on')
      set(b13,'Enable','on')
      set(b14,'Enable','on')
      set(b15,'Enable','on')
```

```
 else
   set(b17,'Enable','off')
   set(b18,'Enable','off')
   set(b19,'Enable','off')
   set(b13,'Enable','off')
   set(b14,'Enable','off')
   set(b15,'Enable','off')
   set(b16,'String','No Problem Defined so no data Collection')
 end



probs={'ITF -Insulation thickness failures',...
   'RIS - Rough Insulation Surface',...
   'LCD - Low Conductor Diameter',...
   'WIW - Wrong Input Wire',...
   'IC - Incomplete Core',...
   'SIF - Short Cut Supplied in place of full coil',...
   'WL - Wrong Label',...
   'NL - No Label',...
   'TPs - Torn Poly-Sheet',...
   'ISI - Inconsistency in the Shape Of Insulation',...
   'BC - Bridging Cable'};



str1={'Historical Data Analysis Summary',...
   '===================================',...
   'Defects Summary',...
   '===================================',...
   ['ITF -Insulation thickness failures:','',num2str(defectdatatotal(1))],...
   ['RIS - Rough Insulation Surface:','',num2str(defectdatatotal(2))],...
   ['LCD - Low Conductor Diameter:','',num2str(defectdatatotal(3))],...
   ['WIW - Wrong Input Wire:','',num2str(defectdatatotal(4))],...
   ['IC - Incomplete Core:','',num2str(defectdatatotal(5))],...
   ['SIF - Short Cut Supplied in place of full coil:','',num2str(defectdatatotal(6))],...
   ['WL - Wrong Label:','',num2str(defectdatatotal(7))],...
   ['NL - No Label:','',num2str(defectdatatotal(8))],...
   ['TPs - Torn Poly-Sheet:','',num2str(defectdatatotal(9))]...
   ['ISI - Inconsistency in the Shape Of Insulation:','',num2str(defectdatatotal(10))],...
   ['BC - Bridging Cable:',num2str(defectdatatotal(11))]};

str2={'',...
   '===================================',...
   'Defects Finance Cost Summary',...
   '===================================',...
   ['Bench Mark for Selection:','','N',num2str(costbm)],...
   '===================================',...
   ['ITF -Insulation thickness failures:','','N',num2str(financedatatotal(1))],...
   ['RIS - Rough Insulation Surface:','','N',num2str(financedatatotal(2))],...
   ['LCD - Low Conductor Diameter:','','N',num2str(financedatatotal(3))],...
   ['WIW - Wrong Input Wire:','','N',num2str(financedatatotal(4))],...
   ['IC - Incomplete Core:','','N',num2str(financedatatotal(5))],...
   ['SIF - Short Cut Supplied in place of full coil:','','N',num2str(financedatatotal(6))],...
   ['WL - Wrong Label:','','N',num2str(financedatatotal(7))],...
   ['NL - No Label:','','N',num2str(financedatatotal(8))],...
```

```
    ['TPs - Torn Poly-Sheet:','','N',num2str(financedatatotal(9))],...
    ['ISI - Inconsistency in the Shape Of Insulation:','','N',num2str(financedatatotal(10))],...
    ['BC - Bridging Cable:','','N',num2str(financedatatotal(11))]};

str3={'',...
    '===================================',...
    'Selection for Improvement Summary',...
    '===================================',...
    ['ITF -','',recom{1}],...
    ['RIS -','',recom{2}],...
    ['LCD -','',recom{3}],...
    ['WIW -','',recom{4}],...
    ['IC - ','',recom{5}],...
    ['SIF -','',recom{6}],...
    ['WL - ','',recom{7}],...
    ['NL - ','',recom{8}],...
    ['TPs - ','',recom{9}]...
    ['ISI - ','',recom{10}],...
    ['BC - ','',recom{11}],...
    '',...
    '===================================',...
    'Defects Selected for Improvement',...
    '==================================='};

str4=probs(defnpi);
str=[str1,str2,str3,str4];



    set(b6,'Enable','on');
    set(b7,'Enable','on');
    set(b8,'Enable','on');
    set(b9,'Enable','on');
    set(b10,'Enable','on');
    set(b11,'Enable','on');
    set(b12,'Enable','on');
    set(b20,'Enable','on');
    set(b21,'Enable','on');
    set(b3,'String','Click buttons below to view plots')
% set(b6,'String',{'Project Charter','Critical to Quality Characteristics:',data{1,1}})
set(b6,'String',str)




    else
    set(b3,'String','Start Year to End Year must be five years. Go to settings and adjust ')
end




function plotdbtn_callback(src,event)

global year defectdata defects ;
%3d Bar Plot of Defects and Associated Costs

f1=figure('Name','Knowledge Based Design with Six Sigma - 3D Defects Plot',...
    'NumberTitle','off',...
   'MenuBar','none');
bar3(defectdata')
```

```
xlabel('Defect Type')
ylabel('Year')
title('Historical Defect Data')
set(gca,'XTickLabel',defects)
set(gca,'YTickLabel',year)
zlabel('Number of Defects')

function plotfbtn_callback(src,event)
global year financedata defects ;
f2=figure('Name','Knowledge Based Design with Six Sigma - 3D Finance Cost Plot',...
    'NumberTitle','off',...
   'MenuBar','none');
bar3(financedata')
xlabel('Defect Type')
ylabel('Year')
title('Historical Defect Financial Cost Data')
set(gca,'XTickLabel',defects)
set(gca,'YTickLabel',year)
zlabel('Financial Cost (NGN)')

function plotxbtn_callback(src,event)

global defectdata;
f3=figure('Name','Knowledge Based Design with Six Sigma - X-Bar and S-Chart',...
    'NumberTitle','off',...
   'MenuBar','none');
subplot(2,1,1)
xbarplot(defectdata) % yearly sets
xlabel('Defect Types')
ylabel('Yearly Average Defects')
subplot(2,1,2)
schart(defectdata)
xlabel('Defect Types')
ylabel('Yearly Standard Deviation')

function plotdpbtn_callback(src,event)
global defectdatatotal defects ;
%Pareto Chart of Historical Defect Data form 2013 to 2017
f4=figure('Name','Knowledge Based Design with Six Sigma - Pareto Defects Plot',...
    'NumberTitle','off',...
   'MenuBar','none');
pareto(defectdatatotal);
xlabel('Defect Type')
ylabel('Number of Defects')
set(gca,'XTickLabel',defects)
title('Paroto Chart of Historical Defect Data form 2013 to 2017')

function plotfpbtn_callback(src,event)

global costbm defects financedatatotal;
%Financial Bench Mark for Project Charter

f5=figure('Name','Knowledge Based Design with Six Sigma - Pareto Finance Cost Plot',...
    'NumberTitle','off',...
   'MenuBar','none');
pareto(financedatatotal);
xlabel('Defect Type')
ylabel('Financial Cost (NGN)')
set(gca,'XTickLabel',defects)
```

```
title('Paroto Chart of Historical Financial Cost Data form 2013 to 2017')

hold;
costbmB=costbm*(ones(1,length(financedatatotal)));
plot(costbmB,'r');

%Hist  Fit plot
function histfitbtn_callback(src,event)
global financedatatotal ;
f7=figure('Name','Knowledge Based Design with Six Sigma - Defects Finance Cost Histogram Fit',...
    'NumberTitle','off',...
   'MenuBar','none');
histfit(financedatatotal')
h1 = findobj(gca,'Type','patch');   % let's format the plot
clr = [.9 .9 1];
set(h1,'FaceColor',clr,'EdgeColor','k')
[historic_mean, historic_stdev] = normfit(financedatatotal')
ylabel('Frequency (counts)')
xlabel('Defect Finance Cost(Naira)')
title('Defect Finance Cost Histogram')
text(2e4,8,['Mean:',num2str(historic_mean)])
text(2e4,7.5,['Standard Deviation:',num2str(historic_stdev)])
%view problem defined result
function defnresult_callback(src,event)

global costbm  defects financedatatotal defectdatatotal;
projectdefects = defects';

 %Project Charter
   n=length(defects);
    data{n,4} = [];

for i=1:n
    data(i,1)={projectdefects(i)};
    data(i,2)={num2str(defectdatatotal(i))};
    data(i,3)={num2str(financedatatotal(i))};


    if financedatatotal(i)>=costbm
        data(i,4)={'High Cost Defects: Selected for Improvement'};
    elseif financedatatotal(i)==0;
        data(i,4)={'No Defects'};
    else
        data(i,4)={'Cost of Defects is Insignificant'};
    end
end

f6=figure('Name','Knowledge Based Design with Six Sigma - Problem Defined Results',...
   'NumberTitle','off',...
    'Position',[200 80 700 400],...
    'Resize','off',...
'MenuBar','none');
columnname = {'Defects','Number Of Defects','Financial Cost of Defects','Selection for Improvement'};
columnformat = {'char', 'char', 'char','char'};
defnTable = uitable(f6,'Position',[25 25 650 360],'Data',data,'ColumnWidth',80);

defnTable.ColumnName=columnname;
```

```
%% Data Analysis Page

function analyze2_callback(src,event)

global data1 data2 data3 bound1 bound2 bound3 defnprobs dataname1 ...
    dataname2 dataname3 d1 d2 d3 t1 t2 t3;



b1=findobj('Tag','anatxt');
b2=findobj('Tag','analistbox');
set(b1,'String','Anaylzing loaded experimental Data ........')
set(b2,'String','Anaylzing loaded experimental Data ........','Enable','on')
b3=findobj('Tag','expbtn');
b4=findobj('Tag','plotxbtn2');
b5=findobj('Tag','plotxbtn21');
b6=findobj('Tag','plotxbtn22');
b7=findobj('Tag','histfitbtn1');
b8=findobj('Tag','histfitbtn2');
b9=findobj('Tag','histfitbtn3');
b10=findobj('Tag','probplotbtn1');
b11=findobj('Tag','probplotbtn2');
b12=findobj('Tag','probplotbtn3');
b13=findobj('Tag','capaplotbtn1');
b14=findobj('Tag','capaplotbtn2');
b15=findobj('Tag','capaplotbtn3');
b16=findobj('Tag','improvbtn');



str4={'',...
    '===================================',...
    'Selection for Improvement Summary',...
    '===================================',...
    '===================================',...
    'Data to be Collected in the Next Page',...
    '==================================='};




 l=length(defnprobs);
  if l==1
       siz1=size(data1);
if siz1(2)==1
    d1=data1;
else
d1=mean(data1')';
end
sd1 = capability(d1,bound1);
Cpm= (bound1(2)-bound1(1))/(6*t1);
CR= (100 * (6*sd1.sigma))/(bound1(2)-bound1(1)) ;
Zu=(bound1(2)-sd1.mu)/sd1.sigma;
Zl=(sd1.mu-bound1(1))/sd1.sigma;

%Remark
if sd1.Cp<1
    Cprk='- Possible Defects Expected';
elseif sd1.Cp>2
    Cprk='- Specification Tolerance is far Apart';
```

```
else
   Cprk='-No Possible Defects Foreseen';
end

if CR<=75
   CRrk='- Appropriate Parameter Settings';
else
   CRrk='- High Percentage of Engineering Requirement';
end

if sd1.Cpk<1
   Cpkrk='- Continous Improvement is Required';
elseif sd1.Cpk>2
   Cpkrk='- Design of New Engineering Tolerance is Required';
else
   Cpkrk='-No Improvment Reqired';
end

if Zu<3
   Zurk='- Higher Percentage of Production will Exceed Upper Limit';
elseif Zu>6
   Zurk='- Inappropriate Engineering Specification';
else
   Zurk='- Production will be Within Upper Limit';
end

if Zl<3
   Zlrk='- Higher Percentage of Production will be Below Lower Limit';
elseif Zl>6
   Zlrk='- Inappropriate Engineering Specification';
else
   Zlrk='- Production will be Within Lower Limit';
end
     str1={'Data Analysis Summary',...
   '===================================',...
   ['Capabilty Summary - ',dataname1],...
   '===================================',...
   ['Sample Mean(mu) - ',num2str(sd1.mu)],...
   ['Sample Standard Deviation(sigma) - ', num2str(sd1.sigma)],...
    ['Estimated probability of being within limits(P) - ', num2str(sd1.P)],...
     ['Estimated probability of being below L (lower spec)(Pl) - ', num2str(sd1.Pl)],...
       ['Estimated probability of being above U (upper spec)(Pu) - ', num2str(sd1.Pu)],...
       ['Cp, (U-L)/(6*sigma) - ', num2str(sd1.Cp)],...
        ['Cpl ,(mu-L)./(3.*sigma) - ', num2str(sd1.Cpl)],...
       ['Cpu ,(U-mu)./(3.*sigma) - ', num2str(sd1.Cpu)],...
        ['Cpk ,min(Cpl, Cpu) - ', num2str(sd1.Cpk)],...
        ['Cpm,(U-L)(6*t) -',num2str(Cpm)],...
         ['Capability Ratio,CR -',num2str(CR)],...
          ['Zu, (U-mu)/sigma -',num2str(Zu)],...
           ['Zl, (mu-L)/sigma -',num2str(Zl)],...
           'Remark:',Cprk,CRrk,Cpkrk,Zurk,Zlrk,...
    '===================================',...
    '',''};
      set(b3,'Enable','on');
  set(b4,'Enable','on');
   set(b5,'Enable','off');
   set(b6,'Enable','off');
   set(b7,'Enable','on');
   set(b8,'Enable','off');
```

```
    set(b9,'Enable','off');
    set(b10,'Enable','on');
    set(b11,'Enable','off');
    set(b12,'Enable','off');
    set(b13,'Enable','on');
     set(b14,'Enable','off');
      set(b15,'Enable','off');
    str2='';
    str3='';

       elseif l==2
           siz1=size(data1);
if siz1(2)==1
    d1=data1;
else
d1=mean(data1')';
end
sd1 = capability(d1,bound1);
Cpm= (bound1(2)-bound1(1))/(6*t1);
CR= (100 * (6*sd1.sigma))/(bound1(2)-bound1(1)) ;
Zu=(bound1(2)-sd1.mu)/sd1.sigma;
Zl=(sd1.mu-bound1(1))/sd1.sigma;

%Remark
if sd1.Cp<1
    Cprk='- Possible Defects Expected';
elseif sd1.Cp>2
    Cprk='- Specification Tolerance is far Apart';
else
    Cprk='-No Possible Defects Foreseen';
end

if CR<=75
    CRrk='- Appropriate Parameter Settings';
else
    CRrk='- High Percentage of Engineering Requirement';
end

if sd1.Cpk<1
    Cpkrk='- Continous Improvement is Required';
elseif sd1.Cpk>2
    Cpkrk='- Design of New Engineering Tolerance is Required';
else
    Cpkrk='-No Improvment Reqired';
end

if Zu<3
    Zurk='- Higher Percentage of Production will Exceed Upper Limit';
elseif Zu>6
    Zurk='- Inappropriate Engineering Specification';
else
    Zurk='- Production will be Within Upper Limit';
end

if Zl<3
    Zlrk='- Higher Percentage of Production will be Below Lower Limit';
elseif Zl>6
    Zlrk='- Inappropriate Engineering Specification';
else
```

```
   Zlrk='- Production will be Within Lower Limit';
end

  siz2=size(data2);
if siz2(2)==1
   d2=data2;
else
d2=mean(data2')';
end
sd2 = capability(d2,bound2);
Cpm2= (bound2(2)-bound2(1))/(6*t2);
CR2= (100 * (6*sd2.sigma))/(bound2(2)-bound2(1))    ;
Zu2=(bound2(2)-sd2.mu)/sd2.sigma;
Zl2=(sd2.mu-bound2(1))/sd2.sigma;

%Remark
if sd2.Cp<1
   Cprk2='- Possible Defects Expected';
elseif sd2.Cp>2
   Cprk2='- Specification Tolerance is far Apart';
else
   Cprk2='-No Possible Defects Foreseen';
end

if CR2<=75
   CRrk2='- Appropriate Parameter Settings';
else
   CRrk2='- High Percentage of Engineering Requirement';
end

if sd2.Cpk<1
   Cpkrk2='- Continous Improvement is Required';
elseif sd2.Cpk>2
   Cpkrk2='- Design of New Engineering Tolerance is Required';
else
   Cpkrk2='-No Improvment Reqired';
end

if Zu2<3
   Zurk2='- Higher Percentage of Production will Exceed Upper Limit';
elseif Zu2>6
   Zurk2='- Inappropriate Engineering Specification';
else
   Zurk2='- Production will be Within Upper Limit';
end

if Zl2<3
   Zlrk2='- Higher Percentage of Production will be Below Lower Limit';
elseif Zl2>6
   Zlrk2='- Inappropriate Engineering Specification';
else
   Zlrk2='- Production will be Within Lower Limit';
end
        str1={'Data Analysis Summary',...
   '===================================',...
   ['Capabilty Summary - ',dataname1],...
   '===================================',...
   ['Sample Mean(mu) : ',num2str(sd1.mu)],...
   ['Sample Standard Deviation(sigma) : ', num2str(sd1.sigma)],...
```

```
    ['Estimated probability of being within limits(P) : ', num2str(sd1.P)],...
     ['Estimated probability of being below L (lower spec)(Pl) : ', num2str(sd1.Pl)],...
       ['Estimated probability of being above U (upper spec)(Pu) : ', num2str(sd1.Pu)],...
       ['Cp, (U-L)/(6*sigma) : ', num2str(sd1.Cp)],...
        ['Cpl ,(mu-L)./(3.*sigma) : ', num2str(sd1.Cpl)],...
       ['Cpu ,(U-mu)./(3.*sigma) : ', num2str(sd1.Cpu)],...
        ['Cpk ,min(Cpl, Cpu) : ', num2str(sd1.Cpk)],...
              ['Cpm,(U-L)(6*t) :',num2str(Cpm)],...
         ['Capability Ratio,CR :',num2str(CR)],...
          ['Zu, (U-mu)/sigma :',num2str(Zu)],...
           ['Zl, (mu-L)/sigma :',num2str(Zl)],...
            'Remark:',Cprk,CRrk,Cpkrk,Zurk,Zlrk,...
    '==================================',...
    '',''};

str2={'==================================',...
   ['Capabilty Summary - ',dataname2],...
   '==================================',...
   ['Sample Mean(mu) - ',num2str(sd2.mu)],...
   ['Sample Standard Deviation(sigma) - ', num2str(sd2.sigma)],...
    ['Estimated probability of being within limits(P) - ', num2str(sd2.P)],...
     ['Estimated probability of being below L (lower spec)(Pl) - ', num2str(sd2.Pl)],...
       ['Estimated probability of being above U (upper spec)(Pu) - ', num2str(sd2.Pu)],...
       ['Cp, (U-L)/(6*sigma) - ', num2str(sd2.Cp)],...
        ['Cpl ,(mu-L)./(3.*sigma) - ', num2str(sd2.Cpl)],...
       ['Cpu ,(U-mu)./(3.*sigma) - ', num2str(sd2.Cpu)],...
        ['Cpk ,min(Cpl, Cpu) - ', num2str(sd2.Cpk)],...
        ['Cpm,(U-L)(6*t) :',num2str(Cpm2)],...
         ['Capability Ratio,CR :',num2str(CR2)],...
          ['Zu, (U-mu)/sigma :',num2str(Zu2)],...
           ['Zl, (mu-L)/sigma :',num2str(Zl2)],...
                'Remark:',Cprk2,CRrk2,Cpkrk2,Zurk2,Zlrk2,...
    '==================================',...
    '',''};
str3='';
           set(b3,'Enable','on');
 set(b4,'Enable','on');
  set(b5,'Enable','on');
   set(b6,'Enable','off');
   set(b7,'Enable','on');
   set(b8,'Enable','on');
   set(b9,'Enable','off');
   set(b10,'Enable','on');
   set(b11,'Enable','on');
   set(b12,'Enable','off');
   set(b13,'Enable','on');
   set(b14,'Enable','on');
   set(b15,'Enable','off');

         elseif l==3
             siz1=size(data1);
if siz1(2)==1
   d1=data1;
else
d1=mean(data1')';
end
sd1 = capability(d1,bound1);
Cpm= (bound1(2)-bound1(1))/(6*t1);
CR= (100 * (6*sd1.sigma))/(bound1(2)-bound1(1)) ;
Zu=(bound1(2)-sd1.mu)/sd1.sigma;
```

```
Zl=(sd1.mu-bound1(1))/sd1.sigma;

%Remark
if sd1.Cp<1
   Cprk='- Possible Defects Expected';
elseif sd1.Cp>2
   Cprk='- Specification Tolerance is far Apart';
else
   Cprk='-No Possible Defects Foreseen';
end

if CR<=75
   CRrk='- Appropriate Parameter Settings';
else
   CRrk='- High Percentage of Engineering Requirement';
end

if sd1.Cpk<1
   Cpkrk='- Continous Improvement is Required';
elseif sd1.Cpk>2
   Cpkrk='- Design of New Engineering Tolerance is Required';
else
   Cpkrk='-No Improvment Reqired';
end

if Zu<3
   Zurk='- Higher Percentage of Production will Exceed Upper Limit';
elseif Zu>6
   Zurk='- Inappropriate Engineering Specification';
else
   Zurk='- Production will be Within Upper Limit';
end

if Zl<3
   Zlrk='- Higher Percentage of Production will be Below Lower Limit';
elseif Zl>6
   Zlrk='- Inappropriate Engineering Specification';
else
   Zlrk='- Production will be Within Lower Limit';
end
siz2=size(data2);
if siz2(2)==1
   d2=data2;
else
d2=mean(data2')';
end
sd2 = capability(d2,bound2);
Cpm2= (bound2(2)-bound2(1))/(6*t2);
CR2= (100 * (6*sd2.sigma))/(bound2(2)-bound2(1))    ;
Zu2=(bound2(2)-sd2.mu)/sd2.sigma;
Zl2=(sd2.mu-bound2(1))/sd2.sigma;

%Remark
if sd2.Cp<1
   Cprk2='- Possible Defects Expected';
elseif sd2.Cp>2
   Cprk2='- Specification Tolerance is far Apart';
else
   Cprk2='-No Possible Defects Foreseen';
```

```
end

if CR2<=75
   CRrk2='- Appropriate Parameter Settings';
else
   CRrk2='- High Percentage of Engineering Requirement';
end

if sd2.Cpk<1
   Cpkrk2='- Continous Improvement is Required';
elseif sd2.Cpk>2
   Cpkrk2='- Design of New Engineering Tolerance is Required';
else
   Cpkrk2='-No Improvment Reqired';
end

if Zu2<3
   Zurk2='- Higher Percentage of Production will Exceed Upper Limit';
elseif Zu2>6
   Zurk2='- Inappropriate Engineering Specification';
else
   Zurk2='- Production will be Within Upper Limit';
end

if Zl2<3
   Zlrk2='- Higher Percentage of Production will be Below Lower Limit';
elseif Zl2>6
   Zlrk2='- Inappropriate Engineering Specification';
else
   Zlrk2='- Production will be Within Lower Limit';
end

siz3=size(data3);
if siz3(2)==1
   d3=data3;
else
d3=mean(data3')';
end
sd3 = capability(data3,bound3);
Cpm3= (bound3(2)-bound3(1))/(6*t3);
CR3= (100 * (6*sd3.sigma))/(bound3(2)-bound3(1))    ;
Zu3=(bound3(2)-sd3.mu)/sd3.sigma;
Zl3=(sd3.mu-bound3(1))/sd3.sigma;

%Remark
if sd3.Cp<1
   Cprk3='- Possible Defects Expected';
elseif sd3.Cp>2
   Cprk3='- Specification Tolerance is far Apart';
else
   Cprk2='-No Possible Defects Foreseen';
end

if CR3<=75
   CRrk3='- Appropriate Parameter Settings';
else
   CRrk3='- High Percentage of Engineering Requirement';
end
```

```
if sd3.Cpk<1
   Cpkrk3='- Continous Improvement is Required';
elseif sd3.Cpk>2
   Cpkrk3='- Design of New Engineering Tolerance is Required';
else
   Cpkrk3='-No Improvment Reqired';
end

if Zu3<3
   Zurk3='- Higher Percentage of Production will Exceed Upper Limit';
elseif Zu3>6
   Zurk3='- Inappropriate Engineering Specification';
else
   Zurk3='- Production will be Within Upper Limit';
end

if Zl3<3
   Zlrk3='- Higher Percentage of Production will be Below Lower Limit';
elseif Zl3>6
   Zlrk3='- Inappropriate Engineering Specification';
else
   Zlrk3='- Production will be Within Lower Limit';
end
            str1={'Data Analysis Summary',...
   '===================================',...
   ['Capabilty Summary - ',dataname1],...
   '===================================',...
  ['Sample Mean(mu) : ',num2str(sd1.mu)],...
   ['Sample Standard Deviation(sigma) : ', num2str(sd1.sigma)],...
    ['Estimated probability of being within limits(P) : ', num2str(sd1.P)],...
     ['Estimated probability of being below L (lower spec)(Pl) : ', num2str(sd1.Pl)],...
       ['Estimated probability of being above U (upper spec)(Pu) : ', num2str(sd1.Pu)],...
       ['Cp, (U-L)/(6*sigma) : ', num2str(sd1.Cp)],...
        ['Cpl ,(mu-L)./(3.*sigma) : ', num2str(sd1.Cpl)],...
       ['Cpu ,(U-mu)./(3.*sigma) : ', num2str(sd1.Cpu)],...
        ['Cpk ,min(Cpl, Cpu) : ', num2str(sd1.Cpk)],...
             ['Cpm,(U-L)(6*t) :',num2str(Cpm)],...
         ['Capability Ratio,CR :',num2str(CR)],...
          ['Zu, (U-mu)/sigma :',num2str(Zu)],...
           ['Zl, (mu-L)/sigma :',num2str(Zl)],...
    'Remark:',Cprk,CRrk,Cpkrk,Zurk,Zlrk,...
    '===================================',...
    '',''};

 str2={'===================================',...
   ['Capabilty Summary - ',dataname2],...
   '===================================',...
   ['Sample Mean(mu) - ',num2str(sd2.mu)],...
   ['Sample Standard Deviation(sigma) - ', num2str(sd2.sigma)],...
    ['Estimated probability of being within limits(P) - ', num2str(sd2.P)],...
     ['Estimated probability of being below L (lower spec)(Pl) - ', num2str(sd2.Pl)],...
       ['Estimated probability of being above U (upper spec)(Pu) - ', num2str(sd2.Pu)],...
       ['Cp, (U-L)/(6*sigma) - ', num2str(sd2.Cp)],...
        ['Cpl ,(mu-L)./(3.*sigma) - ', num2str(sd2.Cpl)],...
       ['Cpu ,(U-mu)./(3.*sigma) - ', num2str(sd2.Cpu)],...
        ['Cpk ,min(Cpl, Cpu) - ', num2str(sd2.Cpk)],...
                  ['Cpm,(U-L)(6*t) :',num2str(Cpm2)],...
         ['Capability Ratio,CR :',num2str(CR2)],...
          ['Zu, (U-mu)/sigma :',num2str(Zu2)],...
           ['Zl, (mu-L)/sigma :',num2str(Zl2)],...
```

```
            'Remark:',Cprk2,CRrk2,Cpkrk2,Zurk2,Zlrk2,...
    '==================================',...
    '',''};

 str3={'==================================',...
   ['Capabilty Summary - ',dataname3],...
   '==================================',...
   ['Sample Mean(mu) - ',num2str(sd3.mu)],...
   ['Sample Standard Deviation(sigma) - ', num2str(sd3.sigma)],...
    ['Estimated probability of being within limits(P) - ', num2str(sd3.P)],...
     ['Estimated probability of being below L (lower spec)(Pl) - ', num2str(sd3.Pl)],...
       ['Estimated probability of being above U (upper spec)(Pu) - ', num2str(sd3.Pu)],...
       ['Cp, (U-L)/(6*sigma) - ', num2str(sd3.Cp)],...
        ['Cpl ,(mu-L)./(3.*sigma) - ', num2str(sd3.Cpl)],...
       ['Cpu ,(U-mu)./(3.*sigma) - ', num2str(sd3.Cpu)],...
        ['Cpk ,min(Cpl, Cpu) - ', num2str(sd3.Cpk)],...
        ['Cpm,(U-L)(6*t) :',num2str(Cpm3)],...
         ['Capability Ratio,CR :',num2str(CR3)],...
          ['Zu, (U-mu)/sigma :',num2str(Zu3)],...
           ['Zl, (mu-L)/sigma :',num2str(Zl3)],...
            'Remark:',Cprk3,CRrk3,Cpkrk3,Zurk3,Zlrk3,...
    '==================================',...
    '',''};

   set(b3,'Enable','on');
  set(b4,'Enable','on');
   set(b5,'Enable','on');
   set(b6,'Enable','on');
   set(b7,'Enable','on');
   set(b8,'Enable','on');
   set(b9,'Enable','on');
   set(b10,'Enable','on');
   set(b11,'Enable','on');
   set(b12,'Enable','on');
    set(b13,'Enable','on');
   set(b14,'Enable','on');
   set(b15,'Enable','on');

               elseif l>3
                   siz1=size(data1);
if siz1(2)==1
   d1=data1;
else
d1=mean(data1')';
end
sd1 = capability(d1,bound1);
Cpm= (bound1(2)-bound1(1))/(6*t1);
CR= (100 * (6*sd1.sigma))/(bound1(2)-bound1(1)) ;
Zu=(bound1(2)-sd1.mu)/sd1.sigma;
Zl=(sd1.mu-bound1(1))/sd1.sigma;
%Remark
if sd1.Cp<1
   Cprk='- Possible Defects Expected';
elseif sd1.Cp>2
   Cprk='- Specification Tolerance is far Apart';
else
   Cprk='-No Possible Defects Foreseen';
end
```

```
if CR<=75
   CRrk='- Appropriate Parameter Settings';
else
   CRrk='- High Percentage of Engineering Requirement';
end

if sd1.Cpk<1
   Cpkrk='- Continous Improvement is Required';
elseif sd1.Cpk>2
   Cpkrk='- Design of New Engineering Tolerance is Required';
else
   Cpkrk='-No Improvment Reqired';
end

if Zu<3
   Zurk='- Higher Percentage of Production will Exceed Upper Limit';
elseif Zu>6
   Zurk='- Inappropriate Engineering Specification';
else
   Zurk='- Production will be Within Upper Limit';
end

if Zl<3
   Zlrk='- Higher Percentage of Production will be Below Lower Limit';
elseif Zl>6
   Zlrk='- Inappropriate Engineering Specification';
else
   Zlrk='- Production will be Within Lower Limit';
end

siz2=size(data2);
if siz2(2)==1
   d2=data2;
else
d2=mean(data2')';
end
sd2 = capability(d2,bound2);
Cpm2= (bound2(2)-bound2(1))/(6*t2);
CR2= (100 * (6*sd2.sigma))/(bound2(2)-bound2(1))    ;
Zu2=(bound2(2)-sd2.mu)/sd2.sigma;
Zl2=(sd2.mu-bound2(1))/sd2.sigma;

%Remark
if sd2.Cp<1
   Cprk2='- Possible Defects Expected';
elseif sd2.Cp>2
   Cprk2='- Specification Tolerance is far Apart';
else
   Cprk2='-No Possible Defects Foreseen';
end

if CR2<=75
   CRrk2='- Appropriate Parameter Settings';
else
   CRrk2='- High Percentage of Engineering Requirement';
end

if sd2.Cpk<1
   Cpkrk2='- Continous Improvement is Required';
```

```
elseif sd2.Cpk>2
   Cpkrk2='- Design of New Engineering Tolerance is Required';
else
   Cpkrk2='-No Improvment Reqired';
end

if Zu2<3
   Zurk2='- Higher Percentage of Production will Exceed Upper Limit';
elseif Zu2>6
   Zurk2='- Inappropriate Engineering Specification';
else
   Zurk2='- Production will be Within Upper Limit';
end

if Zl2<3
   Zlrk2='- Higher Percentage of Production will be Below Lower Limit';
elseif Zl2>6
   Zlrk2='- Inappropriate Engineering Specification';
else
   Zlrk2='- Production will be Within Lower Limit';
end

siz3=size(data3);
if siz3(2)==1
   d3=data3;
else
d3=mean(data3')';
end
sd3 = capability(d3,bound3);
Cpm3= (bound3(2)-bound3(1))/(6*t3);
CR3= (100 * (6*sd3.sigma))/(bound3(2)-bound3(1))    ;
Zu3=(bound3(2)-sd3.mu)/sd3.sigma;
Zl3=(sd3.mu-bound3(1))/sd3.sigma;

%Remark
if sd3.Cp<1
   Cprk3='- Possible Defects Expected';
elseif sd3.Cp>2
   Cprk3='- Specification Tolerance is far Apart';
else
   Cprk2='-No Possible Defects Foreseen';
end

if CR3<=75
   CRrk3='- Appropriate Parameter Settings';
else
   CRrk3='- High Percentage of Engineering Requirement';
end

if sd3.Cpk<1
   Cpkrk3='- Continous Improvement is Required';
elseif sd3.Cpk>2
   Cpkrk3='- Design of New Engineering Tolerance is Required';
else
   Cpkrk3='-No Improvment Reqired';
end

if Zu3<3
   Zurk3='- Higher Percentage of Production will Exceed Upper Limit';
```

```
elseif Zu3>6
   Zurk3='- Inappropriate Engineering Specification';
else
   Zurk3='- Production will be Within Upper Limit';
end

if Zl3<3
   Zlrk3='- Higher Percentage of Production will be Below Lower Limit';
elseif Zl3>6
   Zlrk3='- Inappropriate Engineering Specification';
else
   Zlrk3='- Production will be Within Lower Limit';
end

                str1={'Data Analysis Summary',...
   '===================================',...
   ['Capabilty Summary - ',dataname1],...
   '===================================',...
   ['Sample Mean(mu) : ',num2str(sd1.mu)],...
   ['Sample Standard Deviation(sigma) : ', num2str(sd1.sigma)],...
    ['Estimated probability of being within limits(P) : ', num2str(sd1.P)],...
     ['Estimated probability of being below L (lower spec)(Pl) : ', num2str(sd1.Pl)],...
       ['Estimated probability of being above U (upper spec)(Pu) : ', num2str(sd1.Pu)],...
       ['Cp, (U-L)/(6*sigma) : ', num2str(sd1.Cp)],...
        ['Cpl ,(mu-L)./(3.*sigma) : ', num2str(sd1.Cpl)],...
       ['Cpu ,(U-mu)./(3.*sigma) : ', num2str(sd1.Cpu)],...
        ['Cpk ,min(Cpl, Cpu) : ', num2str(sd1.Cpk)],...
              ['Cpm,(U-L)(6*t) :',num2str(Cpm)],...
         ['Capability Ratio,CR :',num2str(CR)],...
          ['Zu, (U-mu)/sigma :',num2str(Zu)],...
           ['Zl, (mu-L)/sigma :',num2str(Zl)],...
    'Remark:',Cprk,CRrk,Cpkrk,Zurk,Zlrk,...
    '===================================',...
    '',''};

 str2={'===================================',...
   ['Capabilty Summary - ',dataname2],...
   '===================================',...
   ['Sample Mean(mu) - ',num2str(sd2.mu)],...
   ['Sample Standard Deviation(sigma) - ', num2str(sd2.sigma)],...
    ['Estimated probability of being within limits(P) - ', num2str(sd2.P)],...
     ['Estimated probability of being below L (lower spec)(Pl) - ', num2str(sd2.Pl)],...
       ['Estimated probability of being above U (upper spec)(Pu) - ', num2str(sd2.Pu)],...
       ['Cp, (U-L)/(6*sigma) - ', num2str(sd2.Cp)],...
        ['Cpl ,(mu-L)./(3.*sigma) - ', num2str(sd2.Cpl)],...
       ['Cpu ,(U-mu)./(3.*sigma) - ', num2str(sd2.Cpu)],...
        ['Cpk ,min(Cpl, Cpu) - ', num2str(sd2.Cpk)],...
                    ['Cpm,(U-L)(6*t) :',num2str(Cpm2)],...
         ['Capability Ratio,CR :',num2str(CR2)],...
          ['Zu, (U-mu)/sigma :',num2str(Zu2)],...
           ['Zl, (mu-L)/sigma :',num2str(Zl2)],...
            'Remark:',Cprk2,CRrk2,Cpkrk2,Zurk2,Zlrk2,...
    '===================================',...
    '',''};

 str3={'===================================',...
   ['Capabilty Summary - ',dataname3],...
   '===================================',...
   ['Sample Mean(mu) - ',num2str(sd3.mu)],...
```

```
['Sample Standard Deviation(sigma) - ', num2str(sd3.sigma)],...
 ['Estimated probability of being within limits(P) - ', num2str(sd3.P)],...
  ['Estimated probability of being below L (lower spec)(Pl) - ', num2str(sd3.Pl)],...
    ['Estimated probability of being above U (upper spec)(Pu) - ', num2str(sd3.Pu)],...
    ['Cp, (U-L)/(6*sigma) - ', num2str(sd3.Cp)],...
     ['Cpl ,(mu-L)./(3.*sigma) - ', num2str(sd3.Cpl)],...
    ['Cpu ,(U-mu)./(3.*sigma) - ', num2str(sd3.Cpu)],...
     ['Cpk ,min(Cpl, Cpu) - ', num2str(sd3.Cpk)],...
              ['Cpm,(U-L)(6*t) :',num2str(Cpm3)],...
      ['Capability Ratio,CR :',num2str(CR3)],...
       ['Zu, (U-mu)/sigma :',num2str(Zu3)],...
        ['Zl, (mu-L)/sigma :',num2str(Zl3)],...
         'Remark:',Cprk3,CRrk3,Cpkrk3,Zurk3,Zlrk3,...
 '===================================',...
 ","};

 set(b3,'Enable','on');
set(b4,'Enable','on');
 set(b5,'Enable','on');
  set(b6,'Enable','on');
  set(b7,'Enable','on');
  set(b8,'Enable','on');
  set(b9,'Enable','on');
  set(b10,'Enable','on');
  set(b11,'Enable','on');
  set(b12,'Enable','on');
   set(b13,'Enable','on');
  set(b14,'Enable','on');
  set(b15,'Enable','on');

                    else
set(b1,'String','Experimental Data cannot be accessed')
  end

  set(b1,'String','Click buttons below to view plots')
str=[str1,str2,str3];
set(b2,'String',str)
 set(b16,'Enable','on')
function expbtn_callback(src,event)

global data1 data2 data3 data4 bound1 bound2 bound3...
    defnprobs capt extruder dataname1 dataname2 dataname3;
b1=findobj('Tag','anatxt');

capt=data4(:,1);
extruder=data4(:,2);
ml=length(data4);

 l=length(defnprobs);
 if l==1
siz1=size(data1);

if siz1(2)==1
    d1=data1;
else
d1=mean(data1')';
end

siz2=size(data2);
```

```
 for m=2:ml+1;
Table{ml+1,3} = [];
Table(1,1:3) = {'Caps Tan(rpm)' 'Extruder(rpm)'  dataname1};
Table(m,1)={num2str(capt(m-1,1))};
Table(m,2)={num2str(extruder(m-1,1))};
Table(m,3)={num2str(d1(m-1,1))};
end
footer='Design Experiment';
statdisptable(Table, 'Data Analysis', 'Experimental Result Table', footer,[-1 -1 0 -1 2 4]);

  elseif l==2
siz1=size(data1);

if siz1(2)==1
    d1=data1;
else
d1=mean(data1')';
end

siz2=size(data2);

if siz2(2)==1
    d2=data2;
else
d2=mean(data2')';
end




for m=2:ml+1;
Table{ml+1,4} = [];
Table(1,1:4) = {'Caps Tan(rpm)' 'Extruder(rpm)'  dataname1 dataname2};
Table(m,1)={num2str(capt(m-1,1))};
Table(m,2)={num2str(extruder(m-1,1))};
Table(m,3)={num2str(d1(m-1,1))};
Table(m,4)={num2str((d2(m-1,1)))};

end
footer='Design Experiment';


statdisptable(Table, 'Data Analysis', 'Experimental Result Table', footer,[-1 -1 0 -1 2 4]);

  elseif l==3
siz1=size(data1);

if siz1(2)==1
    d1=data1;
else
d1=mean(data1')';
end

siz2=size(data2);

if siz2(2)==1
```

```
   d2=data2;
else
d2=mean(data2')';
end

siz3=size(data3);

if siz3(2)==1
   d3=data3;
else
d3=mean(data3')';
end

for m=2:ml+1;
Table{ml+1,5} = [];
Table(1,1:5) = {'Caps Tan(rpm)' 'Extruder(rpm)'  dataname1 dataname2 dataname3};
Table(m,1)={num2str(capt(m-1,1))};
Table(m,2)={num2str(extruder(m-1,1))};
Table(m,3)={num2str(d1(m-1,1))};
Table(m,4)={num2str((d2(m-1,1)))};
Table(m,5)={num2str((d3(m-1,1)))};
end
footer='Design Experiment';
statdisptable(Table, 'Data Analysis', 'Experimental Result Table', footer,[-1 -1 0 -1 2 4]);

  elseif l>3

siz1=size(data1);

if siz1(2)==1
   d1=data1;
else
d1=mean(data1')';
end

siz2=size(data2);

if siz2(2)==1
   d2=data2;
else
d2=mean(data2')';
end

siz3=size(data3);

if siz3(2)==1
   d3=data3;
else
d3=mean(data3')';
end

for m=2:ml+1;
Table{ml+1,5} = [];
Table(1,1:5) = {'Caps Tan(rpm)' 'Extruder(rpm)'  dataname1 dataname2 dataname3};
Table(m,1)={num2str(capt(m-1,1))};
Table(m,2)={num2str(extruder(m-1,1))};
Table(m,3)={num2str(d1(m-1,1))};
Table(m,4)={num2str((d2(m-1,1)))};
```

```
Table(m,5)={num2str((d3(m-1,1)))};
end
footer='Design Experiment';
statdisptable(Table, 'Data Analysis', 'Experimental Result Table', footer,[-1 -1 0 -1 2 4]);

  else
set(b1,'String','Experimental Data cannot be accessed')
  end



function plotxbtn2_callback(src,event)

global data1 dataname1 bound1;
f3=figure('Name','Knowledge Based Design with Six Sigma -Data 1 X-Bar and S-Chart',...
    'NumberTitle','off',...
   'MenuBar','none');
subplot(2,1,1)

xbarplot(data1,0.997,bound1)
xlabel(dataname1)
ylabel('Mean ')
subplot(2,1,2)
schart(data1)
xlabel(dataname1)
ylabel('Standard Deviation')

function plotxbtn21_callback(src,event)

global data2 bound2 dataname2;
f3=figure('Name','Knowledge Based Design with Six Sigma - Data 2 X-Bar and S-Chart',...
    'NumberTitle','off',...
   'MenuBar','none');
subplot(2,1,1)
xbarplot(data2,0.997,bound2)
xlabel(dataname2)
ylabel('Mean ')
subplot(2,1,2)
schart(data2)
xlabel(dataname2)
ylabel('Standard Deviation')

function plotxbtn22_callback(src,event)

global data3 bound3 dataname3;
f3=figure('Name','Knowledge Based Design with Six Sigma - Data 3 X-Bar and S-Chart',...
    'NumberTitle','off',...
   'MenuBar','none');
subplot(2,1,1)
xbarplot(data3,0.997,bound3)
xlabel(dataname3)
ylabel('Mean ')
subplot(2,1,2)
schart(data3)
xlabel(dataname3)
ylabel('Standard Deviation')

%Histogram Fit
function histfitbtn1_callback(src,event)
```

```
global data1 dataname1;
f7=figure('Name','Knowledge Based Design with Six Sigma - Data 1 Histogram Fit',...
    'NumberTitle','off',...
   'MenuBar','none');

siz1=size(data1);

if siz1(2)==1
    d1=data1;
else
d1=mean(data1')';
end

histfit(d1)
h1 = findobj(gca,'Type','patch');   % let's format the plot
clr = [.9 .9 1];
set(h1,'FaceColor',clr,'EdgeColor','k')
[historic_mean, historic_stdev] = normfit(d1);
ylabel('Frequency (counts)')
xlabel(dataname1)
title(['Histogram Fit - ' dataname1])
z=length(d1);
text(d1(z),8,['Mean:',num2str(historic_mean)])
text(d1(z),7.5,['Stand Dev:',num2str(historic_stdev)])

function histfitbtn2_callback(src,event)

global data2 dataname2;
f7=figure('Name','Knowledge Based Design with Six Sigma - Data 2 Histogram Fit',...
    'NumberTitle','off',...
   'MenuBar','none');
siz2=size(data2);
if siz2(2)==1
    d2=data2;
else
d2=mean(data2')';
end

histfit(d2)
h1 = findobj(gca,'Type','patch');   % let's format the plot
clr = [.9 .9 1];
set(h1,'FaceColor',clr,'EdgeColor','k')
[historic_mean, historic_stdev] = normfit(d2);
ylabel('Frequency (counts)')
xlabel(dataname2)
title(['Histogram Fit - ' dataname2])
z=length(d2);
text(d2(z),35,['Mean:',num2str(historic_mean)])
text(d2(z),33,['Stand Dev:',num2str(historic_stdev)])

function histfitbtn3_callback(src,event)

global data3 dataname3;
f7=figure('Name','Knowledge Based Design with Six Sigma - Data 3 Histogram Fit',...
    'NumberTitle','off',...
   'MenuBar','none');
siz3=size(data3);
```

```
if siz3(2)==1
    d3=data3;
else
d3=mean(data3')';
end

histfit(d3)
h1 = findobj(gca,'Type','patch');   % let's format the plot
clr = [.9 .9 1];
set(h1,'FaceColor',clr,'EdgeColor','k')
[historic_mean, historic_stdev] = normfit(d3);
ylabel('Frequency (counts)')
xlabel(dataname3)
title(['Histogram Fit - ' dataname3])
text(0.7,35,['Mean:',num2str(historic_mean)])
text(0.7,33,['Stand Dev:',num2str(historic_stdev)])

%Probability Plot
function probplotbtn1_callback(src,event)

global data1 dataname1;
f3=figure('Name','Knowledge Based Design with Six Sigma - Probability Plot Data 1',...
    'NumberTitle','off',...
   'MenuBar','none');
probplot(data1)
ylabel('Percent')
xlabel(dataname1)

function probplotbtn2_callback(src,event)

global data2 dataname2;
f3=figure('Name','Knowledge Based Design with Six Sigma - Probability Plot Data 2',...
    'NumberTitle','off',...
   'MenuBar','none');
probplot(data2)
ylabel('Percent')
xlabel(dataname2)
function probplotbtn3_callback(src,event)

global data3 dataname3;
f3=figure('Name','Knowledge Based Design with Six Sigma - Probability Plot Data 3',...
    'NumberTitle','off',...
   'MenuBar','none');
probplot(data3)
ylabel('Percent')
xlabel(dataname3)

%Capability Plot
function capaplotbtn1_callback(src,event)

global data1 dataname1 bound1;
f3=figure('Name','Knowledge Based Design with Six Sigma - Capbability Plot Data 1',...
    'NumberTitle','off',...
   'MenuBar','none');

siz1=size(data1);

if siz1(2)==1
```

```
    d1=data1;
else
d1=mean(data1')';
end

capaplot(d1,bound1)
ylabel('Percent')
xlabel(dataname1)

function capaplotbtn2_callback(src,event)

global data2 dataname2 bound2;
f3=figure('Name','Knowledge Based Design with Six Sigma - Capability Plot Data 2',...
    'NumberTitle','off',...
   'MenuBar','none');
siz2=size(data2);
if siz2(2)==1
    d2=data2;
else
d2=mean(data2')';
end

capaplot(d2,bound2)
ylabel('Percent')
xlabel(dataname2)
function capaplotbtn3_callback(src,event)

global data3 dataname3 bound3;
f3=figure('Name','Knowledge Based Design with Six Sigma - Capability Plot Data 3',...
    'NumberTitle','off',...
   'MenuBar','none');
siz3=size(data3);
if siz3(2)==1
    d3=data3;
else
d3=mean(data3')';
end

capaplot(d3,bound3)
ylabel('Percent')
xlabel(dataname3)
%% Improvement Page

function improvbtn_callback(src,event)

global bound1 bound2 bound3  defnprobs d1 d2 d3 data4 ...
    t1 t2 t3 dataname1 dataname2 dataname3 capt extruder...
    data1 data2 data3 str


b1=findobj('Tag','improvtxt');
set(b1,'String','Anaylzing loaded Data ........')
b2=findobj('Tag','improvlistbox');
b3=findobj('Tag','coeftestbtn');
b4=findobj('Tag','coeftestbtn2');
b5=findobj('Tag','coeftestbtn3');
b6=findobj('Tag','predictbtn');
b7=findobj('Tag','predictbtn2');
```

```
b8=findobj('Tag','predictbtn3');
b9=findobj('Tag','simdatabtn1');
b10=findobj('Tag','simdatabtn2');
b11=findobj('Tag','simdatabtn3');
b12=findobj('Tag','exportsimdata');

%

 l=length(defnprobs);
  if l==1
        siz1=size(data1);
if siz1(2)==1
    d1=data1;
else
d1=mean(data1')';
end

for i=1:length(data4)
    dsim1(i,1)=d1(i);
end
sim1 = regstats(dsim1, data4, 'quadratic');
mse1=sim1.mse;
Rsquare1 = sim1.rsquare;
rmse1 = sqrt(sim1.mse);

      str1={'Improvment Summary',...
    '===================================',...
    ['Model Summary - ',dataname1],...
    '===================================',...
    ['MSE - ',num2str(mse1)],...
    ['Rsquare - ', num2str(Rsquare1)],...
     ['RMSE - ', num2str(rmse1)],...
         '===================================',...
     '',''};
 set(b2,'Enable','on');
  set(b3,'Enable','on');
  set(b4,'Enable','off');
   set(b5,'Enable','off');
    set(b6,'Enable','on');
    set(b7,'Enable','off');
    set(b8,'Enable','off');
    set(b9,'Enable','on');
    set(b10,'Enable','off');
    set(b11,'Enable','off');
    set(b12,'Enable','on');

    str2='';
    str3='';

       elseif l==2
          siz1=size(data1);
if siz1(2)==1
    d1=data1;
```

```
else
d1=mean(data1')';
end
for i=1:length(data4)
   dsim1(i,1)=d1(i);
end
  siz2=size(data2);
if siz2(2)==1
   d2=data2;
else
d2=mean(data2')';
end
for i=1:length(data4)
   dsim2(i,1)=d2(i);
end

sim1 = regstats(dsim1, data4, 'quadratic');
mse1=sim1.mse;
Rsquare1 = sim1.rsquare;
rmse1 = sqrt(sim1.mse);

sim2 = regstats(dsim2, data4, 'quadratic');
mse2=sim2.mse;
Rsquare2= sim2.rsquare;
rmse2 = sqrt(sim2.mse);
           str1={'Improvment Summary',...
               '====================================',...
    ['Model Summary - ',dataname1],...
    '====================================',...
    ['MSE - ',num2str(mse1)],...
    ['Rsquare - ', num2str(Rsquare1)],...
    ['RMSE - ', num2str(rmse1)],...
    '====================================',...
     '',''};
 str2={'====================================',...
    ['Model Summary - ',dataname2],...
    '====================================',...
    ['MSE - ',num2str(mse2)],...
    ['Rsquare - ', num2str(Rsquare2)],...
     ['RMSE - ', num2str(rmse2)],...
         '====================================',...
     '',''};

 str3='';
   set(b2,'Enable','on');
  set(b3,'Enable','on');
  set(b4,'Enable','on');
   set(b5,'Enable','off');
    set(b6,'Enable','on');
    set(b7,'Enable','on');
    set(b8,'Enable','off');
    set(b9,'Enable','on');
    set(b10,'Enable','on');
    set(b11,'Enable','off');
    set(b12,'Enable','on');

             elseif l==3
                 siz1=size(data1);
if siz1(2)==1
```

```
   d1=data1;
else
d1=mean(data1')';
end

for i=1:length(data4)
   dsim1(i,1)=d1(i);
end
siz2=size(data2);
if siz2(2)==1
   d2=data2;
else
d2=mean(data2')';
end
for i=1:length(data4)
   dsim2(i,1)=d2(i);
end
siz3=size(data3);
if siz3(2)==1
   d3=data3;
else
d3=mean(data3')';
end
for i=1:length(data4)
   dsim3(i,1)=d3(i);
end
sim1 = regstats(dsim1, data4, 'quadratic');
mse1=sim1.mse;
Rsquare1 = sim1.rsquare;
rmse1 = sqrt(sim1.mse);

sim2 = regstats(dsim2, data4, 'quadratic');
mse2=sim2.mse;
Rsquare2= sim2.rsquare;
rmse2 = sqrt(sim2.mse);

sim3 = regstats(dsim3, data4, 'quadratic');
mse3=sim3.mse;
Rsquare3= sim3.rsquare;
rmse3 = sqrt(sim3.mse);

        str1={'Improvment Summary',...
   '===================================',...
   ['Model Summary - ',dataname1],...
   '===================================',...
   ['MSE - ',num2str(mse1)],...
   ['Rsquare - ', num2str(Rsquare1)],...
    ['RMSE - ', num2str(rmse1)],...
       '===================================',...
    '',''};
 str2={'===================================',...
   ['Model Summary - ',dataname2],...
   '===================================',...
   ['MSE - ',num2str(mse2)],...
   ['Rsquare - ', num2str(Rsquare2)],...
    ['RMSE - ', num2str(rmse2)],...
       '===================================',...
    '',''};
  str3={'===================================',...
```

```
    ['Model Summary - ',dataname3],...
    '===================================',...
    ['MSE - ',num2str(mse3)],...
    ['Rsquare - ', num2str(Rsquare3)],...
     ['RMSE - ', num2str(rmse3)],...
        '===================================',...
     ","};
 set(b2,'Enable','on');
    set(b3,'Enable','on');
  set(b4,'Enable','on');
   set(b5,'Enable','on');
    set(b6,'Enable','on');
    set(b7,'Enable','on');
    set(b8,'Enable','on');
    set(b9,'Enable','on');
    set(b10,'Enable','on');
    set(b11,'Enable','on');
    set(b12,'Enable','on');


                elseif l>3
                    siz1=size(data1);
if siz1(2)==1
    d1=data1;
else
d1=mean(data1')';
end
for i=1:length(data4)
    dsim1(i,1)=d1(i);
end
siz2=size(data2);
if siz2(2)==1
    d2=data2;
else
d2=mean(data2')';
end
for i=1:length(data4)
    dsim2(i,1)=d2(i);
end
siz3=size(data3);
if siz3(2)==1
    d3=data3;
else
d3=mean(data3')';
end
for i=1:length(data4)
    dsim3(i,1)=d3(i);
end
  sim1 = regstats(dsim1, data4, 'quadratic');
mse1=sim1.mse;
Rsquare1 = sim1.rsquare;
rmse1 = sqrt(sim1.mse);

sim2 = regstats(dsim2, data4, 'quadratic');
mse2=sim2.mse;
Rsquare2= sim2.rsquare;
rmse2 = sqrt(sim2.mse);

sim3 = regstats(dsim3, data4, 'quadratic');
```

```
mse3=sim3.mse;
Rsquare3= sim3.rsquare;
rmse3 = sqrt(sim3.mse);

        str1={'Improvment Summary',...
    '===================================',...
    ['Model Summary - ',dataname1],...
    '===================================',...
    ['MSE - ',num2str(mse1)],...
    ['Rsquare - ', num2str(Rsquare1)],...
     ['RMSE - ', num2str(rmse1)],...
         '===================================',...
     '',''};
 str2={'===================================',...
    ['Model Summary - ',dataname2],...
    '===================================',...
    ['MSE - ',num2str(mse2)],...
    ['Rsquare - ', num2str(Rsquare2)],...
     ['RMSE - ', num2str(rmse2)],...
         '===================================',...
     '',''};
  str3={'===================================',...
    ['Model Summary - ',dataname3],...
    '===================================',...
    ['MSE - ',num2str(mse3)],...
    ['Rsquare - ', num2str(Rsquare3)],...
     ['RMSE - ', num2str(rmse3)],...
         '===================================',...
     '',''};
 set(b2,'Enable','on');
    set(b3,'Enable','on');
  set(b4,'Enable','on');
   set(b5,'Enable','on');
    set(b6,'Enable','on');
    set(b7,'Enable','on');
    set(b8,'Enable','on');
    set(b9,'Enable','on');
    set(b10,'Enable','on');
    set(b11,'Enable','on');
    set(b12,'Enable','on');

                        else
set(b1,'String','Experimental Data cannot be accessed')
  end

    set(b1,'String','Click buttons below to view plots')
str=[str1,str2,str3];
set(b2,'String',str)



function coeftestbtn_callback(src,event)
global bound1 bound2 bound3  defnprobs d1 d2 d3 data4 ...
    t1 t2 t3 dataname1 dataname2 dataname3 capt extruder

for i=1:length(data4)
    dsim1(i,1)=d1(i);
end
```

```
%
 coeffname = {'Cap tans' 'Extruder'...
    'C*E' 'C^2' 'E^2' ''};
sim1 = regstats(dsim1, data4, 'quadratic');
rmse1=sim1.mse

f5=figure('Name','Knowledge Based Design with Six Sigma - Coefficient Test Plot 1',...
    'NumberTitle','off',...
   'MenuBar','none');
 h = bar(sim1.beta(2:6)); set(h,'facecolor',[.8 .8 .9]);
 legend('Coefficient');
 set(gcf,'units','normalized','position',[.05 .4 .7 .4])
 set(gca,'xticklabel',coeffname);
 ylabel(dataname1)
 xlabel('Normalized Coefficient')
 title(['Quadratic Model Coefficients - ' dataname1])

 function coeftestbtn2_callback(src,event)

 function coeftestbtn3_callback(src,event)

function predictbtn_callback(src,event)
global data4 dataname1 d1 V1x1 V1x2 sn1 t1 Vy1
for i=1:length(data4)
    dsim1(i,1)=d1(i);
end
xname = {'Cap Tans';'Extruder'};
yname = {dataname1};
rstool(data4,dsim1,'quadratic',.05,xname,yname)

b2=findobj('Tag','linfig');
b3=findobj(gcf,'Type','axes');
set(b3,'ButtonDownFcn',@getValue1)

clear V1x1 V1x2 Vy1 sn1;
 mm=mean(data4);
 sn1=1;
V1x1=mm(1);
 V1x2=mm(2);
 Vy1=t1;



function predictbtn2_callback(src,event)
global data4 dataname2 d2 V2x1 V2x2 sn2 t2 Vy2
for i=1:length(data4)
    dsim2(i,1)=d2(i);
end
xname = {'Cap Tans';'Extruder'};
yname = {dataname2};
rstool(data4,dsim2,'quadratic',.05,xname,yname)

b2=findobj('Tag','linfig');
b3=findobj(gcf,'Type','axes');
set(b3,'ButtonDownFcn',@getValue2)
 mm=mean(data4)

 clear V2x1 V2x2 Vy2 sn2
```

```
 sn2=1;
V2x1=mm(1);
 V2x2=mm(2);
 Vy2=t2;

function predictbtn3_callback(src,event)
global data4 dataname3 d3 V3x1 V3x2 sn3 Vy3 t3
for i=1:length(data4)
    dsim3(i,1)=d3(i);
end
xname = {'Cap Tans';'Extruder'};
yname = {dataname3};
rstool(data4,dsim3,'quadratic',.05,xname,yname)

b2=findobj('Tag','linfig');
b3=findobj(gcf,'Type','axes');
set(b3,'ButtonDownFcn',@getValue3)
 mm=mean(data4);
  clear V3x1 V3x2 Vy3 sn3
 sn3=1;
V3x1=mm(1);
 V3x2=mm(2);
 Vy3=t3;



function getValue1(src,event)
    global V1x1 V1x2 Vy1 gvtxt1 dataname1 str sn1

b1=findobj('Tag','improvlistbox');

i=length(V1x1)+1
V1=get(gca,'CurrentPoint');

if V1(1,1)>500

V1x1(i)=V1x1(i-1);
V1x2(i)=V1(1,1);
Vy1(i)=V1(1,2);
else
V1x1(i)=V1(1,1);
V1x2(i)=V1x2(i-1);
Vy1(i)=V1(1,2);
end
sn1(i)=i;

gvtxt1={'==================================',...
    'Predicted Value',...
    '==================================',...
     ['Prediction No.' ':' num2str(sn1(i))],...
    ['Cap tans(rpm)' ':' num2str(V1x1(i))],...
    ['Extruder(rpm)' ':' num2str(V1x2(i))],...
    [dataname1 '(mm)' ':'  num2str(Vy1(i))],...
    '',''};
mstr1=[gvtxt1,str];
set(b1,'String',mstr1)

 function getValue2(src,event)
 global V2x1 V2x2 Vy2 gvtxt2 dataname2 sn2 str
```

```
b1=findobj('Tag','improvlistbox');

i=length(V2x1)+1;
V2=get(gca,'CurrentPoint');

if V2(1,1)>500

V2x1(i)=V2x1(i-1);
V2x2(i)=V2(1,1);
Vy2(i)=V2(1,2);
else
V2x1(i)=V2(1,1);
V2x2(i)=V2x2(i-1);
Vy2(i)=V2(1,2);
end
sn2(i)=i;

gvtxt2={'===================================',...
    'Predicted Value',...
    '===================================',...
     ['Prediction No.' ':' num2str(sn2(i))],...
    ['Cap tans(rpm)' ':' num2str(V2x1(i))],...
    ['Extruder(rpm)' ':' num2str(V2x2(i))],...
    [dataname2 '(mm)' ':'  num2str(Vy2(i))],...
    '','}
mstr2=[gvtxt2,str];
set(b1,'String',mstr2)

 function getValue3(src,event)
 global V3x1 V3x2 Vy3 gvtxt3 dataname3 sn3 str

b1=findobj('Tag','improvlistbox');

i=length(V3x1)+1
V3=get(gca,'CurrentPoint');

if V3(1,1)>500

V3x1(i)=V3x1(i-1);
V3x2(i)=V3(1,1);
Vy3(i)=V3(1,2);
else
V3x1(i)=V3(1,1);
V3x2(i)=V3x2(i-1);
Vy3(i)=V3(1,2);
end

sn3(i)=i;
gvtxt3={'===================================',...
    'Predicted Value',...
    '===================================',...
     ['Prediction No.' ':' num2str(sn3(i))],...
    ['Cap tans(rpm)' ':' num2str(V3x1(i))],...
    ['Extruder(rpm)' ':' num2str(V3x2(i))],...
    [dataname3 '(mm)' ':'  num2str(Vy3(i))],...
    '','}
mstr3=[gvtxt3,str];
```

```
set(b1,'String',mstr3)


function simdatabtn1_callback(src,event)

global V1x1 V1x2 Vy1 sn1 dataname1 Table1;

sn1=sn1';
V1x1=V1x1';
V1x2=V1x2';
Vy1=Vy1';

ml=length(sn1);

for m=2:ml+1;
Table1{ml+1,4} = [];
Table1(1,1:4) = {'Prediction No.' 'Caps Tan(rpm)' 'Extruder(rpm)'  dataname1};
Table1(m,1)={num2str(sn1(m-1,1))};
Table1(m,2)={num2str(V1x1(m-1,1))};
Table1(m,3)={num2str(V1x2(m-1,1))};
Table1(m,4)={num2str(Vy1(m-1,1))};
end
footer=['Simulation Data - ' dataname1];
statdisptable(Table1, ['Data Improvement -' dataname1], 'Simulation Result Table', footer,[-1 -1 0 -1 2 4]);

function simdatabtn2_callback(src,event)

global V2x1 V2x2 Vy2 sn2 dataname2 Table2;

sn2=sn2';
V2x1=V2x1';
V2x2=V2x2';
Vy2=Vy2';

ml=length(sn2);

for m=2:ml+1;
Table2{ml+1,4} = [];
Table2(1,1:4) = {'Prediction No.' 'Caps Tan(rpm)' 'Extruder(rpm)'  dataname2};
Table2(m,1)={num2str(sn2(m-1,1))};
Table2(m,2)={num2str(V2x1(m-1,1))};
Table2(m,3)={num2str(V2x2(m-1,1))};
Table2(m,4)={num2str(Vy2(m-1,1))};
end
footer=['Simulation Data - ' dataname2];
statdisptable(Table2, ['Data Improvement -' dataname2], 'Simulation Result Table ', footer,[-1 -1 0 -1 2 4]);

function simdatabtn3_callback(src,event)

global V3x1 V3x2 Vy3 sn3 dataname3 Table3;

sn3=sn3';
V3x1=V3x1';
V3x2=V3x2';
Vy3=Vy3';

ml=length(sn3);
```

```
for m=2:ml+1;
Table3{ml+1,4} = [];
Table3(1,1:4) = {'Prediction No.' 'Caps Tan(rpm)' 'Extruder(rpm)'  dataname3};
Table3(m,1)={num2str(sn3(m-1,1))};
Table3(m,2)={num2str(V3x1(m-1,1))};
Table3(m,3)={num2str(V3x2(m-1,1))};
Table3(m,4)={num2str(Vy3(m-1,1))};
end
footer=['Simulation Data - ' dataname3];
statdisptable(Table3, ['Data Improvement -' dataname3], 'Simulation Result Table ', footer,[-1 -1 0 -1 2 4]);

function exportsimdata_callback(src,event)
global V1x1 V1x2 V2x1 V2x2 V3x1 V3x2 Vy1 Vy2 Vy3 ...
    PathName dataname1 dataname2 dataname3 str
b1=findobj('Tag','improvlistbox');
b2=findobj('Tag','improvtxt');

set(b2,'String','Simulation Data Exportiing .......')

sfile4a=[PathName,'Simdatainput1.xlsx'];
simout1=[PathName,'Simdataoutput1.xlsx'];
simdata1=[V1x1 V1x2];
 exportsiminput1 = XLSWRITE(sfile4a,simdata1,'InputData');
exportsiminput1b = XLSWRITE(simout1,Vy1,'Sheet1');

 sfile4b=[PathName,'Simdatainput2.xlsx'];
 simout2=[PathName,'Simdataoutput2.xlsx'];
simdata2=[V2x1 V2x2];
 exportsiminput2 = XLSWRITE(sfile4b,simdata2,'InputData');
 exportsiminput2b = XLSWRITE(simout2,Vy2,'Sheet1');

  sfile4c=[PathName,'Simdatainput3.xlsx'];
  simout3=[PathName,'Simdataoutput3.xlsx'];
simdata3=[V3x1 V3x2];
 exportsiminput3 = XLSWRITE(sfile4c,simdata3,'InputData');
 exportsiminput3b = XLSWRITE(simout3,Vy3,'Sheet1');

 exporttxt={'==================================',...
    'Simulated Data Export Paths',...
    '==================================',...
    ['Simulation of Input Data for - ' dataname1 ':' sfile4a ],...
    ['Simulation of Output Data for - ' dataname1 ':' simout1 ],...
     ['Simulation of Input Data for - ' dataname2 ':' sfile4b ],...
     ['Simulation of Output Data for - ' dataname2 ':' simout2 ],...
      ['Simulation of Input Data for - ' dataname3 ':' sfile4c ],...
     ['Simulation of Output Data for - ' dataname3 ':' simout3 ],...
    '',''}
mstr=[exporttxt,str];
set(b1,'String',mstr)
set(b2,'String','Simulation Data Exported to Current Folder Directory')
```

APPENDIX R

GUI VISUAL DISPLAYS

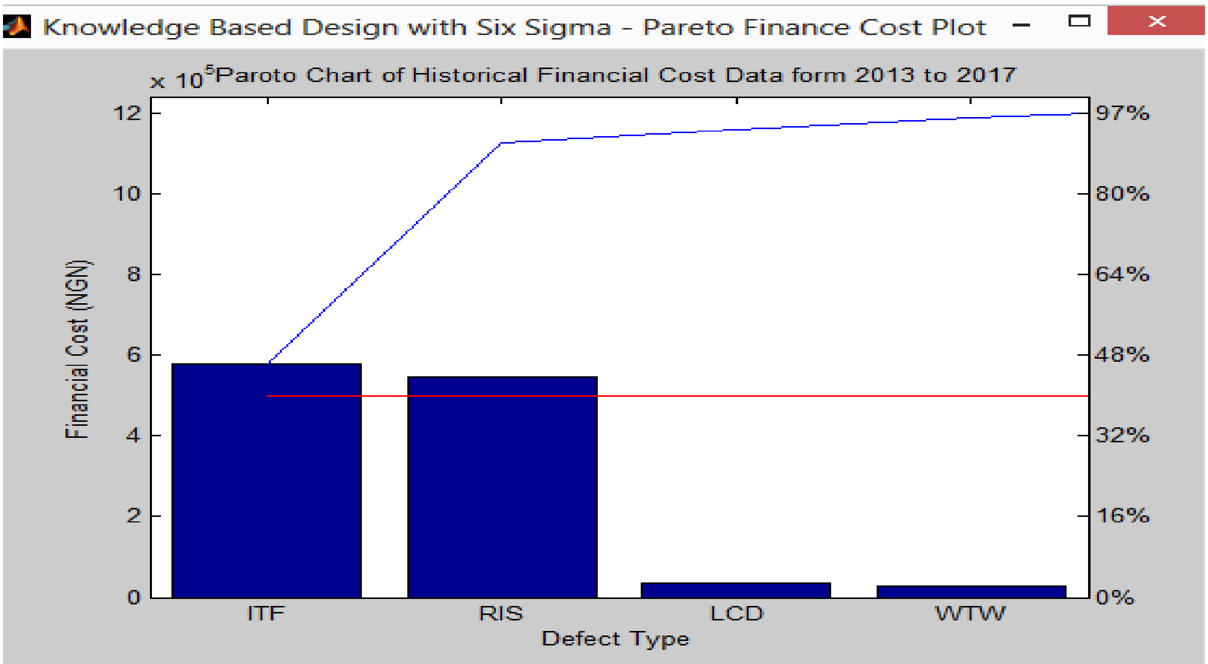


Fig R1: Pareto Chart Display

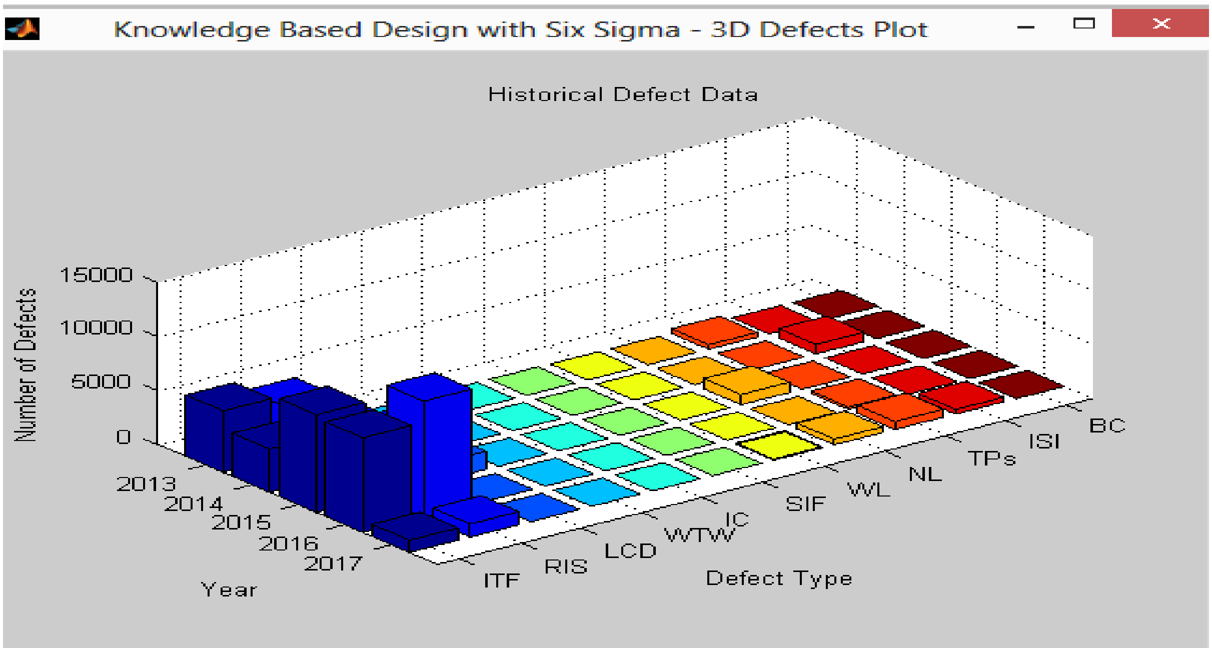


Fig R2: Defect Quantity Display

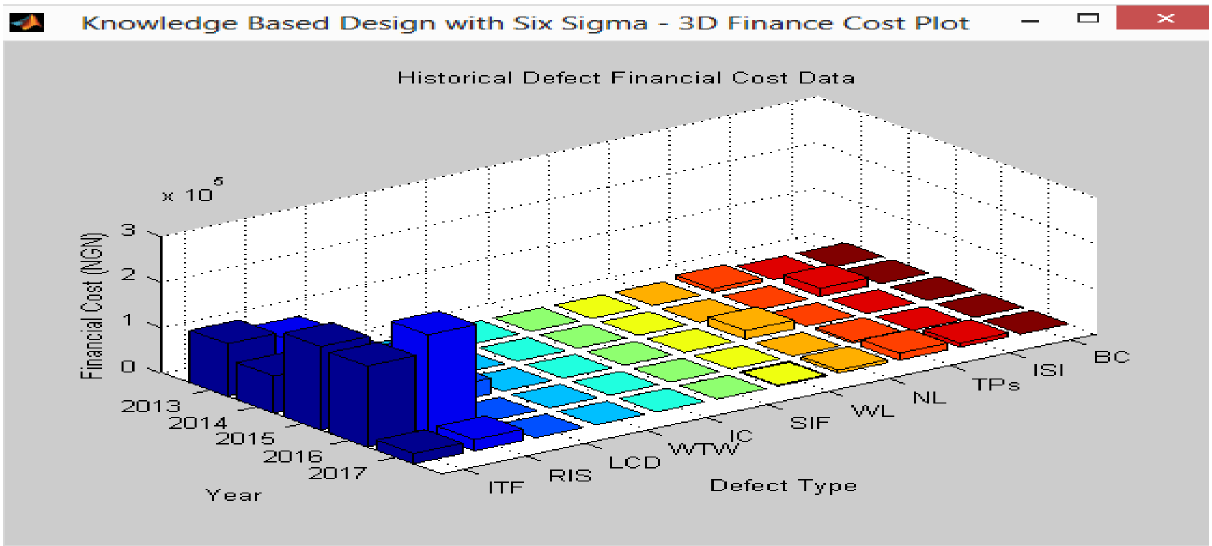


Fig R3: Defects and Associated Financial Cost GUI Display

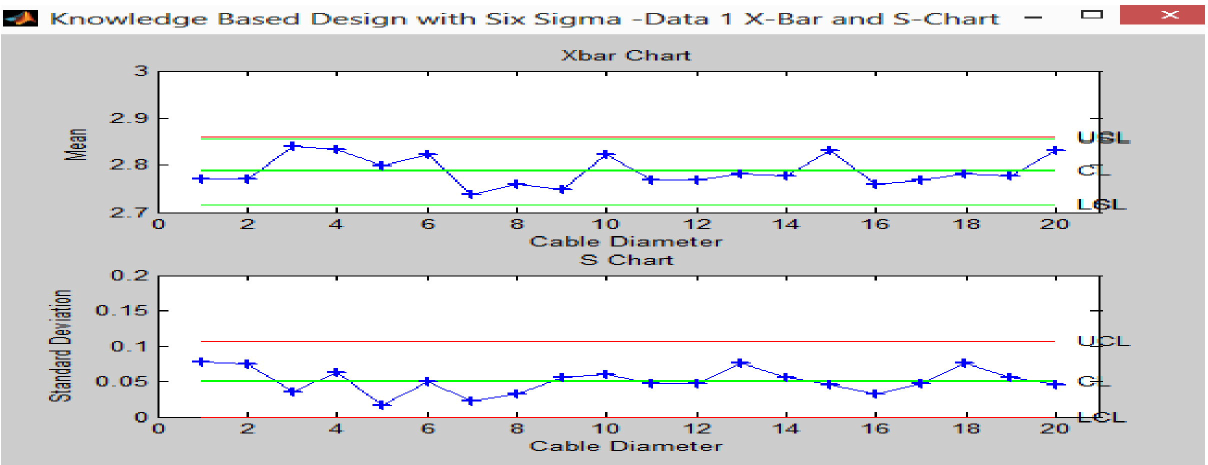


Fig R4: X-Bar and S-Chart GUI Display

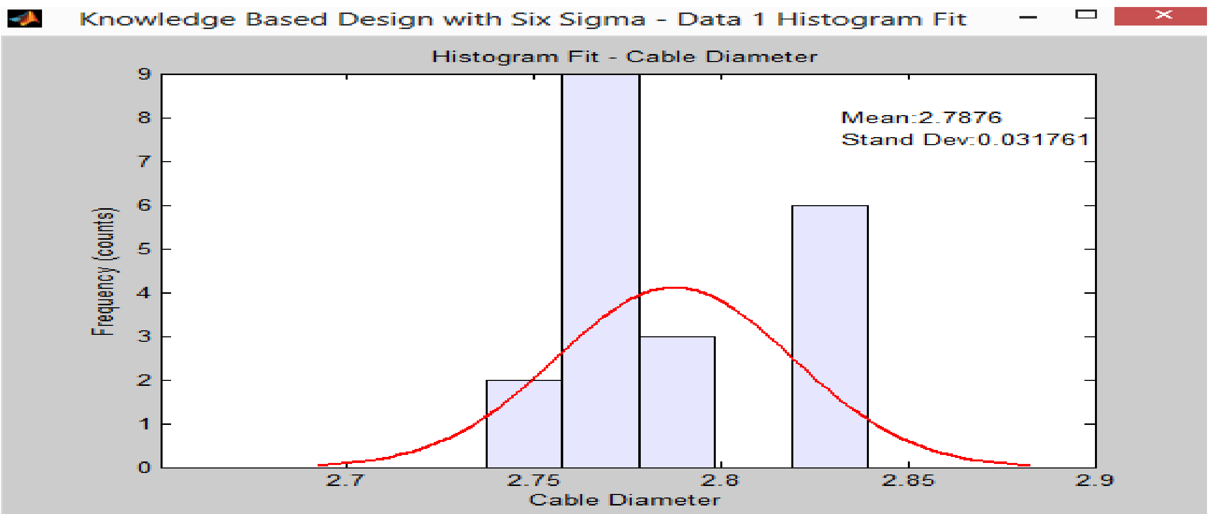


Fig R5: Histogram GUI Display

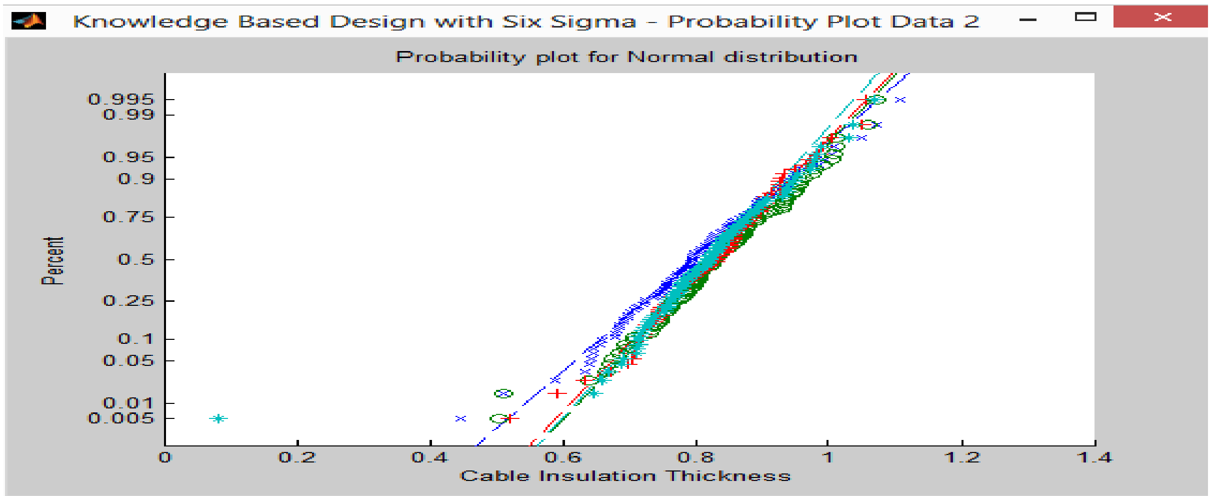


Fig R6: GUI Display of the Probability Plot

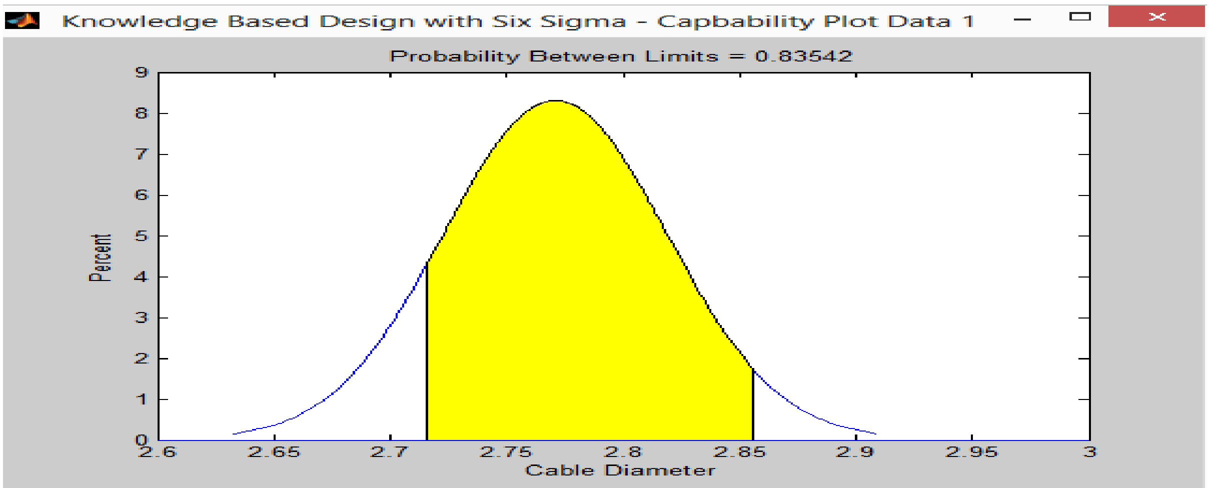


Fig R7: GUI Display of the Capability Plot

Figure 5: Data Analysis

File Edit View Insert Tools Desktop Window Help

Experimental Result Table

Caps Tan(rpm)	Extruder(rpm)	Cable Diameter	Cable Insulation Thickness
375	875	2.77	0.7945
375	900	2.7698	0.88312
375	925	2.8394	0.62615
375	950	2.8346	0.7615
400	875	2.7984	0.78313
400	900	2.8232	0.80238
400	925	2.7372	0.88325
400	950	2.7596	0.79875
425	875	2.75	0.79275
425	900	2.8238	0.82613
425	925	2.7678	0.86825
425	950	2.7682	0.87988
450	875	2.7814	0.84813
450	900	2.7764	0.8495
450	925	2.8324	0.83463
450	950	2.7606	0.88975

Design Experiment

Fig R8: Experimental Result of the GUI Display

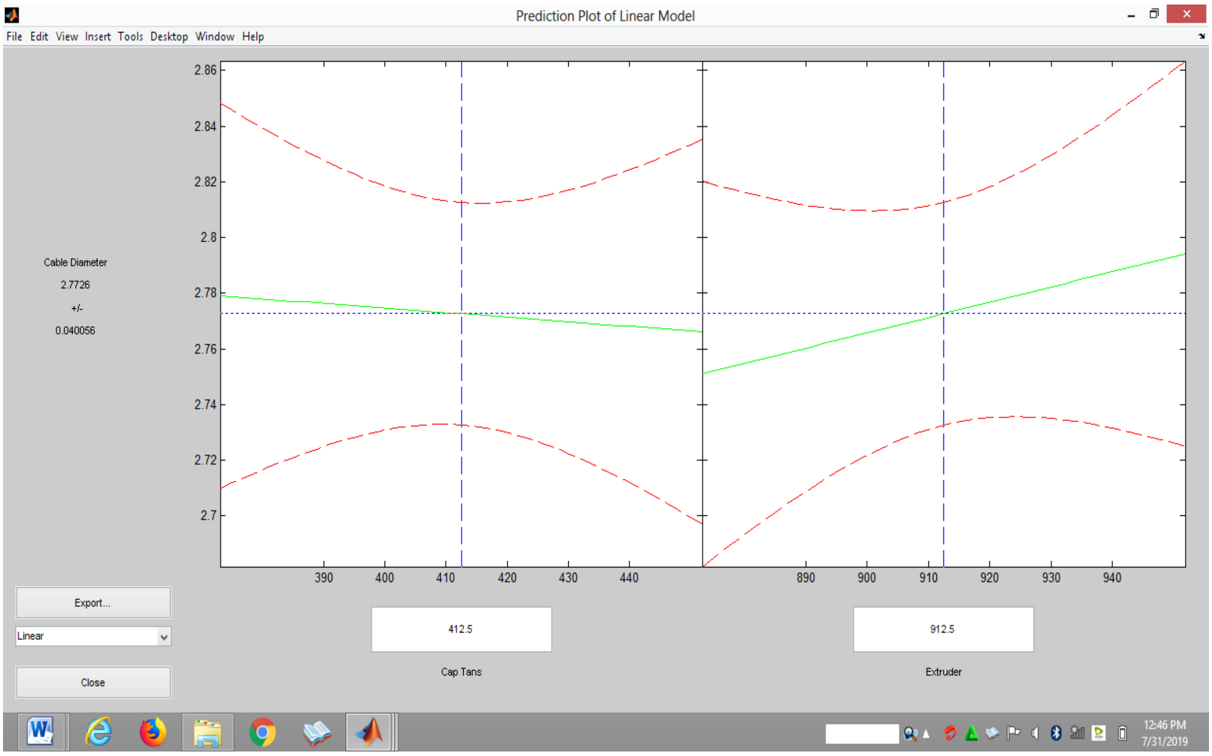


Fig R9: Prediction Plot of the GUI Model

Figure 3: Data Improvement -Cable Diameter

File Edit View Insert Tools Desktop Window Help

Simulation Result Table

Prediction No.	Caps Tan(rpm)	Extruder(rpm)	Cable Diameter
0	389.8514	0	0
2	389.8514	886.6777	2.7558
3	389.8514	895.8198	2.7695
4	420.423	895.8198	2.8284
5	404.0968	895.8198	2.802
6	399.6151	895.8198	2.8274
7	399.6151	886.5173	2.8004
8	399.6151	895.9801	2.7837
9	381.2081	895.9801	2.7837
10	378.9672	895.9801	2.7776
11	427.4657	895.9801	2.7935
12	427.4657	884.2719	2.7848
13	427.4657	895.6594	2.7754

Simulation Data - Cable Diameter

Fig R10: Display of the Simulation Results from GUI

APPENDIX S: Study Application Letter to Cutix Cable Plc

APPENDIX T: Acknowledgement Letter from Cutix Cable Plc

APPENDIX U

Publications from this Research So Far