



Addis Ababa University

College of Technology and Built Environment

School of Mechanical and Industrial Engineering

Industrial Engineering stream

Lean-Six Sigma Approach for Enhanced Efficiency and Quality in Textile Manufacturing; a Case of Else Addis Industrial Development P.L.C., Ethiopia

A master's thesis submitted to the Addis Ababa University College of Technology and Built Environment School of Mechanical and Industrial Engineering partially fulfills the requirements for a master's degree in science in the Industrial Engineering stream

By: Asefa Kebede

Advisor: Dr. Ameha Mulugeta(PhD)

Co-Advisor: Mehret Getachew (Ph. D Cand.)

March 2025

Addis Ababa, Ethiopia



Addis Ababa University
College of Technology and Built Environment
School of Mechanical and Industrial Engineering
Industrial Engineering Stream

**Lean-Six Sigma Approach for Enhanced Efficiency and Quality in Textile
Manufacturing; a Case of Else Addis Industrial Development P.L.C., Ethiopia**

**By: Asefa Kebede
(ID No. 2948/2014)**

Student's signature _____

Approved By the Board of Examiner:

_____	_____	_____
Advisor:	Signature	Date
_____	_____	_____
Co-Advisor:	Signature	Date
_____	_____	_____
Internal Examiner:	Signature	Date
_____	_____	_____
External Examiner:	Signature	Date
_____	_____	_____
Member of school's AC	Signature	Date
_____	_____	_____
Interim head, SMiE	Signature	Date
_____	_____	_____
Interim Executive Dean for Academic Affairs	Signature	Date

Acknowledgement

First and foremost, I would like to express my deepest gratitude to God for giving me the strength, wisdom, and perseverance to complete this research. I am sincerely grateful to my advisor Dr. Ameha Mulugeta and co-advisor Mehret Getachew (PHD Cand.) for their invaluable guidance, constructive feedback, and continuous encouragement throughout this study. There are also thank full for Else Addis Industrial Development P.L.C. production manager and workers for granting me access to their facilities, sharing critical data, and providing necessary data.

Lastly would like to acknowledge the support of my colleagues, friends, and family, for their motivation, advice, and moral support during the challenging phases of this work. This research would not have been possible without the collective support of these individuals and institutions. I am truly thankful for their assistance.

Abstract

The study focuses on addressing textile product quality and process inefficiency challenges, as well as how to enhancing product quality and efficiency through the Lean Six Sigma principles, tools, and techniques in Ethiopia's textile industry, specifically targeting the production of 40Ne yarn count. This particular yarn count was selected due to its recurring quality and efficiency issues, making it a critical area for improvement. The research employs both qualitative and quantitative methods to assess product quality and process efficiency, ensuring a comprehensive validation of the existing problems.

During case company observation major defect were recorded with amount of defect rejected. The major defect identified were; count variation, yarn hairiness, thin-thick place, winding fault, shape of the cone, bad piecing, and nep formation. From the major defect Pareto chart analysis revealed three major defect types contributing to 64% of quality issues. These are count variation (24%), yarn hairiness (22%), and thin/thick places (18%). Root cause analysis using fishbone diagrams identified key contributors including machine inconsistencies, operator skill gaps, material flow inefficiencies, and measurement errors.

Also, from observed data, process efficiency evaluation showed big waste, with only 47.7% value-added time versus 52.3% non-value-added activities, primarily from motion waste (40.4%). The current sigma level of 3.25 indicated big process variability. The DMAIC framework was applied to address these challenges, integrating Lean tools like 5S and Value Stream Mapping (VSM) to reduce waste and Six Sigma methods to minimize defects

DPMO and sigma levels was determined based production per months and defect rejection in production per month. Through the compressive analysis of the winding process using tools, process mapping, 5S, and DMAIC approach with tools, and based on the findings of the analysis, this study was developed and proposes an improvement strategy for the yarn manufacturing industry.

Key Word: *Lean-Six Sigma, DMAIC, Yarn Defects, Process Efficiency, Textile Manufacturing, Quality Improvement.*

Table of Contents

Abstract	vii
List of Table	xi
List of Figure	xii
List of Abbreviations	xiii
CHAPTER ONE	1
INTRODUCTION AND BACKGROUNDS	1
1.1. Introduction	1
1.2. Background of the Study	2
1.3. Statement of the Problem	4
1.4. Research Question	6
1.5. Objective of the Study	7
1.5.1. General Objective	7
1.5.2. Specific Objectives	7
1.6. Significances of the Research	8
1.7. Scope of the Study	8
1.8. Limitation of the study	9
CHAPTER TWO	10
LITERATURE REVIEW	10
2.1. Introduction to Lean Manufacturing	10
2.2. Principles of Lean Manufacturing	11
2.3. Lean Waste in Manufacturing Industry	12
2.4. Basic Concepts and Principles of Six-Sigma	13
2.5. The DMAIC's Roadmap	14
2.6. The Lean-Six Sigma (LSS) Approach	16
2.7. Lean and Six-Sigma Tools	18
2.8. Lean Tools, and Analytical Methods	19
2.9. Review of Related Empirical Literatures	21
2.10. Research Gap	23
CHAPTER THREE	23
Methodology	24
3.1. Research Design	24
3.2. The Research Procedure and Framework	24

3.3.	Data Collection Plan.....	26
3.3.1.	Primary data Collection tools.....	26
3.3.2.	Secondary Data Collection	26
3.4.	Techniques for Data Analysis	27
3.5.	Research population	28
3.6.	Ethical Considerations.....	29
CHAPTER FOUR.....		30
Result and Discussion.....		30
4.1.	Introduction of Case Company Description.....	30
4.2.	Study Area and Product Selection Methods.....	32
4.3.	Product Quality and Process Efficiency measurement on winding section.....	35
4.3.1.	Product quality measurement (yarn quality measurement)	35
4.3.2.	Process efficiency measurements	38
4.4.	Product Quality Analysis with DMAIC Approach	39
4.4.1.	Define phase:	40
4.4.2.	Measurement phase	42
4.4.3.	Analysis phase	45
4.4.4.	Improving and controlling the root causes of defect using (why-why analysis).....	50
4.5.	Process efficiency analysis with lean Approach	53
4.5.1.	Methods of Controlling of Waste Activity (NVA activities).....	55
4.6.	Discussion	57
4.7.	Proposing LSS integration model	57
CHAPTER FIVE		60
Conclusion and Recommendation		60
5.1.	Conclusion.....	60
5.2.	Recommendation.....	60
References.....		62

List of Table

Table 2:1 principle of six sigma	13
Table 3:1 Summery of Data Analysis	28
Table 3:2 Research population	29
Table 4:1 utilizing Five Months (January 01/2024 to May 30/2024) defect recorded data.	32
Table 4:2 product quality Identification	34
Table 4:3 Tested Parameters and Results	35
Table 4:4 Tested result of 40Ne yarn	36
Table 4:5 process activity time measurement	38
Table 4:6 observed result waste activity or process	39
Table 4:7 SIPOC diagram chart	41
Table 4:8 process activity time measurement	44
Table 4:9 Analysis of major defects based on pareto charts	45
Table 4:10 controlling the root causes of defect using (why-why analysis)	51
Table 4:11 Value added and nonvalue added percentage	54
Table 4:12 summary of the table	54
Table 4:13 Non value adding percentage	54
Table 4:14 The major root cause of waste activity	55

List of Figure	
Figure 2:1 DMAIC Road map	14
Figure 2:2 Analog Between Lean and Six Sigma	17
Figure 3:1 Research Procedure and Framework	25
Figure 4:1 Flow Chart of Case Company	30
Figure 4:2 Else Addis Industrial Development (Google Map 2024)	30
Figure 4:3 histogram chart for Area selection	33
Figure 4:4 product comparison histogram chart	34
Figure 4:5 Process mapping of the yarn packaging	45
Figure 4:6 pareto chart analysis	46
Figure 4:7 root cause analysis of count variation	47
Figure 4:8 root cause analysis of yarn hairiness	48
Figure 4:9 root cause analysis of thin- thick place	49
Figure 4:10 Controlling Strategies of Waste Activity	56
Figure 4:11 proposing LSS methods	59

List of Abbreviations

QC:	Quality Control
VAA:	Value Added Activity
NVAA:	Non-Value-Added Activity
SPC:	Statistical Process Control
DMAIC:	Define, Measure, Analyse, Improve, Control
DMADV:	Define, Measure, Analyse, Design, Verify
PCE:	Process Cycle Efficiency
GTP:	Growth Transformation Plan
SIPOC:	Supplier, Input, Process, Output, Customer
DPMO:	Defects per Million Opportunities
TQM:	Total Quality Management,
TPM:	Total Preventive Maintenance,
LSS:	Lean-Six-Sigma
C/T:	Cycle Time

CHAPTER ONE

INTRODUCTION AND BACKGROUNDS

1.1. Introduction

In the current competitive business era, many manufacturing companies have found themselves in great competition for survival; this has driven companies to constantly desire to improve the quality of their products and reduce costs (Potkány et al., 2022). Product quality is the capability of manufactured goods to perform its functions; this includes usually durability, consistency, correctness, ease of function, and manufactured goods repair, as well as other product characteristics. Good or bad quality depends on the company's capabilities and standards able to attain the customer perceptions constantly (Keke et al., 2023). The extreme business competition in getting better the product quality makes quality as the most important for companies in complex systems and limited resources (Adrian & Kosasih, 2023).

Hence, process control, product control and quality improvement are the most remarkable activity in most manufacturing industrial systems (Taylan & Darrab, 2012). The quality of manufactured goods is considered as the main weapon in business competition that provides guarantee for users on the subject of the products that they used (Keke et al. 2023). The fundamental goal of QC is to ensure manufactured goods, and services provided by organization attain customer requirement, reliable, at required quality, and optimum cost (Yang & Pan, 2021).

The key performance indicators for becoming competitive are shorter lead times, higher productivity, better use of resources, better quality, and improved process efficiency (Li et al., 2018). By identifying opportunities for problem solving, defect, imperfection, and process variability reduction, LSS aims to increase manufacturing in order to achieve these goals.

Hence, sound process and quality control strategy is concerned in these industries (Yang & Pan, 2021). As a result, past researchers proposed several enhancement strategies and tools to attain organizational demands, including; Total Quality Management, Quality Awards, Total Preventive Maintenance, Lean and Six Sigma (Gupta, 2013a, 2013b).

1.2. Background of the Study

The textile industry is one of the oldest and largest export industries, generating billions of dollars in sales globally each a year. It is divided into the production of clothing and textiles, having as main characteristics the development of fashion trends, brands, the development of the distribution network through the shops and the optimization of the logistics from production to stores (Dinulescu & Dima, n.d.). The global textile industry faces intensifying competitive pressures, with spinning mills particularly challenged by rising raw material costs, quality demands, and the need for operational excellence. The other challenges are, process waste as well as waste due to defective product and quality loss that occur in the textile yarn production process adversely affects the efficiency of Textile Company in winding, kitting, and weaving processes.

Hence, superior process and quality controlling approach is needed for textiles and apparel industries (Yang & Pan, 2021). To attain the competitive advantage in the market, the industry is turning towards the emerging and effective management techniques and quality improvement methodologies such as Lean and Six Sigma methodologies (Hussain, 2014). LSS combines the wastage-reduction approach of Lean Manufacturing with the statistical methods of Six Sigma for reducing defects, offering a process-improvement methodology. Research confirms its effectiveness in managing high defect rates, inefficiencies in supply chains, and wastage of resources, which are critical issues in textile manufacturing. (Ajmera1, 2017).

Six-Sigma helps in the detection of problems related to the production processes, their examination, improvement and controlling method. While, the Lean methodology's focal point is on consumer, the process flow, and waste detection. Six Sigma methodologies have been applied in various areas in textile industry for the improvement of textile products quality through the reduction of defects occurrence (Hussain, 2014; R. S. Kumar, 2010). For instance, (Mukhopadhyay 2015) studied the application of Six Sigma methodology for reducing yarn packing defects; (Gupta 2013b) studied the implementation of Six Sigma for minimizing the defects rate at a yarn manufacturing company; (Tanveer Hussain 2014) the application of Six Sigma methodology for reducing defects in textile weaving industry of Pakistan. Moreover, (S. Kumar et al. 2023) studied the application of DMAIC methodology for increasing the yarn quality in textile industry.

In the other regard, (Gupta 2013b) studied the practice of Lean manufacturing in textile industries. Despite of the efforts undertaken, it is also mentioned that using the Lean or Six Sigma tools separately has limitations (Hussain, 2014). Hence, considering both Six Sigma and Lean tools together can result in far better improvements than that could not be achieved by using separate methods (Gupta, 2013b). In this regard, in textile industry (Adrian and Kosasih 2023) introduced Lean-Six-Sigma strategy for increasing knitted fabric manufacturing profitability through enhancing the fabric quality and operational efficiency.

In this research work, Lean-Six Sigma simultaneously with the five phases of DMAIC methodology will be considered to develop and propose a model as an improvement strategy for the reduction of defects, as well as unnecessary movement (waste activity), and product quality improvement in textile yarn manufacturing industry. A case study will be conducted at Else Addis Industrial Development P.L.C operating in Ethiopia.

Since Ethiopia's prioritized rapid industrialization in both of its first and second Growth and Transformation Plans (GTPs), the country's expanding textile and apparel industries are bringing about new dynamics in the growth of the manufacturing sector by creating in foreign direct investment and generating employment. According to a declaration from the Ministry of Trade and Industry, manufacturing of textiles and apparel is currently a major economic activity with the objective of limiting the expansion of the national economy through the creation of foreign exchange. Increased export revenue, investment in the subsector, and effective utilization of the actual manufacturing capacity are the primary objectives (Value & Roadmap, 2020). Currently, there are multiplicities of textile and apparel investments in Ethiopia. Among these, Else Addis Industrial Development P.L.C is one of an Integrated Textile Factory that is operating in Ethiopia, Oromia Regional State, East Showa Zone at Adama City.

Two Turkish shareholders founded this company in 2006 E.C. in accordance with Ethiopia's Commercial Code. The spinning section, also known as the yarn manufacturing section, is one of the company's manufacturing divisions. The blow room, carding, draw frame, roving frame, and ring frame are made up of these sections. The process is called as yarn manufacturing process also called as spinning process. The output of the yarn manufacturing section is yarn in the form of specially made package called cops. The next section is called the winding section. The output of

the first yarn manufacturing section is used as the input of the winding section. The process is called as yarn winding to the convenient form of package, which will be an input to the next woven fabrics, and knitted fabric-manufacturing process. The Else Addis Industrial Development P.L.C produces textile yarns (that 40Ne, 20Ne and 16Ne), woven fabrics, and knitted fabric.

1.3. Statement of the Problem

In the textile industry, both the process efficiency and product quality are closely linked to worker movement (value added and non-value-added waste) and quality of yarn used. As clearly elaborate in the introduction part the first step of textile manufacturing process starts from conversion of fibre in to a yarn, which are used to make clothing. This processing step confirmed that quality of textile will be affected by the quality of yarn used. So, it is believed that investing more time on maintaining good quality of yarn processing will reduce the total textile processing problem. Bihola & Amin (2015) support this notation by confirming that problematic issues in textiles are more responsible for deterioration of yarn quality. Because of poor yarn quality, there are breakages in the process and even deteriorate the fabric appearance, especially in weaving and knitting department.

There are several theoretical gaps that justify this problem; First, while Lean and Six Sigma have been applied separately in the textile industry, in Ethiopia there is still poor research on their integrated application (Lean-Six Sigma, LSS) in yarn manufacturing. Previous studies (Gupta, 2013b; Hussain, 2014) only focused on either Lean or Six Sigma alone and did not consider the synergistic benefits of using both approaches. DMAIC has been used in many textile industries and internationally, but there is not sufficient empirical work on it in Ethiopian textile firms where the constraints in operations such as lack of skilled gap and inconsistent functioning of machines would call for a tailored solution. Additionally poor yarn quality affect downstream processes in textile industry, there is insufficient quantitative analysis on its financial and operational impact.

On the other hand, preliminary survey of case company (Else Addis Industrial Development plc) spinning department shows the existence of yarn product quality problem. A 2024 fiscal year five-month (January to May) quality control department data were taken to study whether the defects rejection is existed or not. The result from this survey shows that the spinning department is

suffering in production of defect yarn, especially in winding section. Five months data from the Case company showed that out of the produced 644,289-kilogram yarn with in the five months, around 37,290 kilogram is produced defect rejected product. From spinning department winding section is the main challenge area that more defect rejection or 40Ne yarn defected existed. Objective of the company is to produce quality product (40Ne, 20Ne, and 16Ne yarn) and as well as to produces this by good process performance. Also, the preliminary survey identified that major defects existed in 40Ne like; Count Variation (CV), Thin places, thick places, Nep, unevenness, shape of cone and winding faults are the most frequently happening in this product.

In other way process efficiency in textile manufacturing is hindered by unnecessary movement of workers and recurring yarn defects. Unnecessary workers activities such as unwanted walking, material searching, and unorganized workspace layouts are consumed valuable time without contributing to production output. These inefficiencies adding cycle times, reduce throughput, and increase labour costs.

The study aims to identify the root causes from various perspectives, evaluate the amount of defect rejection and wastes (non-value-added activities) using time measurement at Else Addis Industrial Development P.L.C. In addition, assess their impact on product quality and process performance to propose effective strategies for managing process efficiency and product quality a strategy based on an integrated Lean-Six Sigma approach through the DMAIC (Define, Measure, Analyse, Improve, and Control) methodology. The study seeks that reduces wastes activities (non-value added) and yarn defect rejection, enhancing product quality and process efficiency in textile yarn manufacturing

1.4 Research Question

- ❖ What is the primary source of waste in textile yarn manufacturing process at Else Industrial Development P.L.C.
- ❖ How can lean six sigma methodologies be effectively integrated into the existing production process to enhance efficiency?
- ❖ What strategies can be implemented to improve process efficiency and product quality in case company?

1.5. Objective of the Study

1.5.1. General Objective

The general objective of the study is going to improve product quality as well as processes efficiency particularly in the spinning department by using an integrated approach of lean six sigma (LSS) methodology: a Case study has been conducted at Else Addis Industrial Development P.L.C, Ethiopia.

1.5.2. Specific Objectives

- ❖ To identify and analyse the primary sources of waste (non-value-added activities) in the yarn manufacturing process at Else Addis Industrial Development P.L.C.
- ❖ To develop and evaluate a Lean Six Sigma integration framework for optimizing process efficiency and product quality in the yarn manufacturing process.
- ❖ To propose effective strategies for managing and reducing defects as well as waste activities of yarn manufacturing using LSS methodology.

1.6. Significances of the Research

This work has big academic and industrial value in the Ethiopian textile yarn manufacturing sector. The study explores the operational inefficiencies of Else Addis Industrial Development P. L. C. in particular waste generation and product defects in yarn winding. The study applies Lean Six Sigma (LSS) methodology to systematically address inefficiencies, reduce defect levels, and improve production. The achieved framework directly benefits the product quality and operational efficiency of the company which is essential in order to maintain its competitiveness.

From an academic viewpoint, this work fills a critical need in LSS applications to yarn manufacturing, where integrated studies are scarce in the literature (though separate LSS studies have been carried out for weaving and fabric production). The proposed LSS-DMAIC framework provides specific solutions for optimization of yarn production, which will provide a reference case for similar industries in developing countries on the margins of resource-poorness and skill-lacking.

Practically it shows how industry professionals can deploy Lean techniques (Value stream mapping, 5S) and Six Sigma techniques (Pareto analysis, Fishbone diagrams, DPMO calculations) to achieve measurable improvements. The documented case study results give Ethiopian textile industry a practical scenario of adopting LSS techniques to reduce waste and reduce defects, which are directly applicable to actual manufacturing challenges.

1.7. Scope of the Study

This research aims to use an integrated Lean Six Sigma (LSS) approach to enhance process efficiency and product quality in textile yarn manufacturing, with a specific focus on the winding section of Else Addis Industrial Development P.L.C. in Ethiopia. Although the primary focus is on addressing inefficiencies and quality issues in the winding section, the outcomes may provide transferable insights applicable to other stages of yarn manufacturing and broader textile production processes. The study is delimited to the systematic application of the DMAIC (Define, Measure, Analyze, Improve, Control) methodology within the spinning department, targeting key operational challenges such as excessive non-value-added activities, yarn defects including count variation, thin and thick places, and nep formation and general process inefficiencies.

The scope of the study involves a comprehensive evaluation of quality control parameters and workflow inefficiencies, leveraging specific Lean Six Sigma tools such as Value Stream Mapping to identify waste, Pareto analysis to prioritize defects, Fishbone diagrams for root cause analysis, and statistical process control methods for performance monitoring. The LSS model to be developed will be customized to address the distinctive constraints of Ethiopian textile manufacturing, including limited resources and workforce skill gaps, while maintaining relevance to similar industrial settings in other developing countries.

1.8. Limitation of the study

This study has several limitations that should be acknowledged. First, the research focuses solely on the winding section of the yarn manufacturing process at Else Addis Industrial Development P.L.C., which limit the generalizability of the findings to other stages of textile production, meaning the results may not be applicable to textile industries in different regions with varying operational conditions. Challenges during data collection also posed limitations, including limited access to historical defect records, inconsistencies in data recording by the company, and time constraints in gathering real-time production data. Also, resistance from employees in adopting new LSS practices and a lack of prior exposure to structured quality improvement methodologies may hinder the effective implementation of proposed strategies.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction to Lean Manufacturing

Lean is the philosophy of developing pull management system inside the manufacturing system which have a propensity to direct towards six-sigma standard (A. Nedra, S. Néjib, C. Yassine, 2019). Lean is also procedure that enable to manufacture products by minimizing waste which eventually contribute for the reduction of production cost and promotes the competitive advantage of the industry (S. Kumar et al., 2023). Lean is a business strategy that helps to do more with less resources through eliminating seven deadly wastages amongst value added activities such as transportation, movement, overproduction and over processing, defects, inventory and waiting (Khatri. 2020).

The fundamental concept of lean was first introduced by Toyota industry, with the aim to minimize the fragment or losses, and increase the productivity. The concept is oriented to the Toyota Production System (TPS), which determines activities that have value and eliminates non-added value activities so that each step of production adds value to the process. Lean is an ongoing effort to reduce waste and increase the added value of products to provide value to customers (customer value) (Ismail & Zainal, 2021). The thrust of lean philosophy is waste elimination in every ‘aspect of a firm’s production activities. As waste is eliminated, quality improves while production time and cost are reduced (Hussain, 2014).

The concept of lean manufacturing includes several elements which tend to develop lesser defective products through the implementation of certain tools (Babu 2015; S. Kumar et al. 2023). In the sense of no waste, Lean has been interpreted as having less levels of management. In the Lean organization, the organization chart is flatter, bringing everyone closer to the work processes being managed. From the customers’ viewpoints. Lean focuses on value-added expenditure of resources (Mukhopadhyay, 2015). Hence, the lean concept indicates a systematic approach in identifying and eliminating waste by providing the product at the pull of the customer in pursuit of perfection. This leads to improved quality, better cash flow, increased sales, greater productivity and throughput, and improved confidence (Khatri. 2020).

The most important features of lean manufacturing system include; decreasing the lead time, improving the satisfaction customer, reduction of defective products and waste. Lean manufacturing system also enable an industrial system to enhances the quality, efficiency and productivity which results for the manufacturing products to be produced according to the requirement of market demand and consumers (P. Kumar, M. A. Khan, U. K. Mughal 2020; S. Kumar et al. 2023). Moreover, it also aid for the improvement of the overall performance of the manufacturing system (A. Nedra, S. Néjib, C. Yassine, 2019).

Manufacturing companies often implement lean manufacturing to optimize their production process due to waste activities that arise (Ismail & Zainal, 2021). The Lean philosophy provides a set of tools which work as a helping hand completely independently from other management tools such as Value Stream Map (VSM), Total Production Maintenance (TPM), Just in Time (JIT), 5s and Kaizen (Khatri. 2020). Hence, Lean is the set of "tools" which aids in the identification and steady elimination of waste (Adrian & Kosasih, 2023).

2.2. Principles of Lean Manufacturing

There are five principles of lean manufacturing: Value, Value Stream, Flow, Pull system and Strive towards Perfection (Sodhi et al., 2020a). Value is the starting point of lean thinking and can be defined by the end customer. Value has defined as the ability to fulfil the customers demand at the right time, quantity and price. Value-Added: the activities that create value to the product are called value addition process. Rest of the activities has been called waste or non-value-added activities that are of two types. Type one wastes are the activities that create no value but they are unavoidable with the current production system. Type two wastes are the activities that create no value but there is a possibility to avoid them (Rathore, n.d.)). Value-Stream, according to (Hislop, 2013) the value stream is defined as the set of activities that are used to describe the flow of product at each stage of production, from concept to the dispatch of the product.

While, flow is the movement of product and information along value stream. Flow identifies value-added and non-value-added activities by analyzing the processing load, interruptions, delays, and bottlenecks. Develop the Pull: Information and goods are drawn throughout the production system by consumer demand. It performs different ways from the Push system, which is less customer-responsive and leads to higher inventory levels. It adheres to JIT and minimizes inventory levels.

Look for Complete elimination of wastes along the value stream is the definition of perfection. Potential areas for improvement are examined and put into action. It lowers costs and response times for customers, makes use of available space and capacity, and enhances customer satisfaction.(Rathore, n.d.);(Sodhi et al., 2020b).

2.3. Lean Waste in Manufacturing Industry

Lean assembling is a precise method for disposing of waste and making stream in the generation procedure (Sodhi et al., 2020b). Waste can be defined as any work activity that does not add value to transforming inputs into outputs along the value stream (Ismail & Zainal, 2021). The popular definitions of lean manufacturing and Toyota Production System (TPS) are a complete technique when combined and mature, which will help to reduce and then eliminate the seven types of waste (Ismail & Zainal, 2021). One of the objectives of the Toyota Production System is to find defects and dispose of it (Rathore, n.d.).

TPM concentrates on the end of seven types of wastes by (Elrhanimi et al., 2016) (Rathore, n.d.). The seven types of waste are overproduction, defects, unnecessary inventory, inappropriate processing, excessive transportation, waiting, and unnecessary motion¹³(Ismail & Zainal, 2021). Overproduction affects the process flow smoothness and leads to excessive lead time, with large inventory increases holding and obsolescence costs. Defects are produced due to improper work and causes large loss of resources. Waste also created by keeping excess stock of the requirement, and causes a burden to the logistics department and can be caused by long lead time, overproduction and forecasting errors (Rathore, n.d.).

Unnecessary movement involves ergonomics of production where operators have to perform certain actions that can cause excessive fatigue to workers and reduce their productivity or often affects quality; includes stretching, bending and pick up. The waste that is arises due to excessive processing than the market needs. Moreover, waiting waste occurs due inefficient time management and affects both material and work force. In addition, excessive transportation in the factories is likely to cause damage to the materials (Elrhanimi et al., 2016). Besides of the seven waste categories, underutilized employees have been mentioned as an eighth waste to TPM original seven wastes (Rathore, n.d.). There are several methods that can be used for waste

measurement, and Waste assessment model (WAM) facilitates the process of identifying the impact of seven types of waste is one of the newest methods⁹ (Henny & Budiman, 2018).

2.4. Basic Concepts and Principles of Six-Sigma

Six-Sigma is a proved methodology used to assess, examine and improve problematic areas in manufacturing and service industries (E.V. Gijo, J. Scaria 2011; Gaikwad et al. 2017). Six Sigma is a data driven methodology used to identify root causes for variations in a production process in order to achieve organizational excellence. Six Sigma strategies require process improvement through identifying problem, root causes, process design, reengineering, and process management (Hussain, 2014). Six Sigma (SS) is a highly structured and data-driven method that uses statistical tools to drive into a decision (Garza-Reyes et al., 2015).

Six-Sigma is the benchmark, which ultimately manufactures the goods with insignificant defective items. Six-Sigma is dominant method that can be employed for the reduction of production cost; enhance the process of material handling, manufacturing system and product quality that results value addition for the company (Babu, 2015). Six-Sigma aids in the identification of process inconvenience, their analysis, rectification and controlling mechanisms (Hussain, 2014). Six-Sigma can be used for the improvement of product quality (Kurnia, Sihar, Tumanggor, Jaqin, et al. 2021). It is a problem solving and improvement method that a business uses to achieve and sustain a healthy level of success (Babu 2015). The principle of Six-Sigma is to reduce inconsistency or variation from a process and achieve 3.4% Defects Per Million Opportunities (DPMO), or yield of 99.9997% (perfect parts); principle of six sigma.

Table 2:1 principle of six sigma

SIGMA	DPMO	Capability
6 Sigma	3.4	World Class
5-Sigma	230	
4-Sigma	6200	Industry Average
3-Sigma	67000	
2-Sigma	310,000	Non-competitive
1-Sigma		

To achieve this, different organisations adopt different tools (such as process map, control chart, ANOVA, SIPCO, 5s, 5why etc. some popular tools) along with advanced methods such as DMAIC's roadmap and Design for Six Sigma (DFSS) (Mukhopadhyay, 2015). Among these methods, the DMAIC's roadmap or method prominently performed on an existing process (Adrian & Kosasih, 2023). The success of Six-Sigma depends upon the selection of different tools and techniques at each stage. Furthermore, the tools and techniques selection depend on the type of problem (Patel, 2017) (Kurnia, Jaqin, et al., 2021).

2.5. The DMAIC's Roadmap

Lean manufacturing system can be implemented in various organization for different purposes such as to the production of high quality good, to maintain high quality in decision-making process, for enhancing the operational health and security of employees and many other services (S. Kumar et al. 2023). While Six-Sigma could be implemented to the processes of producing manufacturing goods, business trade, executive management, and services (Gupta, 2013b). The DMAIC's roadmap has been used as a common framework for process improvement, and within these particular phases where the lean tools have been embedded (Gupta, 2013b).

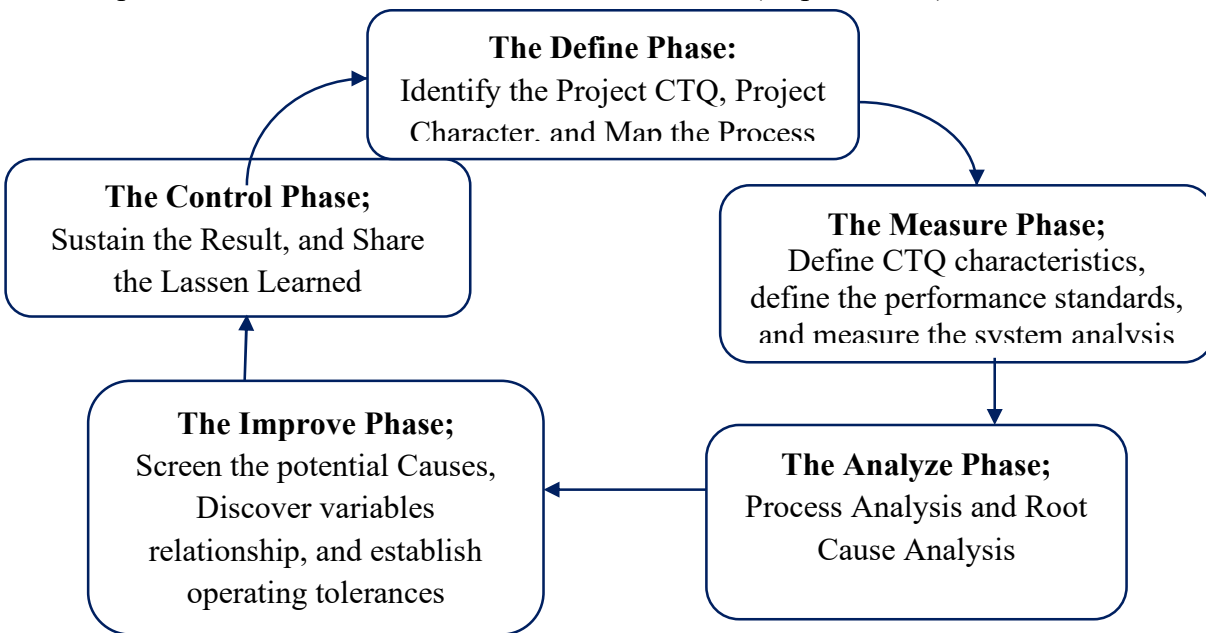


Figure 2:1 DMAIC Road map

The DMAIC method is performed on an existing process (Adrian & Kosasih, 2023). Lean-Six Sigma (LSS) uses the DMAIC method in the process of solving problems over the five phases of DMAIC method, namely the Design phase, Measure phase, analyse phase, improve phase, and Control phase that continuously utilized to improve the efficiency of the production process and reduces the number of defects as minimum as possible (Gupta 2013b).

DMAIC is a systematic six-sigma project management practice inspired by Deming's PDCA (Plan, Do, Check, and Act) Cycle. DMAIC is the abbreviation for five phases (Define, Measure, Analyse, Improve and Control) which identifies the phases or process of DMAIC methodology (Gasperz & Fontana, 2011; Gupta, 2013a; Martin, 2014). The DMAIC approaches are mostly used where improvement is required in overall process of the system (Tajammal Hussain and Mohsin, n.d.; E.V. Gijo, J. Scaria 2011).

The Define phase concentrates on forming the team, defining the project's goals, mapping the process, identifying customers, and identifying the high impact characteristics or the characteristics that are Critical to Quality (CTQ) (Gasperz & Fontana 2011; Adrian and Kosasih 2023).

The Measure phase consists of defining and executing a systematic data collection plan for the key measures (CTQs) for the targeted process. Thus, the data collected in the Measure phase are analyzed in the Analyze phase to identify the root causes behind the gap between the current performance and the goals identified in the first phase by defining the main type of imperfections and wastes embedded within the production processes, and the root causes for their occurrence. The Improve phase focuses on identifying expected solutions, suggest set of alternative solutions to enhance performance, and implement some of these solutions according to the available budget and the expected cost for each alternative. The Control phase concentrates on creating and implementing monitoring and response plans for sustaining improvements, spread out the outcome and the methodology for the whole organization, insure the establishment of a new culture within the organization (Adrian and Kosasih 2023).

2.6. The Lean-Six Sigma (LSS) Approach

The lean philosophy identifies the category of waste that occurs in the system, it helps for the elimination of waste and activities that do not offer added- value, and along with the lean, the constant improvement with the Six Sigma technique aids for the reduction of the quantity of defective products and services simultaneously (Gasperz & Fontana, 2011). On the other hand, Six Sigma aids for the elimination of imperfection, however it does not address about the manufacturing process optimization (Adrian & Kosasih, 2023; Kingdom, 2019).

Lean assembly is an exact way to get eliminate of waste and streamline the production process, while Six Sigma refers to a number of techniques that aim to significantly slow down the rate of errors. Lean sees methods to create streams, while Six Sigma focuses on achieving dependable results. This is the main difference between the two methodologies. The similarity between Six Sigma and Lean is that both have demonstrated that it is possible to greatly enhance the quality of goods and customer experience by enhancing processes.(Sodhi et al., 2020b). Hence, using one of these tools separately cannot able to achieve a holistic approach. Therefore, applying an integrated Six Sigma and Lean tools position the results for extremely better improvements than that could be attained due to the usage of individual methods separately (Adrian & Kosasih, 2023; Kingdom, 2019).

To put it simply, the primary difference between Lean and Six Sigma is that they identify the primary cause of waste in a novel way. Lean manufacturing is a systematic approach to waste elimination and improving the generation process, while Six Sigma refers to a collection of techniques that aim to significantly reduce the rate of defects. Even though many analysts compare Lean and Six Sigma, when used together, they can often be even more effective (Sodhi et al., 2020b). Thus, the LSS integrating concept not only focus on operational efficiency or inefficiency, but also focuses on the improvement of product quality with the support of the six-sigma method (Hussain, 2014).

Lean-Six Sigma tools take a holistic approach to ensure employees are engaged in identifying and eliminating non-value-added or wastage in production (Hussain, 2014). Hence, the combination of the two tools has been used as balancing to the deficiency associated with the separate tools. The Lean-Six Sigma (LSS) also measures the efficiency of the particular operation by calculating process cycle efficiency (PCE). PCE is a metric that can be used for examining the efficiency of

the in-progress process in an industry based on the proportion of instances/time on activities that adds significance or value to the total lead time in value stream mapping (Adrian & Kosasih, 2023; Gasperz & Fontana, 2011).

Lean and Six Sigma have been implemented successfully in the manufacturing and service sectors to optimize different performance measures. Both lean and Six Sigma methodologies have proven over that last twenty years that it is possible to achieve dramatic improvements in cost, quality, and production time focusing on process performance (Gupta, 2013b). While the term “Lean-Six Sigma” is quite commonly used, the definition varies across different sources. Some common perceptions about Lean Six Sigma (LSS) are; Lean-Six Sigma (LSS) is a combined approach developed by combining the Lean philosophy with the Six Sigma tool (Gasperz & Fontana, 2011). It is a condensed and less costly version of Six Sigma combined with lean tools for better results (Adrian & Kosasih, 2023; Gasperz & Fontana, 2011).

Lean's Shortcoming	How Six Sigma Helps	Application of lean six sigma
Focuses only on visible waste (e.g., excess inventory, motion)	Detects and eliminates hidden waste (e.g., defects, such as thin place)	Lean reduces fabric stock, but Six Sigma prevents defects that cause scrap.
Improves speed but may compromise quality	Ensures processes remain defect-free at high speeds	Lean speeds up efficiency, but Six Sigma reduces defects.
Lacks statistical tools for deep analysis	Uses data-driven methods (DMAIC, SPC) to find root causes	Lean identifies bottlenecks; Six Sigma fixes yarn breakage issues with data.
May improve flow but ignore variability	Stabilizes processes by reducing variation	Lean improves efficiency; Six Sigma ensures consistent sizing.

Figure 2:2 Analog Between Lean and Six Sigma

Critics of Lean Manufacturing and Six Sigma claimed that tools of Lean manufacturing and DMAIC methodology have scope for enhancement, if used in integration (Naslund et al., 2017). Barton (2015) agreed that both Lean and Six Sigma are key business process methodologies that are utilized by organizations to improve their assembling execution (Sodhi et al., 2020b). As a result, many researchers proposed various models and frameworks of LSS. In this regard, recently, (Sodhi et al., 2020b) has evaluated and examined various models of Lean Manufacturing, Six Sigma and LSS and developed an advanced LSS model that can be deployed in any manufacture organization with the purpose to reduce waste.

2.7. Lean and Six-Sigma Tools

In order to achieve the targeted goal six-sigma, different organisations adopt different tools (such as control chart, SIPOC (Supplier, Input, Process, Output, Customer), ANOVA, 5s, 5why etc. some popular tools) along with the DMAIC methods (Adrian and Kosasih 2023).

Control Chart; a control cart is a tool that describes the production process of the object under study. A control chart is a statistical tool used to distinguish between variations in a process resulting from common causes and variation resulting from special causes (Taye & Bekele, n.d.). Based on the type of data observed, the C-chart encloses of upper control limit, lower control limit, centre line, and plot data (Adrian & Kosasih, 2023; Martin, 2014). C-charts can be classified based on the type of the observed data such as data continuity, sample size, imperfection per unit, or the number of defect or imperfections.

SIPOC Diagram; the SIPOC (Supplier, Input, Process, Output, Customer) diagram represents the plot for the association between Supplier, Raw materials, Production process, Products produced, and Customers for the yarn production industry (Adrian and Kosasih 2023). In this study the SIPOC diagram will be used to plot the association between cotton fibre (Raw materials) and intermediary processing material Supplier, Production process, Products produced, and Customers for the yarn production industry

Pareto Diagram: it is an illustration, which considered as one of the problem-solving tools that is extensively used to find out priorities for rectification (Martin, 2014). The analysis of Pareto diagram uses the 80/20 principle as a foundation for determining priorities which is based on the

supremacy of the impacts caused by the type of waste and the type of defect or imperfection being observed (Adrian & Kosasih, 2023).

Fishbone Diagram: An illustration plots the major cause and effect relationship of a problem observed. Sodhi et al. (2012) investigated that management of waste in any manufacturing organization revolves around controlling the following four critical parameters of any organization that is men, methods, machines and material (Sodhi et al., 2020b). The diagram thoroughly plots distinctive factor that causes a difficulty concisely and comprehensively based on the six-major characteristics, including; Man, Material, Method, Measurement, Machine, and Environment (Gasperz & Fontana, 2011).

Defects per Million Opportunities (DPMO); DPMO is a metric that measures the number of defects per million opportunities. DPMO can be used to calculate the sigma value that shows the capability level of the production process other than Cp and Cpk. DPMO can be calculated using the following formula (Adrian & Kosasih, 2023). Hence, in this study the yarn DPMO will be calculated by using the formula presented in (equation-1):

$$DPMO = \frac{(\text{Total Defects})}{\text{Total Units} \times \text{Total Opportunities!}} \times 1.000.000 \dots \dots \dots \quad (\text{Equesion-1})$$

2.8. Lean Tools, and Analytical Methods

Since, the fundamental concept of lean was first introduced by Toyota industry, with the aim to minimize the fragment or losses, and increase the productivity. The concept is oriented to the Toyota Production System (TPS), which determines activities that have value and eliminates non-added value activities so that each step of production adds value to the process Lean is an ongoing effort to reduce waste and increase the added value of products to provide value to customers (customer value) (Ismail & Zainal, 2021).

Hence, the Lean philosophy provides a set of tools which work as a helping hand completely independently from other management tools such as the Value Stream Map (VSM), Total Production Maintenance (TPM), Just in Time (JIT), Kaizen, Kanban, and etc. (Khatri. 2020). However, the usage of these tools is situation dependent. However, the commonly known lean

tools value-stream mapping (VSM), Kaizen, and Kanban (Ismail & Zainal, 2021). Thus, in this study, VSM will be considered in textile yarn manufacturing industry (in the case company).

Value Stream Mapping (VSM); Same studies identify that the aim of VSM is improving the production lead time. Hence this research attention for VSM. VSM is an activity required to design and order process from start to the end or final products, from order receiving to delivery time. Map all of the value added and non-value-added activity. According to Yan et al. (2015), lean helps to eliminate non-value adding activities from the production processes while VSM helps to identify value adding and non-value adding activities through visual representation (Rathore, n.d.). Hence, Value Stream Mapping (VSM) is a procedure used to decide the value added to an item as it experiences the production framework. It is pictorial representation used to show the flow of material and information (Rathore, n.d.). According to (Hislop, 2013) the value stream is defined as the set of activities that are used to describe the flow of product at each stage of production, from concept to the dispatch of the product (Rathore, n.d.).

Value stream mapping (VSM) method is an important part in the application of lean manufacturing. VSM aims to describe the flow of product which consist of material and information flow (Henny & Budiman, 2018). VSM is a technique used for visualizing the manufacturing system and all other processes. This technique provides the visual model of the system processes with sufficient information flow. Identify Bottleneck operations and WIP. Calculates processing and production lead time (Kumar & Kumar, 2014) ,(Rathore, n.d.)). Value streams can be divided into two, namely current value stream mapping (CVSM) and future value stream mapping (FVSM). CVSM serves to map the value stream to the current process conditions, while FVSM maps future conditions based on the results of improvements provided to the company (Adrian, 2023).

Here, Value Stream Mapping tools are used to map the origin of waste in the production flow in more detail (Ismail & Zainal, 2021). The application of this method refers to the approach developed by²⁵ (Ismail & Zainal, 2021). The best way to recognize the waste was through the VSM (Uzorh et al., 2018).

2.9. Review of Related Empirical Literatures

Recent literatures and applied research mentioned the prominent benefits, and application of Lean Manufacturing techniques. Singh and Power (2011) implemented a Lean model in the production industry aided by value stream mapping. Letens et al. (2016) proposed a multilevel Lean model for product development system and designing. Pocha et al. (2017) proposed a Lean model for assessing the use of Lean production practices in manufacturing units (Sodhi et al., 2020b). (Henny & Budiman, 2018) has also assessed the implementation lean manufacturing using Waste Assessment Model (WAM) in Shoes Company. From the contexts of textile industry; (Khatri. 2020) studied the applications of lean manufacturing practices in textile industry; (Khatri. 2020) conducted the case study at textile industry of Pakistan and productivity, profitability and quality was investigated.

Natarajan et al. (2017) proposed a Six Sigma model for continuous quality and reliability improvement in new product development (Sodhi et al., 2020b). The application of Six-Sigma methodologies have been studied in various areas of textile and apparel industry for improving product quality and reducing defective products (E.V. Gijo, J. Scaria 2011; Tajammal Hussain and Mohsin, n.d.). The application of Six-Sigma methodology for reducing yarn packing defects were studied by (E.V. Gijo, J. Scaria 2011; Tajammal Hussain and Mohsin, n.d.); the application Six-Sigma to reduce lot-to-lot shade-variation of linen fabrics was studied by (E.V. Gijo, J. Scaria 2011; Tajammal Hussain and Mohsin, n.d.); the application Six-Sigma for reducing fabric defects in textile weaving (Hussain, 2014); the application Six-Sigma for reduction of yarn packing defects (Mukhopadhyay, 2015). Moreover, (Gupta, 2013a) has presented a quality improvement study applied at a yarn manufacturing company based on six sigma methodologies by suing the DMAIC project management-methodology and SS tools; (Wirani et al., 2019) analysed the quality control of carded and combed yarns using SS methods.

Despite, Barton (2015) agreed that both Lean and Six Sigma are key business process methodologies that are utilized by organizations to improve their assembling execution. Many authors have also proposed different models for LSS deployment (Sodhi et al., 2020b). In this regard, Jeyaraman and KeeTeo, (2010) implemented a LSS model in a food industry, which adopts LSS initiatives mainly to increase productivity and to reduce costs, and inventory. Hilton and

Sohal, (2016) proposed a conceptual LSS model for the successful deployment of Lean Six Sigma in air conditioner industry. Antony and Gijo, (2017) proposed LSS model for the application in the airline industry (Sodhi et al., 2020b).

For every stage of the DMAIC roadmap, LSS incorporates the DMAIC technique with a combination of appropriate tools from the Lean toolbox and Six Sigma, as shown in a number of recent works. But according to Singh et al. (2019), LSS values the DMAIC process as a revolutionary concept for LSS endeavors, arguing that it uses the Six Sigma DMAIC structure as a platform for activities in combination with Lean standards and tools. In fact, the executives attributed the success of the LSS venture to the DMAIC technique (Sodhi et al., 2019a). With less importance to its return from its predecessor Six Sigma, the LSS-DMAIC procedure is therefore expected to be an amazing and essential component of the success of LSS ventures. (Sodhi et al., 2020b).

Hence, in the past, in textile industry (Adrian and Kosasih 2023) has studied LSS as a strategy for increasing knitting manufacturing profitability through fabric quality and operational efficiency improvement. Adikorley et al., (2017) investigated the success of LSS project in in the textile and apparel industry; Zaman, & Zerin, (2017), studied the application of LSS-DMAIC's roadmap to reduce sewing defects in readymade garments (Kurnia, Sihar, Tumanggor, & Jaqin, 2021).

2.10. Research Gap

The textile industry, particularly in spinning operations, faces big challenges in maintaining process efficiency and product quality. While much of the existing literature focuses on Lean Six Sigma implementation and defect reduction techniques, there remains a notable gap in examining how value-added (VA) and non-value-added (NVA) activities measured through time studies directly relate to worker training inefficiencies. In the textile industry, worker movement refers to physical activity performed by workers during production process, particularly in the spinning industry. This study determines the amount of (defect) rejection and measures the waste activity (VA and NVA activity) using time measurement techniques. Although it was showing the lack of attention of worker training, which is difficult but ignores how inadequate training leads to errors and inefficiencies.

CHAPTER THREE

Methodology

3.1. Research Design

A research design serves as a roadmap for organizing and carrying out a whole research process. A mix of descriptive, qualitative and quantitative techniques were applied to address the objectives of the study. A systematic research methodology was designed to study yarn product quality, and with a view of identifying process efficiency. During the data collection period, industry-specific information was recorded to obtain quantitative data, and document review, group discussions, and a key informant interview guide were used to collect qualitative data.

3.2. The Research Procedure and Framework

The framework demonstrates how data was collected, analysed, and which tools were used for improvement. Overall, the research framework provides a roadmap for how the study was conducted, from the initial assessment to the final outcomes, allowing for a comprehensive understanding of the research process and the steps taken to achieve the desired objectives of process efficiency and product quality improvement through the lean Six Sigma approach.

The final written report has a predefined format that comprises an introduction, a literature review, data interpretations, suggestions, and discussion. A research framework has been drafted to provide a clear illustration of the steps involved in defining the research problem and finishing the conclusion and recommendation sections. The figure below shows how the general procedures and activities of research are organized and described.

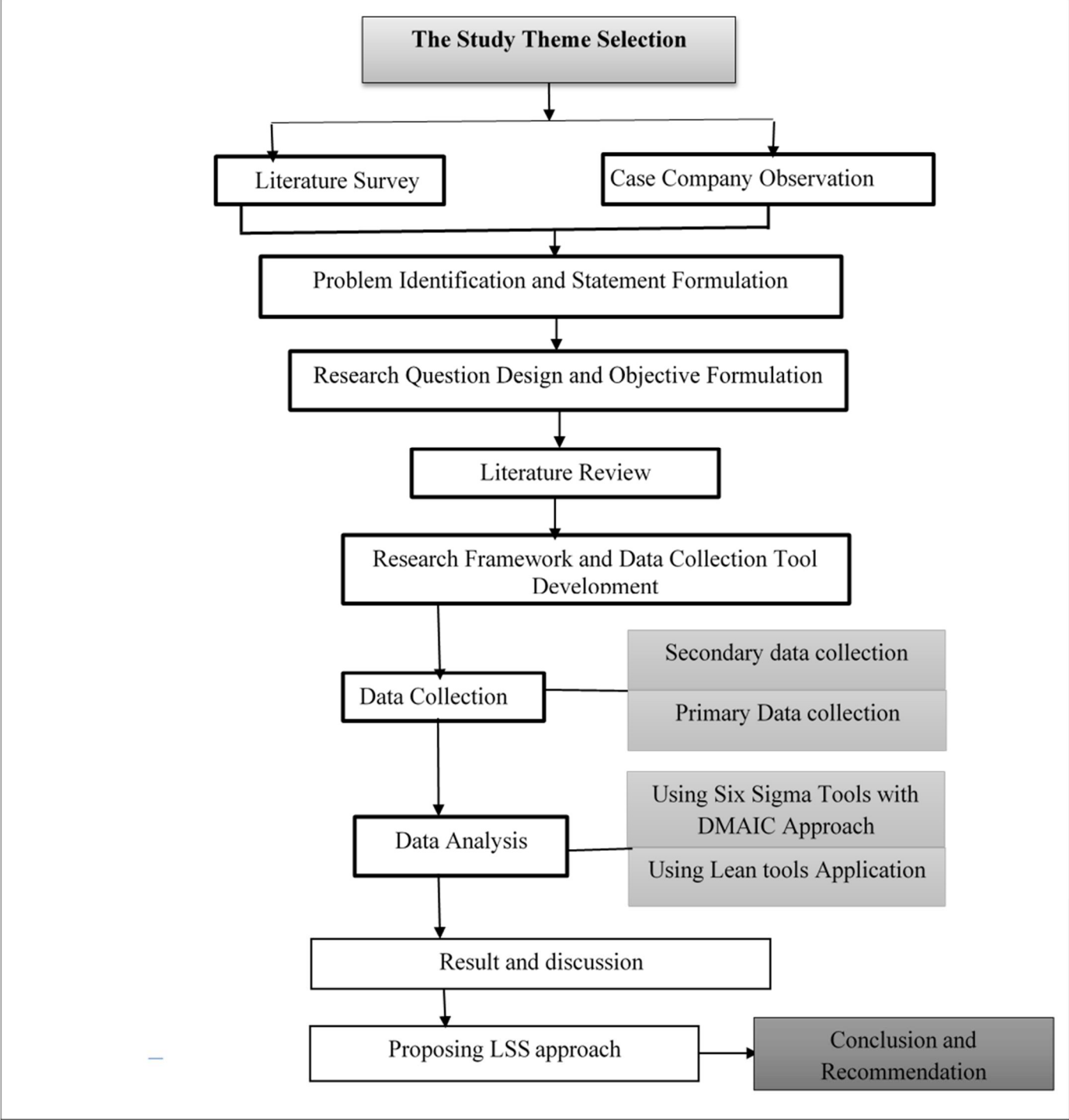


Figure 3:1 Research Procedure and Framework

3.3. Data Collection Plan

A key phase in the research process is data collection, which involves obtaining and quantifying information from the workplace that the researcher will examine and analyze. This study uses both primary (industry observation) and secondary (case company recorded data) data collection methods to address the research questions mentioned above. It is simple to retrieve original and raw data from a primary data collection source. However, secondary data collection sources identify frequently utilized materials and references. Additionally, journals related to yarn, the last five months of data reported from the case company, and various literature reviews conducted by secondary data sources are referenced.

3.3.1. Primary data Collection tools

Observation: - The researcher made observations about the physical layout of the workplace, the arrangement of materials, the primary problems in the 40NE yarn (count variation, thin/thick places, yarn hairiness, winding faults, cone shape, Nep formation), the flow of materials, and the information about VA and NVA activities that were or are being observed.

Group discussion and Interview: - During focus group discussion the root causes of defects, and waste activities or the causes of unnecessary movement were discussed. General reflection of respondent about the information of defect (count variation, yarn hairiness, thin-thick, nep, winding faults and shape of cone) were identified. The purpose of discussion was to determine which of the possible cause was genuine or root causes. Interview was also continued to determine area where more problem existed and common defects also determined by interview session. The centre of the discussion was, Quality department, and production department (production supervisors, shift leader and operators) and maintenance departments.

Questionnaires: - Survey questioner tools are essential for gathering data on critical LSS metrics in winding section, such as defects and the distinctions between VA and NVA activities. The questionnaires' session activities the type of questioner with respondents who have closeness and an authority (such as production shift leader, supervisor, Seiner operators and quality control experts) over the relevant production process in the case company facilitated by the researcher.

The aim of the survey was to identify the root causes of defects, and categorize activities VA and NVA for process efficiency evaluation.

3.3.2. Secondary Data Collection

Secondary sources are crucial for research finding analysis. Secondary data is pre-existing information including reports, records used to analyse trends, like monthly production and defects in spinning departments. It helps identify problems and improve efficiency using data collection. This allowed for the identification and prioritization of the areas in spinning departments where the most problems occurred. The following categories of data are included in this study.

Secondary data collected from case company were; Five months of company records of spinning department and four months of winding section recorded data and also reports, including details about the case's background.

3.4. Techniques for Data Analysis

Tools and methods for data analysis are crucial components of this research. Additional analysis is necessary for a meaningful understanding, especially after the raw data has been or will be collected.

- **Analysis tools**, Pareto analysis and cause-and-effect diagrams, are helpful in determining the root cause of a particular issue.
- **Flow process**: The winding section's process mapping is displayed using small software such as Smart Draw.
- **Recording tools**: stopwatches are used during the study, and any needless worker movements are documented in VA and NVA.

Data analysis tools and techniques are very essential inputs for this study. Particularly, after the raw data is/are collected, further analysis for a meaningful understanding is important.

Table 3-1 Summary of Data Analysis

No	Data analysis tools	Input for analysis	Important	Expected result
1	Pareto analysis	Major defect recorded	Problem identification and prioritization	To determine the area of major problems and more improvement area
2	SIPOC	observation of case company process and respond from the workers	To show work flow (input, process, output, suppliers and customer	understanding of process flow and input materials and output products
3	VSM	Process flow data (VA and NVA) observation	Identifies waste activities and inefficiency	Identifies VA, NVA and cycle time for process improvement
4	Cause and effect Diagram	Data from Pareto chart analysis, focus group discussion	To explain possible causes of the problems	Root causes identification and problem solving

3.5. Research population

The study is being conducted on the spinning production process specifically to the winding section operations. But the winding section takes about 30% of the total workers involved in the company (approaching 205 workers). As a result, for the start-up of this study an appropriate sample size has been selected using a purposive (non-probability sampling technique). This type of sampling would help to select candidates to form the given population according to their specific operations, knowledge, and working experiences. A simplified formula has been used below to calculate the required level of sample sizes form the winding section operations.

$$n = \frac{N}{(1+N(e)^2)}$$

Where; n=sample size, N= Total Population size, e= margin of error

Table 3-2 Research population

Population(N)	Margin of errors (%)	Sample size
50	5	45
100	10	50
150	15	40
205	20	34

Therefore, for a confidence level of 95%, and the population size of 205, the appropriate sample size selected is 34 workers.

3.6. Ethical Considerations

Before conducting the data collection process, it is vital to take under consideration that legal consents letters to be signed (in the case of this research; supporting letter signed by Addis Ababa Institute of Technology, School of Mechanical and Industrial Engineering; from Industrial Engineering Chair) before the actual data collection take place.

During data collection stage, the following safeguarding information will be assured to the case company as well as respondents, in such a way to protect respondent's rights; the research aim and intent will be briefed by the researcher, respondents then be informed about all data collection tools, activities and aim. Moreover, respondents assured that stories and quotes will only be shared with third parties, but no names will be attached, and data security will be maintained.

CHAPTER FOUR

Result and Discussion

4.1. Introduction of Case Company Description

One of Africa's the most rapidly expanding industries is the textile sector in Ethiopia. The sector is given priority by the government through a number of investment initiatives. As a result, domestic as well as foreign investors are entering the market. The organized mill sector and the decentralized handloom sector are the two interconnected segments that make up the textile industry. Else ADDI Industrial development was established in Ethiopia 2004GC by Turkish investor. ELSE ADDIS was organized under mill sectors including weaving, knitting and spinning sectors. The main products of ELSE ADDIS INDUSTRIAL DEVELOPMENT are “different yarn count (40Ne, 20Ne and 16Ne), knitted fabric and weaving fabrics”.

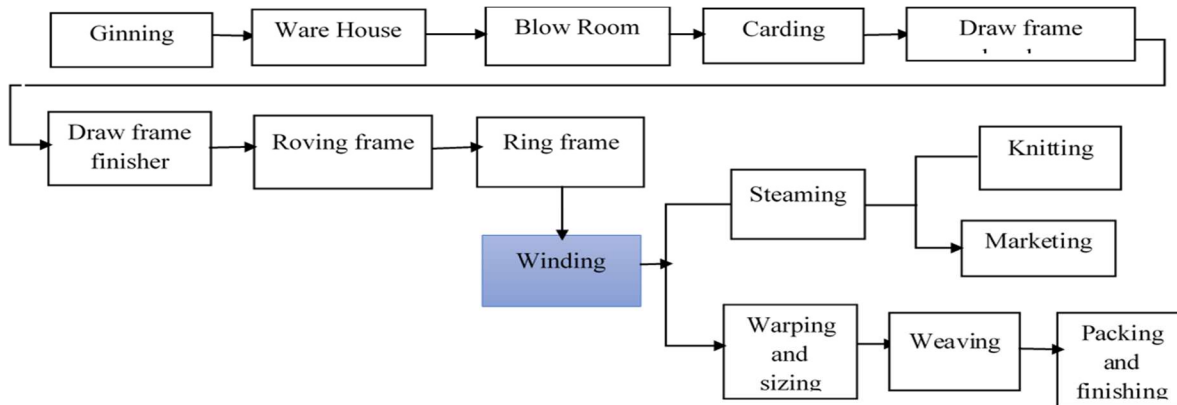


Figure 4:1 Flow Chart of Case Company



Figure 4:2 Else Addis Industrial Development (Google Map 2024)

1. Ginning: Is the process of separating cotton fibres from the seeds of cotton any debris like stems, burrs and soils.

2. warehouse: a place where storing cotton properly to ensure a successful industry. Cotton is a delicate commodity that requires special attention in order to preservation, timely logistics, and optimized transportation routes.

3. Blow Room: is the first stage in the process of producing yarn, where compressed cotton bales are opened, cleaned blended, and Recycling waste. In addition to the aforementioned cleaning efficiency of the blow room, which is the percentage of trash removed, is typically between 40–70%. As significantly demonstrated by depends on the fibre properties and the settings of the blow room machines.

4. Carding Process: Carding process is very important role in spinning mill. It helps Opening of fibres to individual state, Elimination of impurities present in cotton that were not extracted in the previous cleaning departments, disentangling of the nep, Removal of the short fibres, Fibre blending, Sliver formation. in relation to defect occurred during this process in case company are: patch web- because of damaging wire points and high card waste occurring high flat speed.

5. Draw frame: A draw frame is a machine in the spinning mill that improves the quality of yarn by performing the final process of quality improvement. Done by Doubling, Drafting, Blending and Parallelization.

6. Roving frame: A roving frame is a machine used in yarn production in order to thin slivers of fiber into a roving sliver. Additionally, strategically purpose of the machine is in order to reduce the thickness of sliver. Some defects that can occur in this process ae; count variation, yarn hairiness and thin and thick place.

7. Ring frame: Ring Spinning machine is used in textile industry to twist the staple fibers into a yarn and wind on a bobbin for the purpose of storage and also input for the purpose of the winding section for the purpose of more precise the yarn to minimize the defects of end yarn. Ring machine is very important due in order to yarn quality. Defects such as nep, thick place, thin place, and count variation are some of occurred in this section at case company.

8. Winding process: In yarn production, winding is the process of transferring yarn from smaller packages to larger ones, which are subsequently used for the purpose of weaving. The winding process has several objectives, including: converting yarn to a package, increasing quality and extraction of yarn faults.

4.2. Study Area and Product Selection Methods

Study Area Selection: The study focuses on the spinning department, the most critical stage in textile production, which consists of eight sections; Blow room, Carding, draw frame-1, Draw frame-2, Roving frame, Ring frame, Winding, and Packing. Each section plays a vital role in converting raw cotton into yarn. From each section to identify the most problematic area, the study quantitative data (defect records from January to May 2024) alongside qualitative insights from interviews and discussions with shift leaders, supervisors, quality departments and senior operators. Defect rejection of all sections with percentages were written as following table.

Table 4-1 Utilizing Five Months (January 01/2024 to May 30/2024) defect recorded data.

Section or Area	Defect rejection in (kg)	Total %
Winding	9200	25%
Ring	6030	16%
Carding	4700	13%
Roving	4430	12%
Blow room	4100	11%
Draw frame breaker	4050	11%
Draw frame finisher	3910	10%
Packing	870	2%

Histogram chart: The histogram chart from defect rejection data (Jan to May 2024) clearly identifies the areas of the highest defect rate in the spinning process. The vertical axis is the number of defects in kilograms (kg), and the horizontal axis specifies each area or section

The data showing that the winding section had the highest defect rate, accounting for 25% of total rejections, making it the primary focus for improvement. This finding was further supported by employee feedback.

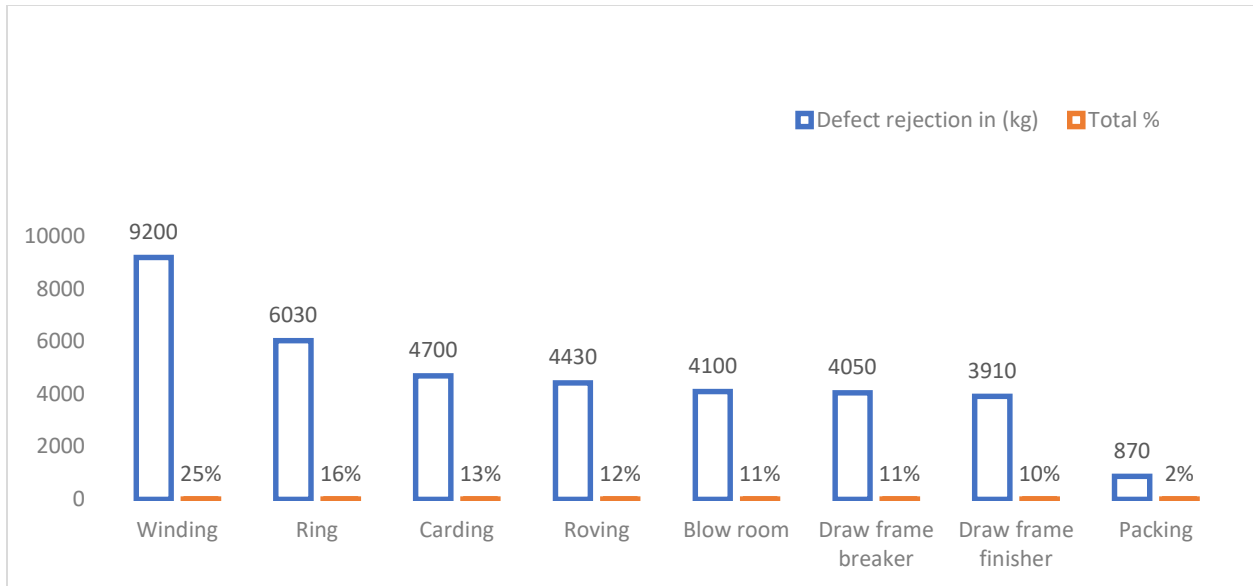


Figure 4:3 histogram chart for Area selection

Product Problem Identification: - The winding section of the case company production process, three distinct yarn products are manufactured: 40Ne, 20Ne, and 16Ne counts. Each product serves different market needs, with 40Ne being used for premium applications like luxury T-shirts and lightweight fabrics, while 20Ne and 16Ne are employed for coarser textiles. The selection of all product to prioritize for quality improvement was conducted through a systematic approach combining quantitative analysis and using expert evaluation.

Product type depending on company needs resolves the number of defects or variations, which were selected by Histogram chart and with expert judgments. Using recorded data case company four months (January 01/01/2024 to April 30/04/2024), to identify the more problematic and requires improvement.

$$\text{Defect rate calculation} = \frac{\text{total defect per month}}{\text{total production per mon}} * 100\%$$

$$\text{Defect rate calculation} = \frac{2457\text{kg}}{61155} * 100\% = 4\%$$

$$\text{Defect rate calculation} = \frac{1704\text{kg}}{66325\text{kg}} * 100\% = 2.57\%$$

$$\text{Defect rate calculation} = \frac{1551}{67611\text{kg}} * 100\% = 2.29\%$$

Table 4-2 product quality Identification

S/no	Product type	Total production /Month	Total defect per Month	Defect percentages
1	40Ne	61155	2447	4%
2	20Ne	66325	1704	2.57%
3	16Ne	67611	1551	2.29%

So, by using this data, researcher draw histogram chart and comparing the product type and prioritize the more problem existed.

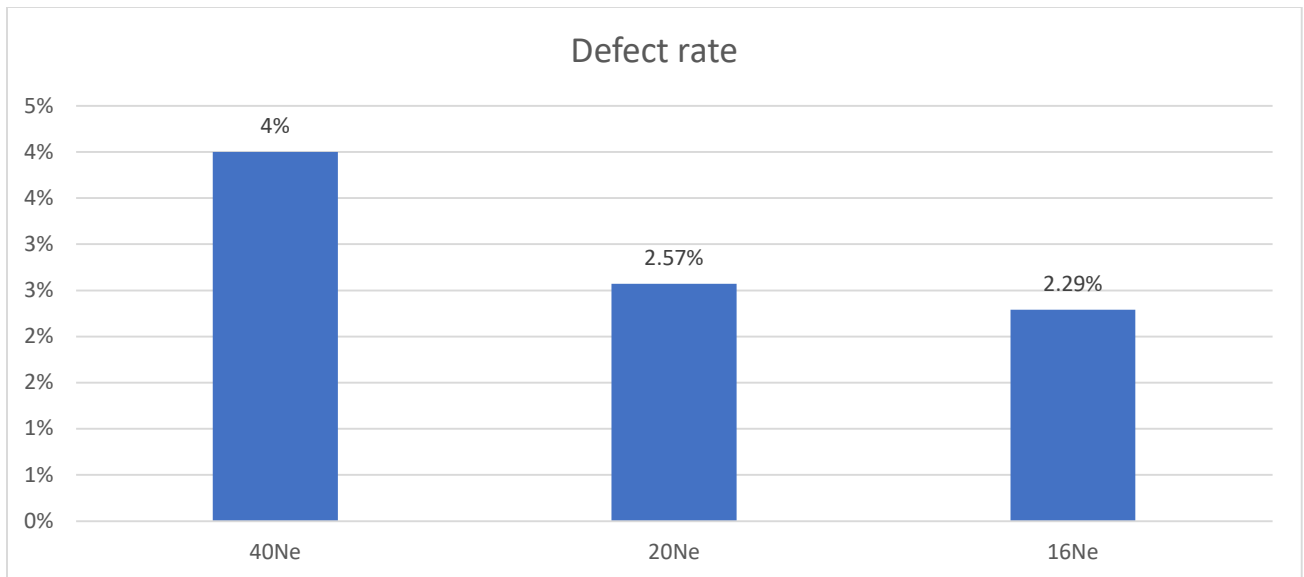


Figure 4:4 Product Comparison Chart

A histogram chart was used to visually compare defect rates across the three yarn types, clearly highlighting that 40Ne had the highest defect percentage (4%), followed by 20Ne (2.57%) and 16Ne (2.29%). This graphical representation made it evident that 40Ne was the most problematic product, with defects significantly impacting production efficiency and product quality.

4.3. Product Quality and Process Efficiency measurement on winding section

In the textile industry, the measurement of yarn product quality and process efficiency is crucial. These were measured using one month of recorded data (March 05, 2024 to April 04, 2024), which included the total production in kilograms, the number of defects rejected, the results of the yarn test, the number of yarns measured, and the number of unnecessary movement operators (transport, waiting time, and motion). This reduces variation or defects and worker movement, which is used to improve the case company's product quality and process efficiency.

4.3.1. Product quality measurement (yarn quality measurement)

In consideration of yarn production process several parameters and testing methods are used in order to measure product quality of a yarn. Given the substantially circumstances of product quality is used in order to that, yarn meets the required standards or customer acceptance. In addition to the aforementioned these instrument USTER® Statistics and manual methods which is globally acceptable tolerance limit for the purpose of different yarn defect. Measuring yarn product quality or 40Ne based on defect yarn product is critical factors in textile industry. As yarn count is fundamental parameter that determine the thickness, thin place, hairiness, nep and consistency of yarn. Variation in yarn can lead defects in fabric. To clarify, as consistency thickness, and fundamental parameter that determine hairiness, the thin place, of nep yarn is count yarn.

In order to measure this yarn product qualities, researcher used USTER® Statistics and manual methods. Consequently, this measurement USTER® Statistics identify (thin/ thick place, hairiness, and nep and hairiness). furthermore, acceptable of tolerance limit is identified as the company standard or customer needs.

Measurement's methods: Using the tested data given as the following, we have measured product quality and evaluate of contribution of variation in 40Ne yarn by using USTER® Statistics to identify (thin/ thick place, hairiness, and count variation). During measurement methods test parameters were taken as follow; coefficient variation or mass variation (CVm%), thin place -50%, thick +50%, Nep +200% and Tenacity (cN/tex) were the major.

Table 4-3 Tested Parameters and Results

S.No	Test Parameters	Test Method	Test Results(yarn)	
			Laboratory Sample Code	
			14152003	
			40 Ne	
			Mean	CV
1	U%	ASTM-D- 1425	13.39	2.6
2	CVm%		17.35	1.9
3	Thin place -50%		32.5	32.2
4	Thick place +50%		539	9.4
5	Neps +200%		1563	9.9
6	Neps +280%		477.5	14.9
7	Elongation% (Fmax)	ASTM-D- 2256	3.63	27.06
8	Maximum force(N)		1.85	29.32
9	Tenacity (cN/tex)		12.55	29.32

Tested parameters and industry standard indicated that there was different result. This shows, there are significant yarn variation that indicate poor yarn quality or product quality. The following table show that tested parameters, tested value, case company standard and status of tested parameters were discussed.

Table 4-4 Tested result of 40Ne yarn

Parameter	Tested value	Industry standard	Status of tested parameters
U%	13.39%	≤10%	Out of standard
CVm%	17.35%	≤12%	Out of standard
Thin place -50%	32.5/km	≤20/km	Out of standard
Thick place +50%	539/km	≤200/km	Out of standard
Neps +200%	1563km	≤300/km	Out of standard

Tenacity (cN/tex)	≥ 15	≤ 14 cN/tex	Out of standard
-------------------	-----------	------------------	-----------------

Quality of the yarn depend on tested parameters, in case of these all of tested result fails outside of industry standard as above table shows. So, the result indicated that big quality issue.

Key observation from tested data:

Mass variation: CVm% (coefficient of mass variation): observation from the data defect rate is high (2.9%), this means poor yarn evenness (CVm%). Yarn count variation (2%) exceeds tolerance limit ($\pm 1.5\%$) it indicated that poor process instability.

Thin place (-50%): - From tested result thin place measured 32.5/km, this shows that the number of thin places detected per kilometers of yarn. A yarn defect where diameter is 50% thinner than the average yarn thickness.

The table shows; ≤ 20 /km =acceptable standard limit 32.5/km= Current defect level 32.5/km thin place per kilometers, this shows yarn thin place is out of standard and product quality is poor.

Thick place +50%: - From test result thick measured 539/km, it indicates the number of thick places found per kilometers of yarn. A yarn fault in which diameter is +50% thicker than the average yarn. ≤ 200 /km =acceptable standard limit 539/km= Current defect level 539/km thick place per kilometers, this shows yarn thick place is out of standard and product quality is poor.

Nep +200%: - From tested result thick measured 1563/km, this shows that the number of nep formation detected per kilometers of yarn. A yarn defect where diameter is +200% higher than the average yarn. This indicates poor fiber properties and fiber fly contamination.

4.3.2. Process efficiency measurements

According to “recorded data indicated; the process efficiency measurement of winding yarn production process.

Table 4-5 process activity time measurement

Yarn packaging Activity processed	VA	NVA	CT	From NVA-T Activities		
				Motion	Waiting	Transportation
Winding machine Preparation	27	65	92	26	3	19
Cop waiting (ring cop)		41	41	7	17	10
Cone loading and joining yarn	30	50	80	19	11	14
Waiting for count checking		17.5	17.5	4	10	2
Yarn Winding process	520	465	985	201.5	105	106.5
doffing full cone	20	40	60	21	4	8
Steaming	90	52	142	20	12	14
Final Quality checking		22.5	22.5	6	5	4
Total	687	753	1440	304.5	167	177.5

Process efficiency calculation: - Observed data categorizes activities as value added (VA), non-value added (NVA), and cycle time (CT). From the table;

- a. The sum of value adding time VA=687min
- b. The sum of Non value adding time NVA =753min
- c. The sum of cycle time = 1440min

Process efficiency percentage time spent on value adding activities relative in order to total cycle time. in accordance with process efficiency (VAR%) =(total VA time)/(total cycle time)*100%

Process efficiency (VAR%) = $(687 / 1440) * 100\% = 47.7\%$, This indicated that low efficiency when comparing company bench mark (75%). <50% indicates that there are unnecessary movement in the process. Pursuant to efficiency (NVAR%) = $(\text{total NVA}) / (\text{Total cycle time}) * 100\%$

Process efficiency (NVAR%) = $753 / 1440 * 100\% = 52.3\%$ This indicated that high waste when comparing VAR (47.7%). Observed point; from data process efficiency analyzed as following

In essence, pursuant = $(\text{total to (NVAR%) = } 753 / 1440 * 100\% \text{ NVA}) / (\text{Total cycle efficiency high (NVAR%) time}) * 100\%$

Observed point; from data process efficiency analysed as following

Table 4-6 observed result waste activity or process

Activity measured	Result	Interpretation
Value added (VAR%)	47.7%	Low efficiency in product process, that means less than half process time.
Non value added (NVAR%)	52.3%	More waste activity generated or more unnecessary activity
Transport waste	23.6%	Significant delay or poor flow material coordination
Motion waste	40.4%	Largest waste activity or searching material during process
Waiting waste	22.2%	Ore waste activity occurred or moving materials takes more time

From the three NVA Key observation from the table; activities; motion waste is the largest contributors and waiting and transport are minor contributors. Knowing the cause for occurrence and making countermeasure, we discuss in the next section.

4.4. Product Quality Analysis with DMAIC Approach

The DMAIC (define, measure, analyze, improve, and control) approach to product quality analysis can identify and manage a variety of yarn count in the production process of the case company. At different stages of the analysis, different six sigma tools can be used. In this instance, the main

defect types were identified using Pareto analysis, and the causes of the defects were identified using cause-and-effect analysis (fish bond diagram).

4.4.1. Define phase:

Beginning with the ginning ends at the winding section, the spinning department started the yarn production process. Since the winding section indicates the conclusion of the final yarn production process, it can be regarded as a crucial section for the case company. But this product has a number of defects that could significantly affect the quality of the finished products. Since the study focuses on yarn product defect of 40Ne yarn it is very important to define the defect in 40Ne product type from suitable standpoint. Defect in (40Ne yarn) are particularly critical because even minor imperfection can significantly impact on fabric quality.

Major Defect Identified; In 40Ne yarn products, the main defects were identified by observation, focus group discussion, and interviews, from the production and quality control departments. The study involved prolonged brainstorming sessions to generate a list of seven major defects impacting the quality of the yarn. The defects were ranked based on the severity, frequency, and aggregate impact on the final product. Therefore, the researchers Recorded the following major defects including: count variation, hairiness of yarn, thin/thin spots, bad piecing, shape of cones, and winding errors. By examining these faulty products, the study aims to enhance quality control procedures and minimize defects in the production of 40Ne yarn

count Variation is created by uneven winding tension, which causes non-uniform yarn weight and potential faults in fabrics. Hairiness on winding section occurs due to excess friction during the process, which reduces smoothness and creates pilling on fabrics. Thin and thick place areas occur because of poor control of tension that create weak areas that causes breakage. Misguided piecing of low-quality splices creates weak joints that break when weaving and knitting. Nep creation (small fibre entanglements) becomes more perceptible in high-count yarns and affects fabric appearance. These defects cumulatively compromise yarn quality, and therefore precise process control in the winding section must be employed for 40Ne yarn production.

The major sources of defect in 40Ne can be machine, lack of measurement, environment, workers skill gaps, lack of supervision and other related factors sum-up together for the overall

production quality problem. As previously mentioned, lean tools are used combined with Six Sigma's DMAIC roadmap to reduce defects.

SIPOC Diagram of 40Ne Yarn of Winding Section: In this study SIPOC diagram used to identifying potential source of defect or inefficiency, such as variation in raw material or issue in the winding section. It also used to as communication tool for everyone who does not understand the process, inputs, and output of the product.

SIPOC diagram (suppliers, inputs process, outputs and customers) for the winding section of yarn manufacturing are;

Table 4-7 SIPOC diagram chart

Categories	Description of 40Ne yarn
Supplier	Spinning department (provides 40Ne yarn cones), Raw material providers from ring, Maintenance team (machine components & lubrication) and Quality control (test data)
Input	40Ne spinning cones, Winding machine settings (speed and tension) and Packaging materials (cones and tubes).
Process	Unwinding yarn from spinning bobbins, Defect elimination (by sensors for removing thick/thin spots), Winding on to new cones/tubes, Tension control (to avoid loose/tight winding), Quality checking (evenness, hairiness, breaks) and packaging for next process (knitting/weaving).
Output	Wound cones of 40Ne yarn, Waste (yarn cuts, defective material), Quality reports (defects per kg, breaks per hour) and Packaged yarn ready for next process
Customer	Weaving and knitting departments and Packaging and distribution and Inventory management and external customers

4.4.2. Measurement phase

Product Quality Measurement (using sigma level): Sigma level is measure process capability and also indicate how well a process is performing in terms of defect rejected during production. In the textile manufacturing sigma level calculation helps to quantify the effectiveness of yarn production process and identify the opportunity of improvement.

Using **Appendix 1** recorded data of one months (march 05/03/2024 to April 04/04 /2024) on winding section researcher measuring the process capability of final yarn product, using the total production in kg per total defect rejection.

Total production Kg/Week= 17600kg/week and Total Defects in Kg /week=510kg/week

Step 1: defect rate calculation;

Defect rate = (total defect)/(total production per months)*100%

Defect rate = (510kg)/17600*100%= 3%

The measurement shows that 3% of total production is defective product. The goal is to propose how to reduce this percentages.

Step 2: Defect Per Million Opportunity (DPMO) calculation;

DPMO = (total defect)/(total production per months)*1000,000

DPMO = (510KG)/17600kg*1000,000 = 40,012, there are 40,012 million per opportunity

Step 3: DPMO to sigma level conversion.

Sigma level can be calculated by utilizing DPMO to sigma level conversation table. Utilizing standard conversation table.

SIGMA LEVEL	DPMO
1	690,000
2	308,000
3	66,800
4	6210
5	233
6	3.4

A DPMO 28,977 falls between 3 sigma level (which are 66800 DPMO). For exact sigma level, we can use the formula.

$$\text{Sigma level} = \text{NORMSINV} (1 - \text{DPMO} / 1,000,000) + 1.5$$

Where NORMSINV is the inverse function of the cumulative standard normal distribution.

$$\text{Sigma level} = \text{NORMSINV} (1 - 28977 / 1,000,000) + 1.5$$

$$\text{Sigma level} = \text{NORMSINV} (0.959988) + 1.5$$

$$\text{the NORMSINV} (0.959988) \approx 1.8$$

Sigma level = 1.8 + 1.5 = 3.3σ the goal is to reach 6σ sigma level.

$$Cp = \text{sigma level} / 3 = \mathbf{1.1}, (Cp > 1 \text{ indicates that the process is capable, but barely.})$$

The Case company's Data shows that Sigma level is 1.8 without a 1.5σ shift, indicating a high defect rate and significant process variation. When accounting for a 1.5σ shift, the Sigma level improves to 3.3, reflecting better process capability and fewer defects. A higher Sigma level (closer to 6σ) is desirable as it signifies greater quality, and efficiency in process. Thus, the company should focus on process efficiency improvement and variation reduction to achieve higher Sigma performance and enhance product.

Value Stream map (VSM): Both value-added and non-value-added activities in the yarn production process are clearly identified by value stream mapping (VSM), a powerful lean tool that effectively contributes in determining waste activity in the operations. We can compare the

provided data for value-adding and non-value-adding activities with the aid of the value stream map technique, and the data allows us to describe the noteworthy yarn packaging activities.

Table 4-8 process activity time measurement

Yarn packaging Activity processed	VA	NVA	CT	From NVA-T Activities		
				Motion	Waiting	Transportation
Winding machine Preparation	27	65	92	26	3	19
Cop waiting (ring cop)		41	41	7	17	10
Cone loading and joining yarn	30	50	80	19	11	14
Waiting for count checking		17.5	17.5	4	10	2
Yarn Winding process	520	465	985	201.5	105	106.5
Collecting and doffing full cone	20	40	60	21	4	8
Steaming	90	52	142	20	12	14
Final Quality checking		22.5	22.5	6	5	4
Total	687	753	1440	304.5	167	177.5

Using the above activity, the process mapping starting from winding machine preparation to final quality checking were taking. In this value adding and non-value adding process with time measurement taken over. Using all these activities, mapping the VSM created.

To create visual map the process flow with value adding and non-value times for each activity.

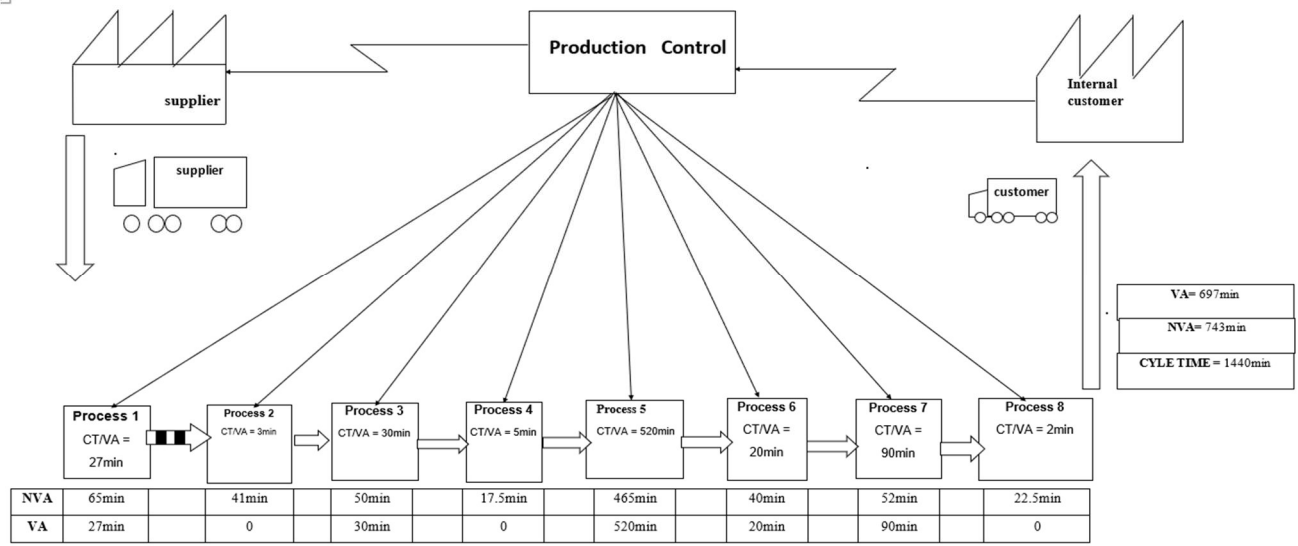


Figure 4:5 Process mapping of the yarn packaging

As the VSM above shows that, the process activity of Yarn packaging represents as process 1 up to process 8. From the VSM analysis yarn winding process is the largest contributors non-value adding with the significant motion waste activity.

Issue identified: from VSM, Process 5 (985min) is the largest bottleneck, consuming a significant portion of time and Process 7 (142 min) is also a potential bottleneck. And the other, motion waste activity is largest contributors.

4.4.3. Analysis phase

In order to carry out the study, which is focused on reducing defects in 40Ne yarn, the focus group and interviewee results was chosen to pinpoint the areas with the greatest problems. Depending on their discussion researcher was identify seven major problems that frequently occurred and impacted the quality of the 40Ne yarn product. Using a Pareto diagram, the main issues of the major defect was prioritized as the following.

Table 4-9 Analysis of major defects based on pareto charts

Defect Identified	Defects Rejected (Kg)	Total %	Cumulative %
Count variation	120	24%	24%
Yarn Hairiness	110	22%	45%
Thin place	90	18%	63%

Bad piecing	67	13%	76%
Winding faults	48	9%	85%
Nep formation	41	8%	93%
Shape of cone	34	7%	100%

Pareto chart analysis: - The researcher utilized four weeks gathering information on production and defects, including interview guides, questioner formats, and group discussions. The researcher prioritized the issues using Pareto charts based on information gathered from the case company's observation.

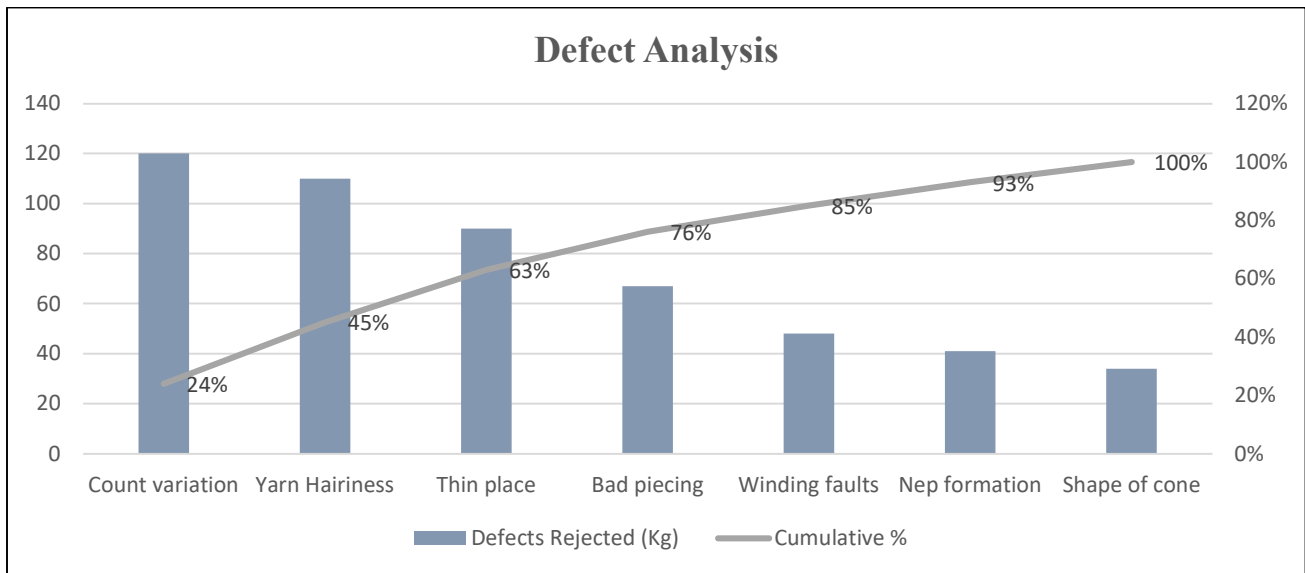


Figure 4:6 pareto chart analysis

Observation from the Pareto Chart Analysis: The pareto chart visualizes the different types of defects in the yarn winding process, their prespective frequencies and their cumulative percentages. From the pareto chart above , Cumulative percentages indicates that;Three major defects are the most significant affecting the of product quality. These are; Thin place, Hairiness, and thin place.

The pareto principle (80/20 rule) applies. The top three defects (Thin place, yarn hairiness and thick place) contribute to the majority of the problems or the causes of product type and amount of defect is more in product.

Fishbone Diagram (Cause and Effect Diagram): - The root reasons of the issues with product quality (40Ne) sources in yarn production were examined using a fishbone diagram (cause and effect). In process improvement techniques, a fishbone diagram is used to determine all of the contributing root causes that are probably causing an issue. The Pareto diagram's analysis results indicate that count variation, yarn hairiness, and thick/thin place are the primary defects that need to be given priority when focusing on defect issues.

The cause and effect of these defects can be created by examining the underlying causes of the defects in the machine, raw materials, labor, procedures, measurement, and environment. Focused group discussions and interviews are used to analyze the root causes of these issues. In the process, the others must be paying attention.

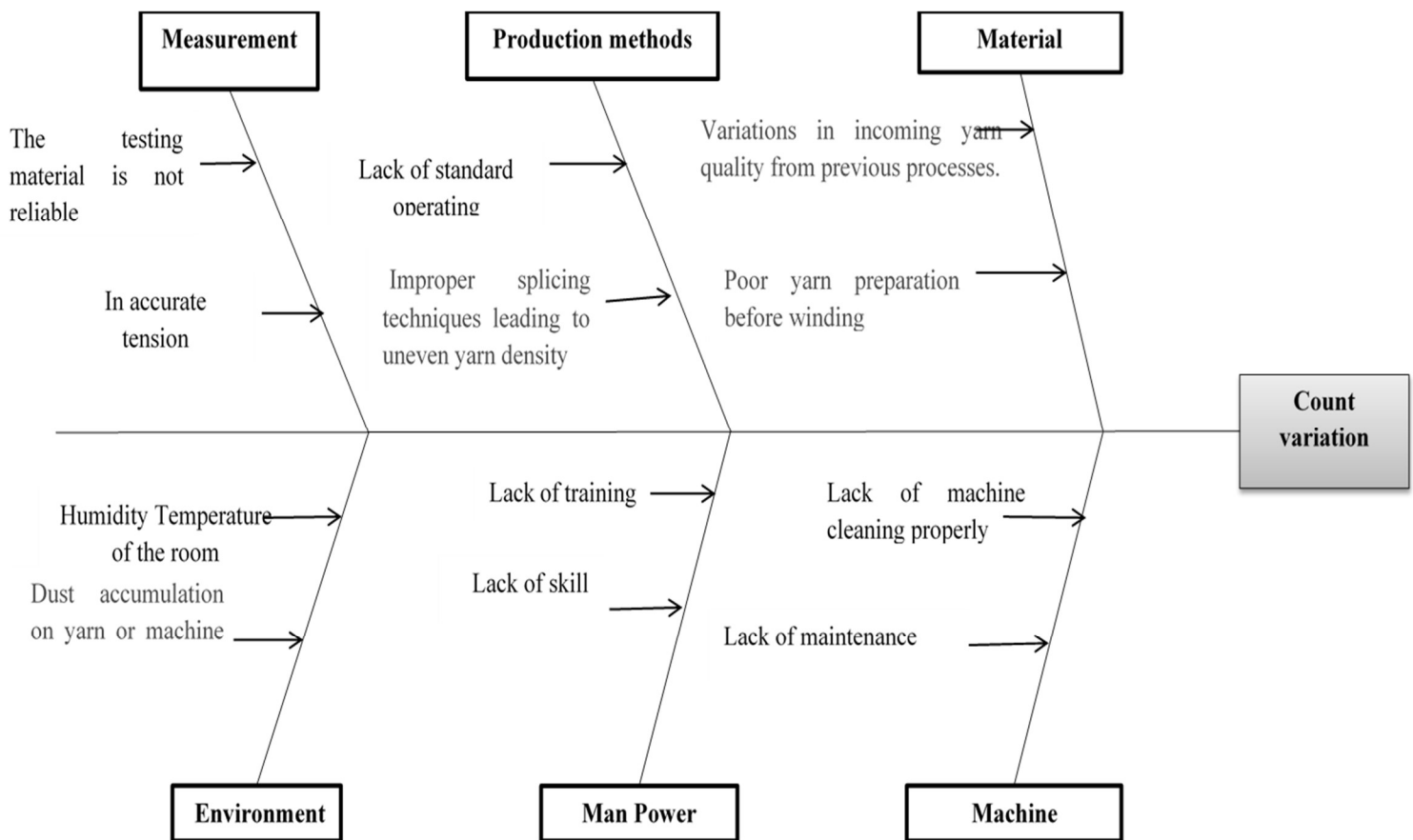


Figure 4:7 root cause analysis of count variation

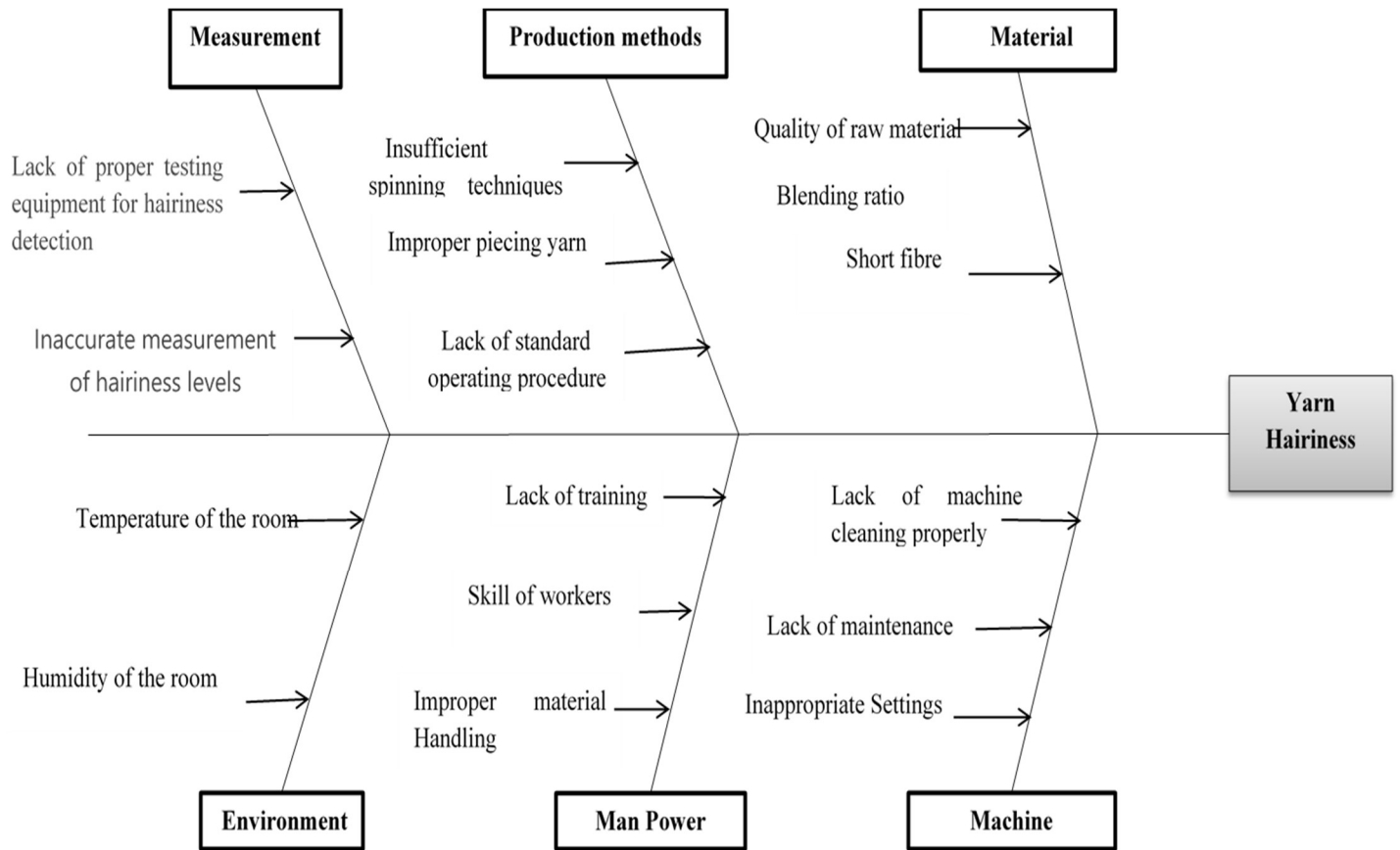


Figure 4:8 root cause analysis of yarn hairiness

Defect Analysis on Thin and Thick place

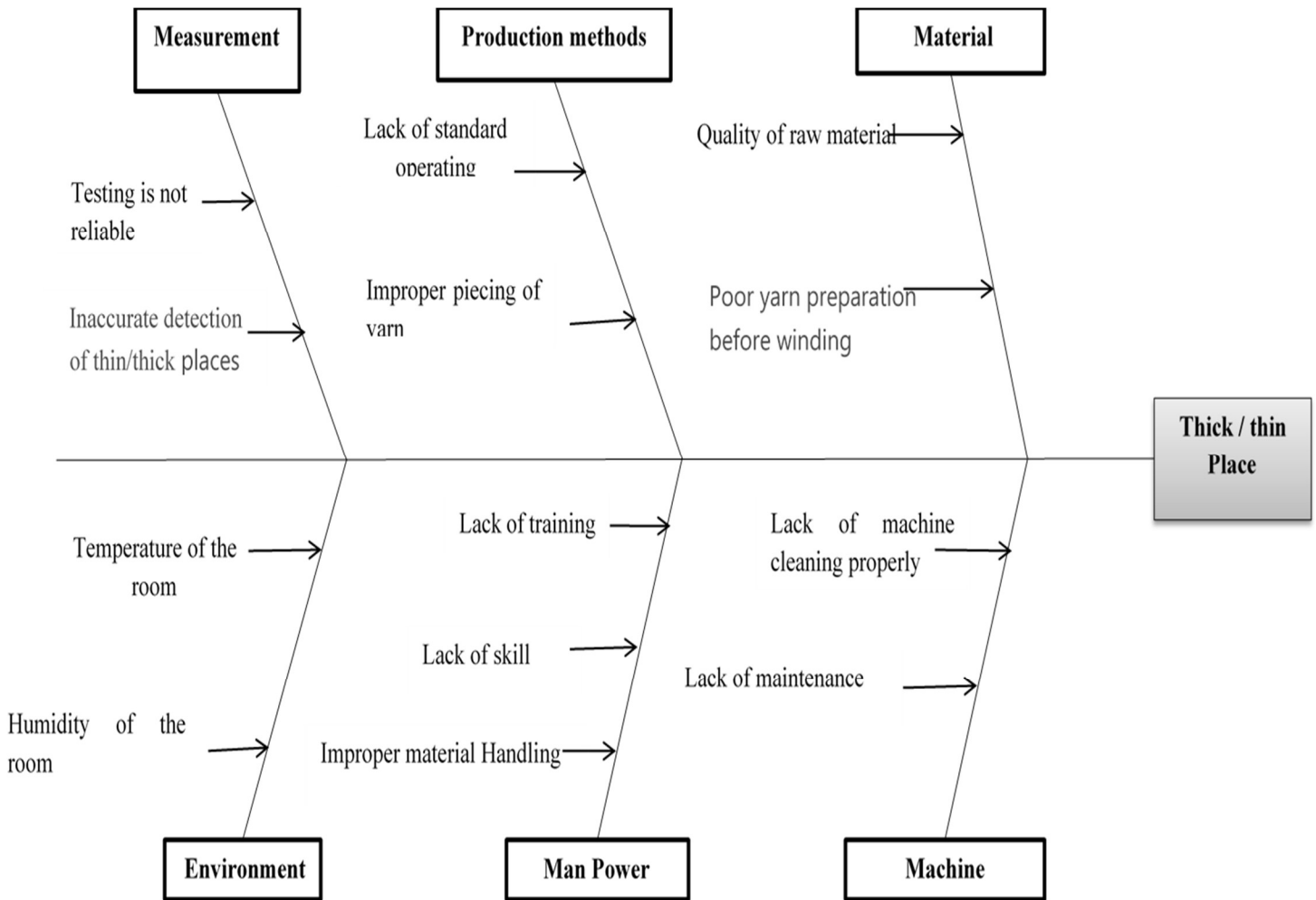


Figure 4:9 root cause analysis of thin- thick place

In addition, the causes of these defects needed investigated to find out why they occur, and to identify preventive measures, so they have been minimized or eliminated.

The above table shows that, experienced employees, supervisor, and production manager identify the root causes with the help of focused group discussion and a summary of the root causes is recorded.

4.4.4. Improving and controlling the root causes of defect using (why-why analysis)

The fish bond diagram above shows a number of defects that can be identified back to different underlying causes. In the controlling phase of the DMAIC methodology, the majority of these causes are classified under operational mistakes (complexity, skills, handling, etc.), and suggestions and alternative solutions are sent out. Consequently, the following general controlling and corrective actions are implemented by identifying each type of defect or variation. In DMAIC, the improvement stage is essential because it is during this phase that changes and action are made to address the identified issue. The primary tasks in this DMAIC phase were providing the best solutions for solving the issue based on the data that was analyzed, formulating a plan for the solution's development to ensure their effectiveness, and tracking its improvement.

Table 4-10 controlling the root causes of defect using (why-why analysis)

Major defects	Root causes	Why-1	Why -2	Why-3	Why -4	Controlling system
Count variation	Improper yarn piecing	Not follow procedure of piecing methods	Lack of training for workers.	Insufficient training program	Lack of fund for training	Implement continuous training and evaluation
	Speed of machines inconstant	Lack of machine maintenance.	Inadequate scheduling	Scheduled program is not trained	Not believe on scheduled program	Establish routine maintenance schedule
	Machine setting error	Maintenance overdue	No preventive maintenance plan	Spar part delayed	Budget cuts prioritize	Create structured discussion channel of all department
Yarn hairiness	Improper machine setting	Insufficient machine checking	Lack standardized process	No real time monitoring system	Predictive maintenance system not implemented	Establish standard process
	Improper yarn handling	No standard operating methods	Work instruction missing	Training is	Budget constraints	Allocate budgeted for training program
	Improper material handling	Lack of training	Limited training	Less attention for training		Give attention for training

Thin and thick place	Improper tension control on winding section	Tension discs worn-out	No replacement schedule	Maintenance is reactive only	Maintenance viewed as cost centre not priority	Install tension controlling device
	Variation of twist level	Spindle speed is inconstant	Machine setting is not controlled	Less attention	Lack of training	Enhance training on controlling

4.5. Process efficiency analysis with lean Approach

Lean methodology focusing on identifying and eliminating waste to improve process efficiency of case company. Data observed includes; value-added and non-value added along with cycle time and time spent on motion, transportation and waiting. These were Necessary movement and unnecessary movement of workers.

Value adding (VA) activities: - In winding section value adding (NVA) activities that add value on the process to enhance efficiency and reduce waste activities.

Non-value-adding activities: - In winding production process are activity that does not add value on the process. Such as cop waiting, movement during the production (motion), waiting of counts checking, and transportation from one section to the next section process.

During case company observation each and every waste activity (VA and NVA) recorded was identified and measured as the following table shows. From recorded data we extract the NVA times for each activity as well as the breakdown of wastes activities (motion, waiting, transportation). Using table 4.8 data given analyzing yarn packaging time measurement.

Value adding: yarn winding process, steaming, Checking the operation of winding machine (Preparation) and Cone loading and joining yarn.

Non value adding: waiting, motion and transportation are non-value adding

To calculate total value adding, non-value adding and cycle time measurement

1. The sum of **value adding** time = the sum of all activities adding value during yarn packaging.
VA=687min
2. The sum of **Non value adding** time = the total sum of all activities that do not adding value during yarn packaging. NVA =753min
3. The **sum of cycle time** = The sum of VA and NVA time, VA +NVA= 1440
Break Down of Non-Value Adding: motion =332.5
Waiting =178
Transportation= 220.5

Process efficiency- $\frac{\text{total VA time}}{\text{total VA time} + \text{total non VA time}} * 100\%$, $\frac{687}{687+753} * 100\% = 47.7\%$

Value added vs non-value-added time;

- **Total value-added time:** 687 min (time that adds value on the process)
- **Total NVA time:** 753 min (waste time including waiting time, transport and motion)
- **Cycle time:** 1440 min (total lead time for the process)

Table 4-11 Value added and nonvalue added percentage

Activity	Time per minute	Percentage
Value added time	687	47.7%
Non-value-added times	753	52.3%
Total	1440	100%

From the above table 47.7% of total time is value added time and 52.3% is non-value-added time. Non value adds times are transportation, motion, waiting and other activities. This is done by time measurement. The non-value-added time is high than value added time. This indicates workers are not paying attention to work. The major non value added and what they causes are identified and analysed. The total cycle tome of NVA process is 753minute. This non-value adding time measurement was breakdown into motion, Transportation and waiting.

From the table non value adding activities are summarized as the following table.

Table 4-12 summary of the table

From non-value adding	Time measurement (minute)	Percentage
Motion	304.5	40.4%
Transportation	177.5	23.6%
Waiting	167	22.2%
Other activities	104	13.8%
Total NVA	753	100%

Table 4-13 Non value adding percentage

Based on the data provided in the above table non-value-added activities in yarn process, various

aspects contribute to inefficiency in the process. The breakdown of time spent on different non value adding activities shows areas where improvements can be targeted to enhance process efficiency and reduce cycle time.

Table 4-14 The major root cause of waste activity

Major waste activities identified	Root Causes	% Contributed
Motion	<ul style="list-style-type: none"> • Poorly organized work areas • Poor planning of raw material storing 	40.4%
Transportation	<ul style="list-style-type: none"> • Poor planning of material flows • Searching of input material 	23.6%
Waiting	<ul style="list-style-type: none"> • Poor communication • Unreliable maintenance schedule 	22.2%
Other	<ul style="list-style-type: none"> • Poor feedback mechanisms, • lack of continuous improvement culture • Gaps of workers skill, and other inefficiency 	13.8%

However, some waste activities that are non-value-added cannot be eliminated (supporting) from the non-value-added time, most of the time is covered by motion, which is 40.4%; waiting is 22.2%; transportation is 23.6% and 13.8% is covered by others. As the results show non-value, activity affects the product performance of the company.

4.5.1. Methods of Controlling of Waste Activity (NVA activities)

Controlling and improving non value adding activity (waste) essential for enhancing efficiency and productivity in operations. The following lean tools are essential for analysing waste activities.

Implement 5S methods: Use the 5S (sort, set in order, shine, standardize, and sustain) approach to workplace organization to make sure that materials and equipment are readily available. Wastes are closely linked to worker movements in the winding section. Therefore, in order to improve product quality during the production process, it is crucial to successfully implement and control the 5S wastes activities (40Ne).

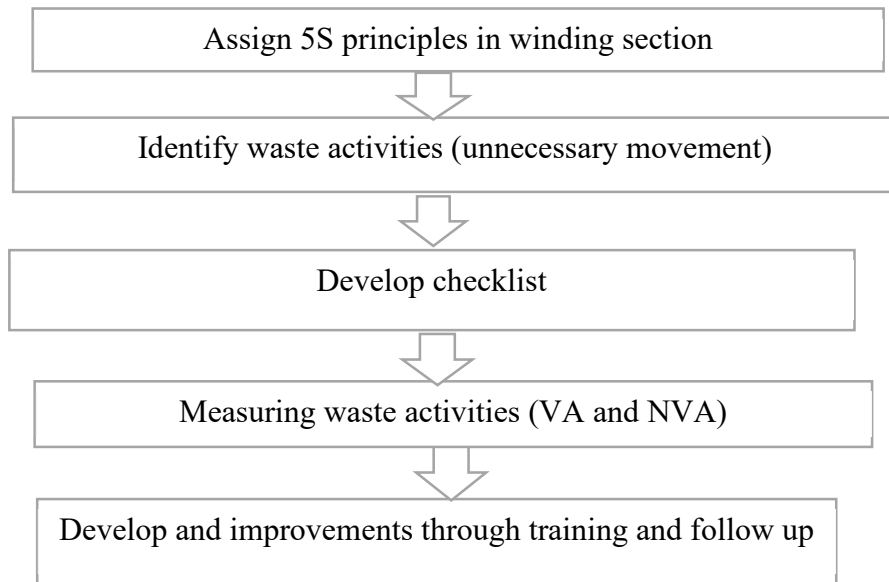


Figure 4:10 Controlling Strategies of Waste Activity

The major significant waste activities is/are identified and explained on the table 8, were controlled and improved using 5S implement strategy or the steps explained above the figure.

5S Implement strategies:

Sort: - Eliminate Unnecessary Item

- Conduct through audit of the work place in order to identify unnecessary tools and materials (unnecessary yarn count, empty cone and unnecessary cop) removing unnecessary items from the workspace.
- leverage red tagging system in order to mark items that are not needed in the work place (necessary yarn count and unnecessary yarn count, cone,)

Set in Order: organize the work place

- designate specific place for the purpose of tools or materials based on frequency of leverage including; organize materials near in order to machine for the purpose of easy access; cones and yarn materials placed near the winding machine
- leverage visual management of tools like labels, and colour coding this used in order to find items easily. this used to reduce unnecessary movement and arrange materials that are needed to commence winding process to reduce extra movement.

Shine: - Clean and Inspect

- develop regular cleaning schedule and it emphasizes regular cleaning, proper storage, and preventative maintenance in order to ensure optimal working conditions for the purpose of machines.
- Activities in this step include the cleaning of foreign materials that create the final product.

Standardize: create standardize

- Create verify list, working standard and schedule for the purpose of waste activity or defect happened
- Train employees on the new standard

Sustain: maintain and inspect

- The last step, sustain, is with regard to continuously reinforcing the improvements made and making them a part of everyday work culture. It involves giving training, and employee engagement in order to ensure the 5S practices

4.6. Discussion

In this study, focused on improving product quality and process efficiency in the winding section of spinning department which was identified as having highest defect rejection rate (25%) and waste activities data has been collected through as a preliminary data assessment. Among the company's three product type including (40Ne, 20Ne, and 16Ne) the 40Ne yarn count was selected for defect reduction due to its big quality issues. Depending on data collected from focus group discussions and expert inputs revealed the major defects through pareto analysis including; count variation (24%), yarn hairiness (22%) and thin /thick place (18%) as well as the result of sigma level of the product quality (40Ne) was 3.25, indicating that the process needs improvement. Root causes analysis identified six key contributors of defects; including machine related issues, operator skill gaps, material flow inefficiency, process variability, and measurement error.

process efficiency analysis of yarn packaging process showed that value non-value activities (52.3%) exceeded value added activities (47.7%) indicated that inefficiency. In other way motion waste (40.4%) was the largest contributors followed by transportation (23.6%), waiting (22.2%)

and others (13.8%). Also further investigate the root causes including; machine related issues, operator skill gaps, material flow inefficiency, process variability, and measurement error were taken.

The study applied DMAIC ((Define, Measure, Analyse, Improve, and Control) approach of lean six sigma to explain these challenges. In the analysis phase cause were examined, while in the improvement stage, the 5W1H and 5S are practiced, and after this, the final stage proposed controlling methods. This study aims to demonstrate the effectiveness of Lean Six Sigma in the DMAIC (Define, Measure, Analyse, Improve, and Control) approach by including core Lean techniques such as Value Stream Mapping (VSM), Pareto analysis, Fishbone diagrams, Why-Why analysis, 5S, and process mapping

4.7. Proposing LSS integration model

The proposed Lean Six Sigma (LSS) integration model follows the DMAIC (Define, Measure, Analyse, Improve, Control) framework to systematically address efficiency and defect issues in the winding process for the 40Ne product type. This structured approach combines Lean methodologies (focused on waste reduction) and Six Sigma (focused on defect elimination) to optimize production processes.

The extent and applications of LSS integration will depend on the number of operations and their complexity. As mentioned in the problem statement of this paper, the study will identify the main problems with process efficiency (specifically for the winding process for the 40Ne product type) in order to analyze and draw conclusions for similar ones. Assessment of production conditions: During this phase, senior management will assess the state of the company's operations with respect to overall product quality and process effectiveness. This may serve as a roadmap for more extensive advancements. The first step in identifying limitations for issues with process efficiency and product quality is evaluating process efficiency. Every operational difficulty is classified under this as an internal or external issue. Workers and machines are the main sources of internal production issues.

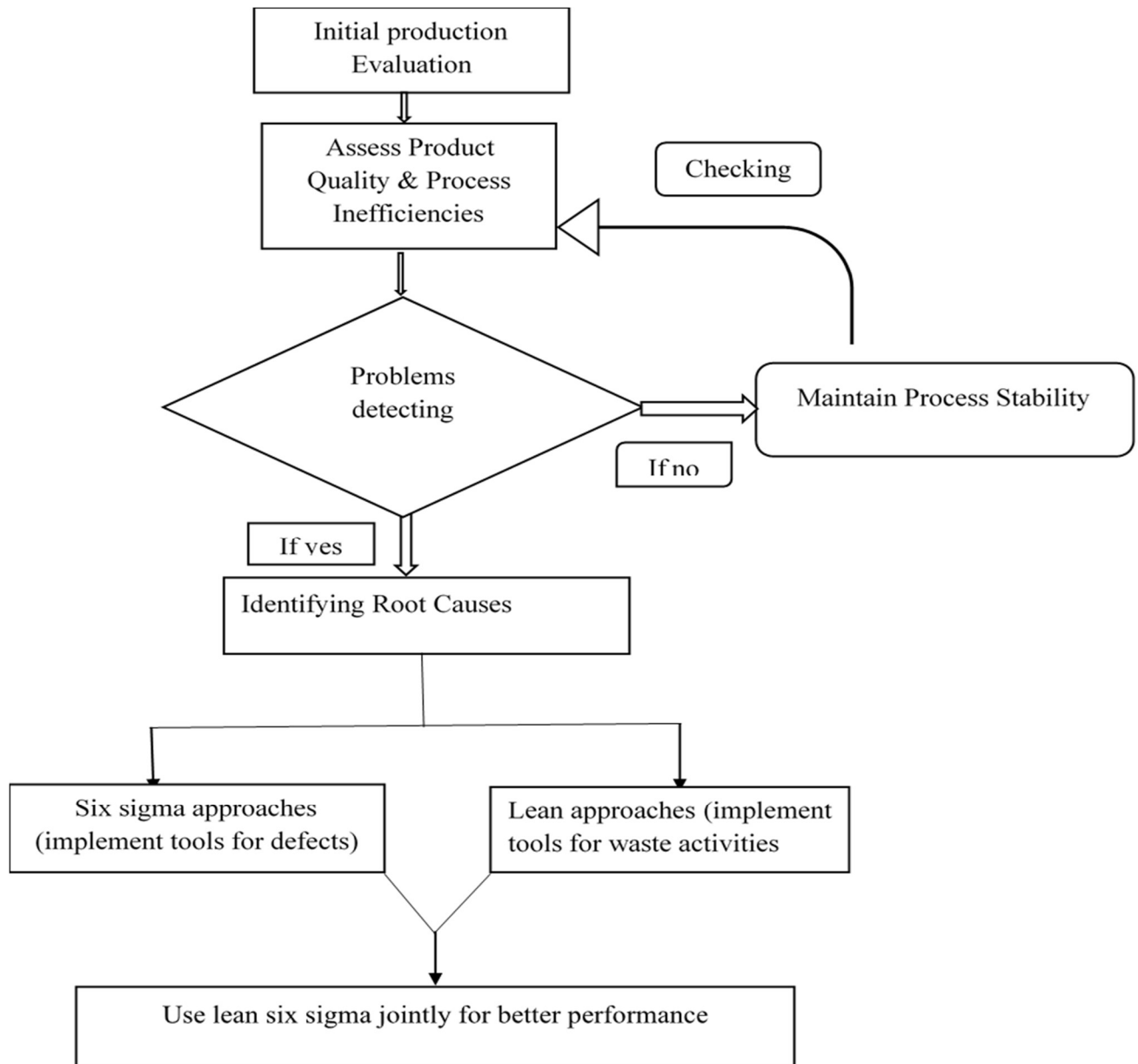


Figure 4:11 proposing LSS methods

CHAPTER FIVE

Conclusion and Recommendation

5.1. Conclusion

This study investigated the application of Lean Six Sigma (LSS) methodologies to improve product quality and process efficiency in the yarn manufacturing process, with a specific focus on the winding section of Else Addis Industrial Development P.L.C. The research identified big challenges in the production of 40Ne yarn, which exhibited the highest defect rejection rate (25%) among the company's products. Through Pareto analysis, the major defects count variation (24%), yarn hairiness (22%), and thin/thick places (18%) were prioritized, collectively accounting for 64% of total defects. Root cause analysis, facilitated by fishbone diagrams and why-why analysis, revealed critical contributors such as machine-related issues, operator skill gaps, material flow inefficiencies, process variability, and measurement errors.

Process efficiency evaluation highlighted that non-value-added (NVA) activities (52.3%) surpassed value-added (VA) activities (47.7%), with motion waste (40.4%) being the most big contributor, followed by transportation (23.6%) and waiting (22.2%). The sigma level of 3.25 indicated big process variation, underscoring the need for targeted improvements. The integration of Lean tools including; 5S, Value Stream Mapping) and Six Sigma's DMAIC framework proved effective in addressing these challenges, demonstrating the potential of LSS to enhance both product quality and operational efficiency in textile manufacturing.

The proposed LSS integration model serves as a practical reference for similar industries, emphasizing the importance of continuous improvement, employee training, and systematic waste reduction. By addressing root causes; this study contributes to the broader adoption of LSS in the textile sector, fostering competitiveness and sustainability.

5.2. Recommendation

Based on the research finding, the researcher makes the following recommendation.

1. **Adopt DMAIC Methodology:** Implement the Define-Measure-Analyze-Improve-Control (DMAIC) framework systematically to reduce defects and process variations. Regular audits

should ensure adherence to standardized procedures, and cross-functional teams should be formed to monitor progress.

2. **Develop Training Programs:** Conduct targeted training sessions to improve operator skills in machine handling, defect detection, and efficient work practices. Cross-departmental workshops can align teams with quality goals, and a structured feedback mechanism should be established to address skill gaps.
3. **Establish Communication Systems:** Establish real-time communication channels between departments (e.g., production, maintenance, quality control) to promptly address issues like machine breakdowns or material delays.
4. **Reduce NVA Activities:** Prioritize minimizing motion, transportation, and waiting wastes through layout reorganization, standardized workflows, and predictive maintenance schedules.
5. **Implement 5S Practices:** Apply the 5S methodology (Sort, Set in Order, Shine, Standardize, Sustain) to organize workspaces, reduce clutter, and improve tool/material accessibility. Regular audits should ensure compliance and identify new improvement opportunities.
6. **Develop Performance Metrics:** Introduce KPIs to monitor VA/NVA activities, defect rates, and ensuring continuous improvement.
7. **Establishing controlling format of VA and NVA activities;** this is used to controlling operator performance and process efficiency improving;

References

- A. Nedra, S. Néjib, C. Yassine, and C. M. (2019). A new lean Six Sigma hybrid method based on the combination of PDCA and the DMAIC to improve process performance: Application to clothing SME., *Ind. Textila*, Vol. 70, No. 5, Pp. 447–456,.
- Adrian, K. (2023). *Lean Six Sigma as A Strategy for Increasing Knitting Manufacturing Profitability Through Fabric Quality and Work Efficiency Improvement*. 760–771. <https://doi.org/10.46254/ap03.20220153>
- Adrian, K., & Kosasih, W. (2023). *Lean Six Sigma as A Strategy for Increasing Knitting Manufacturing Profitability Lean Six Sigma as A Strategy for Increasing Knitting Manufacturing Profitability Through Fabric Quality and Work Efficiency Improvement*. February.
- Babu, B. N. and T. R. (2015). Productivity improvement in manufacturing industry using industrial engineering tools., *J. Mech. Civ. Eng.*, Vol. 6, No. 1, Pp. 11–18,.
- Dinulescu, R., & Dima, A. (n.d.). *PROCEEDINGS OF THE 13 th INTERNATIONAL Management Conference “Management Strategies for High Performance” Improving Performance in Romanian Garment Industry By Using The Lean Six Sigma Methodology*.
- E.V. Gijo, J. Scaria, J. A. (2011). Application of six sigma methodology to reduce defects of a grinding process. *Qual. Reliab. Eng., Int.* 27(8).
- Gaikwad, L. M., Sunnapwar, V. K., Teli, S. N., & Parab, A. B. (2017). Application of DMAIC and SPC to Improve Operational Performance of Manufacturing Industry: A Case Study Application of DMAIC and SPC to Improve Operational Performance of Manufacturing Industry : A Case Study. *Journal of The Institution of Engineers (India): Series C*, October. <https://doi.org/10.1007/s40032-017-0395-5>
- Gasperz & Fontana. (2011). A. LEAN SIX SIGMA for manufacturing and service industries: waste elimination and continuous cost reduction. *Vinchrsto Publication*.
- Gupta, N. (2013a). *An Application of DMAIC Methodology for Increasing the Yarn Quality in Textile Industry*. 6(1), 50–65.

- Gupta, N. (2013b). *Implementation of Six Sigma For Minimizing The Defects Rate At A Yarn Manufacturing Company*. 3(2), 1000–1011.
- Henny, H., & Budiman, H. R. (2018). Implementation lean manufacturing using Waste Assessment Model (WAM) in shoes company. *IOP Conference Series: Materials Science and Engineering*, 407(1). <https://doi.org/10.1088/1757-899X/407/1/012077>
- Hussain, T. (2014). *Reducing defects in textile weaving by applying Six Sigma methodology: a case study Reducing defects in textile weaving by applying Six Sigma methodology: a case study Tanveer Hussain *, Hafsa Jamshaid and Ateeb Sohail. August.*
- Hussain, T., & Mohsin, M. (N.D.). *Knitwear Product Quality Analysis and Development Of*. 1–14.
- Ismail, M. Z. M., & Zainal, A. H. (2021). *Implementation of Lean Manufacturing Process to Reduce Waste : A Case Study Implementation of Lean Manufacturing Process to Reduce Waste : A Case Study*. <https://doi.org/10.1088/1757-899X/1096/1/012006>
- Keke, Y., . V., Putrianto, V., Basyar Azzuhri, M., Pratiwi Perwitasari, E., & . Y. (2023). An Analysis of Quality Control on Defective Products at PT. Signore. *KnE Social Sciences*, 2023, 827–841. <https://doi.org/10.18502/kss.v8i9.13396>
- Khatri., M. A. K. H. B. M. A. (2020). The Applications Of Lean Manufacturing Practices In Textile Industry, *International Conference on Industrial Engineering and Operations Management, Dubai, UAE*, 2360–2361.
- Kingdom, U. (2019). *A Lean, Green and Six Sigma (LG6 σ) for SMEs in the leather industry in Bangladesh*. 7.
- Kumar, R. S. (2010). Six Sigma in the Textile Industry. *Www.Fibre2fashion.Com M*.
- Kumar, S., Kumar, P., Mughal, U. K., & Memon, A. H. (2023). *THE APPLICATION OF DMAIC APPROACH FOR INCREASING THE QUALITY OF YARN MANUFACTURING : A CASE STUDY OF TEXTILE INDUSTRY*. 01, 1826–1839.
- Kurnia, H., Jaqin, C., & Purba, H. H. (2021). *Quality Improvement with the DMAIC Approach Using the Implementation of Benchmarking and KPI Methods*. 2122–2133.

- Kurnia, H., Sihar, O., Tumanggor, P., & Jaqin, C. (2021). *3 Rd Mercu Buana Conference On Industrial Engineering-Mbcie 2021 Lean Six Sigma: Literature Review And Implementation For Textile And Textile Product (Ttp) Industries Abstrak 3 Rd Mercu Buana Conference On Industrial Engineering-Mbcie 2021. January 2022*, 1–10.
- Kurnia, H., Sihar, O., Tumanggor, P., Jaqin, C., & Buana, U. M. (2021). *LEAN SIX SIGMA : LITERATURE REVIEW AND IMPLEMENTATION FOR TEXTILE AND TEXTILE PRODUCT (TTP) INDUSTRIES 3 rd Mercu Buana Conference on Industrial Engineering-MBCIE 2021 LEAN SIX SIGMA : LITERATURE REVIEW AND IMPLEMENTATION FOR TEXTILE AND TEXTILE PRODUCT. October*.
- Li, G., Reimann, M., & Zhang, W. (2018). When remanufacturing meets product quality improvement: The impact of production cost. *European Journal of Operational Research*, 271(3), 913–925. <https://doi.org/10.1016/j.ejor.2018.05.060>
- Martin, J. W. (2014). *LEAN SIX SIGMA For Supply Chain Management: A 10-Step Solution Process (2nd Ed.)*. New York: McGraw-Hill Education LLC.
- Modi, D. B., & Thakkar, H. R. (2014). *Lean Thinking: Reduction of Waste, Lead Time, Cost through Lean Manufacturing Tools and Technique*.
- Mukhopadhyay, A. R. (2015). *Reduction of Yarn Packing Defects Using Six Sigma Methods : A Case Study. December*. <https://doi.org/10.1080/08982110600567533>
- P. Kumar, M. A. Khan, U. K. Mughal, and S. K. (2020). “*Exploring the Potential of Six Sigma (DMAIC) in Minimizing the Production Defects*,.
- Potkány, M., Závadsky, J., Hlawiczka, R., Gejdoš, P., & Schmidtová, J. (2022). Quality Management Practices in Manufacturing Enterprises in the Context of Their Performance. *Journal of Competitiveness*, 14(2), 97–115. <https://doi.org/10.7441/joc.2022.02.06>
- Rathore, A. P. S. (n.d.). *"Implementation of Lean Tools for Process Improvement in a Manufacturing Industry*.

- Sodhi, H. S., Singh, D., & Singh, B. J. (2020a). A conceptual examination of Lean, Six Sigma and Lean Six Sigma models for managing waste in manufacturing SMEs. *World Journal of Science, Technology and Sustainable Development*, 17(1), 20–32. <https://doi.org/10.1108/WJSTSD-10-2019-0073>
- Sodhi, H. S., Singh, D., & Singh, B. J. (2020b). A conceptual examination of Lean, Six Sigma and Lean Six Sigma models for managing waste in manufacturing SMEs. *World Journal of Science, Technology and Sustainable Development*, 17(1), 20–32. <https://doi.org/10.1108/WJSTSD-10-2019-0073>
- Taye, H., & Bekele, A. (n.d.). *Implementation of Statistical Quality Control for Spinning Processes of Dire Dawa Textile*. 1–14.
- Taylan, O., & Darrab, I. A. (2012). Fuzzy control charts for process quality improvement and product assessment in tip shear carpet industry. *Journal of Manufacturing Technology Management Product Assessment in Tip Shear Carpet Industry*. <https://doi.org/10.1108/17410381211217434>
- Uzorh, A., Uzorh, E. A., Olanrewaju, E. F., & Nnanna, E. I. (2018). Integration of Lean Manufacturing And Six Sigma Using Statistical Methods. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN*, 15(4), 63–76. <https://doi.org/10.9790/1684-1504026376>
- Value, C., & Roadmap, C. (2020). *Textile and clothing value chain roadmap 2016-2020*.
- Wirani, A. P., Saroso, D. S., Purba, H. H., Ishak, A., & Siregar, K. (2019). *Analysis Quality Control of Carded and Combed Yarns Using Six Sigma Method*. *Analysis Quality Control of Carded and Combed Yarns Using Six Sigma Method*. <https://doi.org/10.1088/1757-899X/662/6/062008>
- Yang, M., & Pan, J. (2021). *Application of Statistical Control Charts for Monitoring the Textile Yarn Quality*. *Application of Statistical Control Charts for Monitoring the Textile Yarn Quality*. <https://doi.org/10.1088/1742-6596/1973/1/012158>



Addis Ababa University

College of Technology and Built Environment

School of Mechanical and Industrial Engineering

Industrial Engineering Stream

Dear respondents, this questionnaire is prepared to gather relevant data from the spinning department employees of /ELSE ADDIS INDUSTRIAL DEVELOPMENT PLC to study and identify the root cause of defective and wastes impacts on process efficiency and product quality yarn in this company. The aim of this study is for the partial-fulfilment of MSc in industrial engineering from Addis Ababa University.

I. Observation

1. Identify, record, and map the main processes of yarn manufacturing in the case company? (i.e., Identify and map the actual process flow in the case company!)
2. Identify stakeholders, input and output focusing on the Process Mapping of the case company?
3. Identification of value added and non -value added?
4. Here, the SIPOC diagram could be very useful to specify the related stakeholders and the main project activities;

Supplier	Input	Processes	Output	Customer

II.

III. Interview and group discussion points

1. What is/are the most common defect in yarn production process?
2. What do you recognize that the root causes for the occurrence of the defects? Please mention from the following Perspectives' and what mitigation strategy?

Material Perspective;

Machinery Perspective;

Method Perspective;

Man power Perspective;

Environment;

3. What tools or methods are used to detect and measure defects?
4. Can you identify any non-value-adding activities that take up a significant amount of time? Why do these activities happen, and how critical are they to the process?
5. How do you currently measure cycle time and lead time? Are there any bottlenecks that are challenging to address?
6. What role or do operator training or skill preventing defects?

IV. Questionnaires: Detail Causes for frequently happening Defects and waste activities

1. What type of defects are occurring during production process?
2. What are the major causes for count variation, yarn hairiness, thin and thick places of defects? Please mention from the following Perspectives';

Raw Material Perspective;

Machinery Perspective;

Method Perspective;

Man power Perspective;

Environment perspective;

3. How do defects impact final product quality?
4. What tasks do you believe directly contribute to the final quality or production of the product (value-adding tasks)? Operating machinery, monitoring production quality, Packaging and Other (please specify); -----
5. Which tasks do you feel do not directly add value to the product but are necessary to complete the process? Waiting for materials or equipment, moving products between sections, waiting for quality checks and Other (please specify); -----

Appendix-1: capacity of production per month and defect rejected per production recorded format

Period (March, 07 to April 06) Kg/Week	Total Defects in Kg /week
1st week		
2nd week		
3rd week		
4th week		

capacity of production per month and defect rejected per production recorded data in kg.

Product type	Period (March, 05 to April 04)	Total production Kg/Week	Total Defects in Kg /week
16Ne	1st week	4280	138
	2nd week	4470	128
	3rd week	4600	104
	4th week	4250	140

Appendix-2: Defect rejected on winding section recording format?

Defect Type	% Rejected (...Kg's)/month
Rejection due to yarn hairiness	
Rejection due to Count Variation;	
Rejection due to thin and thick place	

Rejection Bad piecing	
Rejection Winding faults	
Rejection Dirty Package	
Rejection Shape of cone	

Appendix-3: -Controlling format VA and NVA controlling format

Activities processed during yarn winding	VA	NVA	CYCLE TIME	From VA and NVA Activities		
Winding machine Preparation						
Cop waiting (ring cop)						
Cone loading and joining yarn						
Waiting for count checking						
Yarn Winding process						
Collecting and doffing full cone						
Steaming						
Final Quality checking						
Winding machine Preparation						
Cop waiting (ring cop)						
Cone loading and joining yarn						
Waiting for count checking						

Appendix-4 recorded data of winding section case company (January 01/01/2024 to April 30/04/2024)

NO	Product type	January		February		March		April		Total pr/M	Total def/M
		Pr/M	Def/M	Pr/M	Def/M	Pr/M	Def/M	Pr/M	Def/M		
1	40ne	15070	690	14390	585	17600	510	14095	672	61155	2457
2	20Ne	15450	395	17450	412	16975	430	16450	420	66325	1664
3	16Ne	17201	370	16200	309	17120	378	17090	394	67611	1551

Appendix-5: - Five months of production and defect recorded data (January 01/2024 to May 30/2024)

Section	Company production per and Defect Rejected Recorded Data in kg per month												
	January		February		March		April		May		Total		
	P/ per month	D/ per month	P/ per month	D/ per month	P/ per month	D/ per month	P/ per month	D/ per month	P/ per month	D/ per month	P/ per month	D/ per month	
Blow room	14570	994	13470	870	15600	894	16422	795	24700	812	84762	4100	
Carding	15432	940	17861	932	18430	977	16211	956	15678	895	83612	4700	
Draw frame breaker	16790	781	15438	789	15432	870	17900	867	16890	743	82450	4050	
Draw frame finisher	17430	765	16228	681	17327	785	15119	890	15464	789	81568	3910	
Roving	15876	870	17901	991	15680	910	14670	789	16545	870	80672	4430	

Ring	19432	1194	13456	1235	16458	1231	14232	1190	14256	1180	77834	6030
Winding	13531	1820	17853	1840	14670	1795	16431	1875	14600	1870	77085	9200
Packing	16931	230	13460	114	15900	125	14235	189	15780	212	76306	870

0

Appendix-6: Cycle time in production process observed by researcher

Yarn packaging Activity processed	VA	NVA	CT	From NVA-T Activities		
				Motion	Waiting	Transportation
Winding machine Preparation	27	65	92	26	3	19
Cop waiting (ring cop)		41	41	7	17	10
Cone loading and joining yarn	30	50	80	19	11	14
Waiting for count checking		17.5	17.5	4	10	2
Yarn Winding process	520	465	985	201.5	105	106.5
Collecting and doffing full cone	20	40	60	21	4	8
Steaming	90	52	142	20	12	14
Final Quality checking		22.5	22.5	6	5	4
Total	687	753	1440	304.5	167	177.5

Appendix -6 sigma table

DPMO : Sigma Level Table

Sigma Level	Without 1.5 sigma shift			With 1.5 sigma shift		
	DPMO	Yield	Defect Rate	DPMO	Yield	Defect Rate
1	317310	68.2690000%	31.7310000%	697612	30.23880%	69.76120%
1.1	271332	72.8668000%	27.1332000%	660082	33.99180%	66.00820%
1.2	230139	76.9861000%	23.0139000%	621378	37.86220%	62.13780%
1.3	193601	80.6399000%	19.3601000%	581814	41.81860%	58.18140%
1.4	161513	83.8487000%	16.1513000%	541693	45.83070%	54.16930%
1.5	133614	86.6386000%	13.3614000%	501349	49.86510%	50.13490%
1.6	109598	89.0402000%	10.9598000%	461139	53.88610%	46.11390%
1.7	89130	91.0870000%	8.9130000%	421427	57.85730%	42.14270%
1.8	71860	92.8140000%	7.1860000%	382572	61.74280%	38.25720%
1.9	57432	94.2568000%	5.7432000%	344915	65.50850%	34.49150%
2	45500	95.4500000%	4.5500000%	308770	69.12300%	30.87700%
2.1	35728	96.4272000%	3.5728000%	274412	72.55880%	27.44120%
2.2	27806	97.2194000%	2.7806000%	242071	75.79290%	24.20710%
2.3	21448	97.8552000%	2.1448000%	211927	78.80730%	21.19270%
2.4	16395	98.3605000%	1.6395000%	184108	81.58920%	18.41080%
2.5	12419	98.7581000%	1.2419000%	158686	84.13140%	15.86860%
2.6	9322	99.0678000%	0.9322000%	135686	86.43140%	13.56860%
2.7	6934	99.3066000%	0.6934000%	115083	88.49170%	11.50830%
2.8	5110	99.4890000%	0.5110000%	96809	90.31910%	9.68090%
2.9	3731	99.6269000%	0.3731000%	80762	91.92380%	8.07620%
3	2699	99.7301000%	0.2699000%	66810	93.31900%	6.68100%
3.1	1935	99.8065000%	0.1935000%	54801	94.51990%	5.48010%
3.2	1374	99.8626000%	0.1374000%	44566	95.54340%	4.45660%
3.3	966	99.9034000%	0.0966000%	35931	96.40690%	3.59310%
3.4	673	99.9327000%	0.0673000%	28716	97.12840%	2.87160%
3.5	465	99.9535000%	0.0465000%	22750	97.72500%	2.27500%
3.6	318	99.9682000%	0.0318000%	17864	98.21360%	1.78640%
3.7	215	99.9785000%	0.0215000%	13903	98.60970%	1.39030%
3.8	144	99.9856000%	0.0144000%	10724	98.92760%	1.07240%
3.9	96	99.9904000%	0.0096000%	8197	99.18030%	0.81970%
4	63	99.9937000%	0.0063000%	6209	99.37910%	0.62090%
4.1	41	99.9959000%	0.0041000%	4661	99.53390%	0.46610%
4.2	26	99.9974000%	0.0026000%	3467	99.65330%	0.34670%
4.3	17	99.9983000%	0.0017000%	2555	99.74450%	0.25550%
4.4	10	99.9990000%	0.0010000%	1865	99.81350%	0.18650%
4.5	6	99.9994000%	0.0006000%	1349	99.86510%	0.13490%
4.6	4	99.9996000%	0.0004000%	967	99.90330%	0.09670%
4.7	2	99.9998000%	0.0002000%	687	99.93130%	0.06870%
4.8	1	99.9999000%	0.0001000%	483	99.95170%	0.04830%
4.9	0.96	99.9999040%	0.0000960%	336	99.96640%	0.03360%
5	0.574	99.9999426%	0.0000574%	232	99.97680%	0.02320%
5.1	0.34	99.9999660%	0.0000340%	159	99.98410%	0.01590%
5.2	0.2	99.9999800%	0.0000200%	107	99.98930%	0.01070%
5.3	0.116	99.9999884%	0.0000116%	72	99.99280%	0.00720%
5.4	0.067	99.9999933%	0.0000067%	48	99.99520%	0.00480%
5.5	0.038	99.9999962%	0.0000038%	31	99.99690%	0.00310%
5.6	0.021	99.9999979%	0.0000021%	20	99.99800%	0.00200%
5.7	0.012	99.9999988%	0.0000012%	13.35	99.99867%	0.00134%
5.8	0.007	99.9999993%	0.0000007%	8.55	99.99915%	0.00086%
5.9	0.004	99.9999996%	0.0000004%	5.42	99.99946%	0.00054%
6	0.002	99.9999998%	0.0000002%	3.4	99.99966%	0.00034%

