# Addis Ababa University

## Collage of Technology and built Environment

## School of mechanical and industrial Engineering


**Improving Quality & Productivity through Lean Six Sigma DMAIC Approach implementation: A case of ERCO Textile and Garment PLC**

A Thesis Submitted to the School of Graduate Studies of Collage of Technology and Built Environment Addis Ababa University in Partial Fulfillment of the Degree of Master of Science in Industrial Engineering


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**Declaration**

I declare that the work presented in this thesis, titled "Improving Quality and Productivity through Lean Six Sigma DMAIC Approach Implementation: A Case of ERCO Textile & Garment PLC," is my original work. It has not been submitted for a degree at any other university, and all sources of material used in this thesis have been properly acknowledged.

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## ABSTRACT

The thesis addresses issues in the textile industry like high defect rates and inefficiency by investigating improvements in quality and productivity at ERCO Textile and Garment PLC using a modified DMAIC approach known as DMAVIIC. It points out important gaps in the literature, namely the lack of problem confirmation and the inability to integrate lean systems across departments.

The study focuses on the knitting department and employs both qualitative and quantitative methodologies. According to preliminary assessments, there was a 17.96% defect rate, a sigma level of 1.36, and a cost of poor quality (COPQ) of 2,338,789.38 birr over three months. Both value-added and non-value-added operations were identified using value stream mapping, with cycle times of 1,320 and 918 minutes, respectively.

After the suggested fixes were put into practice, the sigma level increased to 2.68, the COPQ dropped to 1,386,000.06 birr, and the defect rate dropped to 9.72%. Additionally, cycle periods for value-added operations were shortened to 861 minutes and for non-value-added activities to 250 minutes. Metrics of productivity increased, with worker productivity rising to 72.22% and machine efficiency reaching 76.3%.

Time to market was shortened and customer satisfaction rose as a result of these enhancements. According to the study's findings, the DMAIC approach greatly increases the efficacy and efficiency of improvement projects by incorporating functional department collaboration and root cause verification.



**Key words:** Lean Six Sigma (LSS), DMAIC (Define, Measure, Analyze, Improve, Control), value stream mapping, root cause analysis, defect categories and cost of poor quality.

# Table of Contents

List of Table



List of Figure

## List of abbreviation

DMAIC- Define, Measure, Analysis, improve, Control

LSS- lean six sigma

SS-six sigma

VSM-Value stream mapping

RC-root cause

COPQ- cost of poor quality

SOP- standard operating procedure

LM- lean manufacturing

SLR- systematic literature review

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Almighty God, whose boundless love, protection, blessings, and kindness have continuously inspired me during my path, has my sincere gratitude.

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# CHAPTER ONE

# 1. INTRODUCTION

## 1.1. BACKGROUND

Efficient manufacturing and logistics procedures are necessary due to globalization, increased market competitiveness, complex product offers, and shifting consumer preferences. Therefore, in order to remain competitive, firms need to concentrate on cutting expenses and increasing efficiency. greater Key Performance Indicators (KPIs), such as shorter lead times, more productivity, greater resource utilization, and lower operating costs, result from implementing efficiency enhancement initiatives (Kovács, 2018). Enhancing process performance and product quality is becoming increasingly important for many firms in order to achieve their financial goals, which include competitiveness, market share, sustainability, and profitability. A combination of high productivity and superior quality is essential for every firm to survive in this era of globalization and heightened market competitiveness (Daniyan, 2022)

Businesses are under a lot of pressure these days to increase customer happiness and product quality while cutting down on errors and inefficiencies. Companies must actively seek improvement initiatives in order to draw in and keep customers, who are vital to the economy. To maintain high standards and promote ongoing development inside the company, a variety of ideas, techniques, and resources are accessible (Smętkowska, M., & Mrugalska, B., 2018).

Organizations must implement efficient tactics to deliver sustainably high-quality goods and services and keep a competitive edge in the highly competitive industrial sector. Organizations are improving the quality of their processes as client needs change. Among the different techniques and methodologies for quality improvement, Lean Manufacturing (LM) and Six Sigma (SS) are particularly noteworthy. Lean Manufacturing and Six Sigma have both proven to be successful in resolving process-related problems and encouraging ongoing development inside businesses (Achibat, 2023). Lean, Six Sigma, and Lean Six Sigma are well-liked methods for manufacturing companies to continuously improve their output and quality. This development is made possible by combining the Six Sigma technique of reducing process variance with the Lean strategy of eliminating non-added value. Lean Six Sigma offers a set of metrics for cost, responsiveness, process efficiency, and quality (Abbes, N., Sejri, N., Xu, J., & Cheikhrouhou, M., 2022).

By reducing lead times and increasing efficiency and product quality, the manufacturing sector has experienced significant growth. Numerous tactics focused on technology, worker development, process optimization, product innovation, material efficiency, and effective management have been used to achieve this. Improvements are achieved by using process management techniques that increase quality, product diversity, and manufacturing operations' flexibility while decreasing human labor, space, engineering hours, lead times, and inventory (Shukla, A., & Tyagi, D., 2017). Lean Six Sigma is a combination of Six Sigma and Lean Manufacturing's methods for process improvement and waste reduction. These two quality management techniques are combined in the Lean Six Sigma (LSS) concept to increase the scope and effect of improvements that may be made using either technique alone. When integrated, Six Sigma and Lean Manufacturing minimize each other's shortcomings while maximizing their strengths. Lean Manufacturing and Six Sigma tools and techniques are both used in LSS. (Ajmera, 2017)

The five steps of the Lean Six Sigma process improvement technique are Define, Measure, Analyze, Improve, and Control. It was created in the 1980s by engineer Bill Smith and is founded on the ideas of Shewhart, Deming, Juran, and Taguchi. Lean Six Sigma is acknowledged as a successful organizational improvement approach, particularly when the underlying causes of issues are not immediately apparent. It provides an extensive toolkit aimed at improving product quality through waste reduction and process variability reduction. Through the creation and monitoring of waste reduction and customer satisfaction initiatives, Six Sigma is a business process that enables organizations to achieve significant performance improvements. It assists businesses in successfully removing quality failures and avoiding errors in their procedures. This methodology offers solutions for process modification and improvement in addition to addressing faults. Furthermore, Six Sigma serves as a framework for carrying out projects aimed at improving processes, with a focus on defect elimination and the creation of corrective actions using the DMAIC technique (Ludeña Ramos, 2023). Through waste removal, the Lean Manufacturing concept prioritizes customer satisfaction and product quality in order to achieve continual improvement. Since the use of Lean technologies can increase productivity, reduce costs, and standardize procedures in the short term, this strategy pushes businesses to create better goods.

The 5S approach is a crucial Lean tool for increasing productivity and guaranteeing on-time order fulfillment. The literature states that its main objective is to promote cleanliness and organization at workstations in order to eradicate waste in processes. Another strategy used to reduce downtime and improve production line efficiency is standardizing tasks. Preventing operators from carrying out their duties in an uncontrolled way is the primary goal (Candelario-Cordova, 2023). By determining the underlying reasons for low productivity and making the necessary adjustments, the application of Lean Manufacturing techniques like "5S" and "Just in Time" will assist shorten lead times, improve efficacy and efficiency, and minimize process variability. The company's main problem is low productivity, which is mostly caused by manual activities that lead to faulty products and lengthy wait periods between processes. In contrast to the engineering specification of 28,239 minutes per garment, the current manufacturing time per garment is roughly 33,982 minutes, which is excessive. For every unit generated, this leads to a 5,743-minute time difference. Considering that the business normally produces 2,736 units on average, this timing disparity becomes rather noteworthy (Rodriguez Concha, I. A., & Rosadio Vela, J. R. , 2022).

From fiber preparation to yarn manufacture (in spinning mills), fabric manufacturing (in weaving and knitting), and garment fabrication, the textile business involves multiple processes. Defects or waste in the production process frequently arise during these phases, requiring ongoing investigation and improvement to reach productivity goals. These objectives can be addressed by utilizing the Lean Six Sigma approach, which is extensively used in the manufacturing and service sectors. One important economic sector that has a big influence on day-to-day living is the textile industry. By controlling the quality of raw materials and keeping an eye on the production process, Six Sigma can be used to increase product quality by lowering the number of defective items and raising overall quality (Cost of Quality) (Kurnia, H., Tumanggor, O. S. P., & Jaqin, C., 2021).

Six Sigma is a methodology aimed at lowering process variability, whereas lean manufacturing is a set of methods and instruments intended to remove waste from processes (Olanrewaju F., 2019). In the textile sector, LSS seeks to eradicate non-value-added operations, decrease process and customer service variability, and eliminate defects (Dascălu, N.-M., & Pîslaru, M. , 2023)

According to recent data from the Textile Global Market Report 2023, the global textile market reached 573.22 billion in 2022 and is expected to grow to 573.22 billion in 2022 and 610.91

billion in 2023, representing a compound annual growth rate (CAGR) of 6.6%. Growth projections indicate that it may reach $755.38 billion by 2027. Rapid technical development and industrialization in both developed and emerging nations is a benefit of the industry since it improves product quality and makes it easier to build high-efficiency plants. Nonetheless, there are a lot of obstacles facing the textile sector now and in the future. Global markets are impacted by the ongoing conflict between Russia and Ukraine, which also affects supply lines and raises the cost of raw materials. The textile industry's complex and ever-changing landscape is further influenced by developments in materials, equipment, and procedures targeted at resource optimization, environmental sustainability, innovation, and heightened stakeholder engagement. The goal of the Lean Six Sigma technique is to increase productivity and profitability by optimizing processes. In order to reduce losses, lessen process variability that results in quality problems, and generate value for stakeholders, it integrates Lean Manufacturing (LM) with Six Sigma methodologies. This approach focuses on getting rid of waste—non-value-added activities including overproduction, long wait times, and product damage. Six Sigma primarily focuses on cost reduction and improvement with the goal of streamlining a business's production processes (Jiménez-Delgado, G., 2023). Weaving and knitting are the two main divisions of the fabric manufacturing sector. Textile knitting businesses manufacture knit fabrics by developing a special loop structure that enables shape modifications under stress, loop size alterations, and the use of fewer yarns. However, knitting errors on the manufacturing floor frequently reduce the efficiency of producing knitted fabrics. One of the main issues in knitting operations is lowering these errors and increasing production efficiency.

The Six Sigma methodology can be used as a sustainable solution to these problems in the production of knitted fabrics. Six Sigma's structured project approach, which incorporates a variety of readily applicable problem-solving techniques, makes it a popular tool for driving general organizational improvement initiatives. By applying the Define, Measure, Analyze, Improve, and Control (DMAIC) framework in a methodical, data-driven way, it seeks to eradicate faulty goods and other types of waste from operational processes (Ahmed, 2022).

Several service areas, including banking and finance, education, government, and healthcare, have seen considerable performance increases as a result of the DMAIC approach. Its use in the healthcare industry in particular has led to lower turnaround times for sending medical reports, shorter clinic appointment times, and fewer insurance claim denial (Does R, van den Heuvel E, de Mast J, Bisgaard S, 2002)

The degree to which design faults do not impair the functionality of goods and services is known as quality. Productivity, which is the ratio of outputs to inputs used in the process, is a mean indicator of production efficiency. Total productivity is the sum of all outputs and inputs, determined by their respective economic values. As a gauge of overall production efficiency, the income earned is indicated by the difference between the values of inputs and outputs. Partial productivities, on the other hand, are metrics that concentrate on just a few inputs. While worker hours, materials, or energy spent are examples of company-level partial productivity measurements, labor productivity is a common example and is frequently measured as output per hour, materials, or energy consumed per unit of production. Six Sigma is based on six fundamental ideas that underpin its use in the manufacturing and service sectors. Measurement System Analysis (MSA), Input-Process-Output (IPO) diagrams, Cause-and-Effect diagrams, histograms, Pareto diagrams, and the DMAIC framework (Define, Measure, Analyze, Improve & Control) are some of the crucial tools it uses to enhance the quality of processes and products. Furthermore, it utilizes Design of Experiments (DOE), Failure Mode and Effect Analysis (FMEA), Standard Operating Procedures (SOP), run charts, control charts, scatter diagrams, regression analysis, and Quality Function Deployment (QFD) (Mathew, A., 2017). The goal of the Lean Six Sigma management philosophy is to reduce process variance in order to increase process capability. This approach aims to enhance procedures by decreasing errors (quality improvement), boosting output, cutting cycle times, cutting expenses, and successfully satisfying client demands (Raman, K. K., Sankaran, V., & Jain, N., 2020).

Maintaining excellence in higher education poses serious problems for the long-term viability of professional schools in particular. Stakeholders are concerned about the low employment rate of engineering program graduates, which is only 25%. Engineering graduates must learn the skills required for research in higher education in addition to landing jobs in industry. Customers, which include both industries and research organizations, have very different needs. While research institutes prioritize a solid theoretical foundation, industries prioritize practical abilities for applications and applied research. Because of this discrepancy, educational institutions face difficulties in juggling the conflicting expectations of stakeholders. Educational institutions, especially Engineering Educational Enterprises (EEE), are using effective industrial models to overcome these quality issues. This work centers on the Six Sigma methodology, reviewing relevant literature to propose a comprehensive framework for its implementation at the institutional level. (Ramanan, L., Kumar, M., & Ramanakumar, K. P. V, 2014)

## 1.2. Problem of Statement

Since quality is important in all facets of life, the textile business must reduce lead times, waste, and faults. Ethiopian textile producers are facing fierce rivalry with one another. These producers must reduce product flaws at this crucial juncture in order to become more competitive. Significant waste and high defect rates are currently problems in the textile business. Improving quality, cutting waste, and raising production are required to reach low defect percentages (Rajat Ajmera, Prabhuling Umarani and K.G.Valase, 2017)

Organizations should focus on improving both productivity and quality in order to increase profitability. Improving quality frequently results in higher output, but increasing productivity without improving quality may not produce useful benefits. Deming (1986) emphasized how important it is to raise quality in order to increase productivity. Management must figure out how to increase quality and productivity at the same time if they want their business to prosper. Strictly concentrating on productivity may result in lower output and compromised quality. Organizations can boost acceptable units, overall quality, and eventually productivity by putting process quality first. This will reduce the amount of defective units. There are several benefits to increasing productivity through quality, including as better-quality products, less rework, increased efficiency, lower unit costs, price flexibility, improved customer satisfaction, larger profitability, and the creation of jobs. Customers gain from premium goods at reduced costs in this scenario, suppliers get steady, long-term business, and investors make money, so everyone wins (M. Shanmugaraja and M. Nataraj , 2011). If a product satisfies the company's standards and fits in with customer preferences, it is deemed high quality. The customer's voice is used to include these priorities into the Quality Function Deployment (QFD), and technical criteria are added to establish a quality house (Hibarkah KURNIA, Choesnul JAQIN, Humiras Hardi PURBA, Indra SETIAWAN, 2021).

Due to low productivity and poor quality, the Ethiopian textile industry is not very competitive, and the Lean Six Sigma (LSS) methodology has not yet been used to evaluate and enhance the industry. In order to improve quality and productivity, this study suggests combining Lean and Six Sigma in a synergistic way. Rework and defects can have a detrimental impact on production by leading to inefficiencies, delays, and higher expenses, which in turn can erode customer satisfaction and trust. Businesses must therefore take action to lower errors and increase output. Finding trends and remedies might be aided by examining the reasons behind subpar quality.

Numerous flaws, such as holes, sinker lines, oil stains, broken needles, and tension fluctuations, affect the quality and output of knitted materials at ERCO Textile and Garment. About 15% of the cloth manufactured has defects on average, meaning that 85% of it is of high quality. Additionally, knitting productivity, which averages about 70%, is impacted by personnel, material usage, and machine efficiency, which results in a 30% productivity loss.

Table 1: inspected fabric Report and Defects 6-month data of Single jersey fabric in knitting piuleng Machine (Source: Quality report of case company)

| s/no | Month | Inspected fabric length (m) | Total defect (m) | %age of defect |
|---|---|---|---|---|
| 1. | June | 62452.8 | 9547 | 15.29 |
| 2. | July | 57843.5 | 8453 | 14.61 |
| 3. | August | 53845.6 | 8257 | 15.33 |
| 4. | September | 55794.3 | 8294 | 14.87 |
| 5. | October | 60457.9 | 8798 | 14.55 |
| 6. | November | 61877.7 | 9241 | 14.93 |
| | Average | | | 14.93 |

Table 2: Types of Defects in single jersey Knitting Machine piuleng

| s/no | Defect type |
|---|---|
| 1. | Hole |
| 2. | Needle line |
| 3. | Sinker line |
| 4. | Oil stain |
| 5. | Needle broken |
| 6. | Unevenness |
| 7. | Loos yarn(tension variation) |
| 8. | Broken yarn |
| 9. | Skewing of fabric diagonally |

Table 3: productivity report of 6-month of case company

| s/no | Month | Productivity factor | | | |
|---|---|---|---|---|---|
| | | Machine efficiency | Material utilization | Labor | Quality Productivity |
| | June | 74 | 82 | 58 | 67.5 |
| | July | 76 | 81 | 60 | 63.5 |
| | August | 75 | 83 | 62 | 63 |
| | September | 73 | 79 | 63 | 64.5 |
| | October | 74 | 77 | 59 | 66 |
| | November | 77 | 78 | 58 | 65.5 |

Table 4: productivity factor for knitting department

| s/no | Productivity factor | Productivity |
|---|---|---|
| 1. | Machine efficiency | 75% |
| 2. | Material utilization | 80% |
| 3. | Labor | 60% |
| 4. | Quality Productivity | 65%Agrade fabric |

## 1.3. Research Questions

1. What are the cause of low quality and productivity?
2. Which lean tools are needed for the successful implementation of Lean Six Sigma for quality and productivity improvement?
3. What are the effects of the implementation Lean Six Sigma DMAIC approach in quality and productivity improvement?

## 1.4. Research Objective

### 1.4.1. General objective

The primary objective of this research is to improve product quality and production efficiency (productivity). This will be accomplished through sustainable improvements in areas such as inefficient processes, quality variability, gaps in data utilization, and resistance to change. The study aims to provide enduring enhancements in both quality and productivity, ensuring the organization remains competitive in its industry.

#### 1.4.2. Specific objective

1. To identify, categorize, and tackling quality and productivity bottleneck's
2. To analyze Process Inefficiencies of existing operational processes
3. To apply the lean manufacturing for quality and productivity improvement
4. To assess the effectiveness of Lean Six Sigma (LSS) in enhancing quality and productivity.

### 1.5. Scope of research

The goal of this study is to apply Lean Six Sigma and the DMAIC technique to ERCO Textile and Garment PLC in order to increase the production and quality of knitted fabric in the knitting department. Using the LSS technique, the study will examine the current reasons for low productivity and poor quality and offer remedies for the underlying issues found. ERCO Textile and Garment PLC has been chosen as the case study for improving quality and productivity in the knitting department because management is looking for help in overcoming the company's quality concerns.

### 1.6.Limitations

It might be difficult to extrapolate results from a single case study—in this case, a knitted textile company—to other situations or sectors. The conclusions reached may become less relevant as a result of this limited applicability. Due largely to the distinct operational and cultural traits of Ethiopian businesses, there is a dearth of previous study on the production of knitted fabrics in Ethiopia. The lack of pertinent literature limits how well current research reflects the realities of the nation's knitted fabric industry. Direct comparisons are difficult because Ethiopia differs greatly from other nations in terms of infrastructure, knowledge levels, leadership styles, cultural influences, and economic conditions.

### 1.7.Research Significance

By streamlining operations, cutting waste, and optimizing resource utilization, this study has the potential to significantly increase quality and productivity at Etur Textile PLC, ultimately contributing to the company's success and providing insightful information for the larger textile industry.

Making Informed Decisions: It will give management the resources they need to decide on process enhancements based on data.

Skill Development: By assisting with staff training and skill improvement, the study will promote an ongoing learning culture inside the company.

Model for Other Organizations: Other Ethiopian textile producers may find the structure and conclusions of this study to be a useful resource.

Contribution to Academic Literature: It will provide empirical evidence and insights that could be valuable for future research and academic discussions.

Stakeholder Engagement: This study can promote a deeper understanding of the challenges and opportunities within the organization.

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# CHAPTER TWO

# 2. LITERATURE REVIEW

## 2.1. Introduction

In order to gain a deeper grasp of the research subject, this literature review examines a variety of papers, reviews, journals, case studies, and reports. The assessments mostly focus on Six Sigma, lean concepts, and the importance of combining these approaches. Additionally, it looks into how they are used in the knitting subsector of the textile industry. As a result, this review highlights the significance of this specific topic by pointing out gaps in the existing literature and indicating areas that need more research.

## 2.2. SS and Lean Tools

Lean is a methodical approach that focuses on providing value to the customer while striving for excellence. Its goal is to find and eliminate waste through continuous improvement. Since lean principles are essentially focused on customer value, they can be applied to a variety of production and distribution scenarios. Two management approaches that are widely used in many different industries are Lean Manufacturing and Six Sigma (LSS). A business performance improvement approach called Lean Six Sigma (LSS) combines the ideas of Six Sigma and lean manufacturing. Lean manufacturing, or simply "lean," is a systematic strategy to finding waste and improving procedures through continuous enhancements(Andersson, R.,, 2006).

The five core principles of lean manufacturing are:

1. Understanding Customer Value: Focus on what customers perceive as valuable.
2. Value Stream Analysis: Analyze business processes to identify and retain actions that add value, modifying or eliminating those that don't.
3. Flow: Organize a continuous flow in production or the supply chain instead of large batch movements.
4. Pull: Implement demand chain management, producing only as needed based on customer demand.
5. Perfection: Continuously improve by eliminating waste and striving to reduce time, cost, space, mistakes, and effort.

The goal of the Six Sigma technique is to improve quality by removing flaws and their underlying causes from business processes. Customers' important outputs are the main focus, and their requests are translated into quantifiable requirements called CTQs (Critical to Quality) (Vivekananthamoorthy, N., & Sankar, S., 2011). Lean Six Sigma is a very successful method for finding opportunities and is essential to an organization's ongoing development. By combining Lean and Six Sigma approaches, it helps lower process variation, errors, and waste. By removing waste and reducing variations and flaws, LSS systematically improves organizational performance with the goal of process perfection and quicker gains in cost, quality, productivity, and customer happiness. Lean management and Six Sigma statistical techniques are combined to accelerate the generation of value in organizational processes (Al-Amiri, & Majed A., 2023). Lean Six Sigma is a very effective approach to opportunity identification and is critical to the continuous improvement of a business. Lean and Six Sigma methodologies are combined to reduce waste, mistakes, and process variation. With the aim of process excellence and faster increases in cost, quality, productivity, and customer satisfaction, LSS methodically enhances organizational performance by eliminating waste and minimizing variations and defects. Combining of Six Sigma, statistical methods with lean management speeds up the creation of value in organizational operations. (Pepper & Spedding, 2010). Continuous improvement, process observation, and quality control tools can help reduce energy consumption, waste, and product rejections (Farooq et al, 2017)

By combining Lean and Six Sigma approaches, Lean Six Sigma (LSS) helps manufacturing businesses surpass customer expectations by achieving zero defects, optimal performance, improved product quality, and timely delivery at the lowest cost (Gijo et al., , 2018).

Lean manufacturing works well at mapping processes efficiently and separating activities that provide value from those that don't. Six Sigma, on the other hand, is a methodical, statistical technique that raises customer happiness, encourages innovation, and improves product quality. (Hekmatpanah, 2008). While many businesses have adopted the LSS system for continuous improvement, its success often hinges on effective leadership (McLean, 2017). When done correctly, research has demonstrated that combining Lean and Six Sigma produces useful results.

There are other ways to describe Six Sigma, but many people agree that it includes at least three viewpoints: a technique, a mentality, and a metric (Adams et al., 2003; Brue, 2002; Eckes, 2001;

Pande & Holpp, 2002). Statistically, Six Sigma denotes 3.4 defects per million opportunities, representing 99.99966% accuracy, which is close to perfection (Paul, 1999; Khan, 2005)

## 2.3. LSS in manufacturing sector

Although, Lean Six Sigma was first, used in the manufacturing sector, new data shows that it is also becoming more popular in other industries. One essential element of Lean Six Sigma is the DMAIC technique to problem-solving, which is used in manufacturing industries: DMAIC (Kansal & Singhal, 2017).

1. Define: This phase establishes the foundation for all subsequent steps by clearly identifying the problem, along with existing parameters related to poor quality and low productivity.
2. Measure: In this phase, the focus is on highlighting the most significant impacts on customers and identifying the poor quality and low productivity they cause. It's essential to concentrate on quality-critical variables that have the greatest effect on outcomes.
3. Analyze: This phase aims to determine the root causes of poor quality and low productivity by understanding their sources.
4. Improve: The objective here is to devise, develop, and implement strategies to address poor quality and low productivity.
5. Control: This phase ensures that all critical variables in the improved process remain within acceptable limits. Standard operating procedures are established to maintain performance levels over time.

## 2.4. Why LSS

Although manufacturing companies have been the primary adopters of Six Sigma programs, non-manufacturing industries such as banking, healthcare, education, and hospitality have also made extensive use of them. Furthermore, certain company processes, such financial systems, can benefit from Six Sigma. As it becomes more and more linked with other corporate improvement projects, its usefulness grows. Numerous attempts to integrate Six Sigma with other management techniques, such as TQM, ISO9000, and Lean, are documented in the literature. Interestingly, Lean and Six Sigma are increasingly being combined, with Lean Six Sigma emerging as a key methodology for business improvement in a variety of industries (Ngo, 2010).

Lean and Six Sigma are two potent methodologies that are used in the Lean Six Sigma technique to improve operations and raise quality standards in businesses. Lean leverages concepts like value stream mapping and just-in-time production to identify and eliminate waste in order to enhance efficiency and streamline processes. Better resource use, shorter lead times, and quicker cycle times result from this. Six Sigma, on the other hand, uses the DMAIC (Define, Measure, Analyze, Improve & Control) framework to improve quality and satisfy customer expectations by reducing variations and faults. Six Sigma helps businesses increase process capabilities and reduce errors by using statistical methods. The integration of Lean and Six Sigma offers a comprehensive toolkit for process improvement, with Lean addressing waste and flow, while Six Sigma emphasizes data analysis and variation reduction, creating a powerful synergy for enhancing quality, efficiency, and overall performance (Bulla, N., & Fogla, A., 2023).

Six Sigma lowers variances, which results in fewer errors, more motivated workers, and higher-quality goods and services. In order to overcome their respective deficiencies and create a more comprehensive plan for process optimization and continuous improvement, several companies have decided to integrate Lean and Six Sigma. Compared to applying the strategies alone, this integration improves organizational effectiveness and efficiency, hastening the attainment of superior performance (Krishnan, Mathiyazhagan, & Sreedharan, 2020, 2020).

The use of Lean and Six Sigma approaches has enhanced efficiency, operational effectiveness, and financial performance within the organization (Cima, 2011). Therefore, the goal of this research is to improve quality and productivity and reduce process variability meet customer expectations and increase resource utilization

## 2.5. Summary reviewed literatures

The reviewed literature consists of articles, case studies, books, and reviews from various sources, totaling 62 pieces. Of these, 45 focus on Lean, Six Sigma, and Lean Six Sigma, while 5 relate to other topics. However, only 10 articles are directly relevant to this study on quality and productivity improvement in textile industries. Among those, just 2 specifically address the improvement of quality and productivity in knitted fabrics within knitting textile industries. The analyses and discussions in these 10 works vary in their objectives, methods, and structures

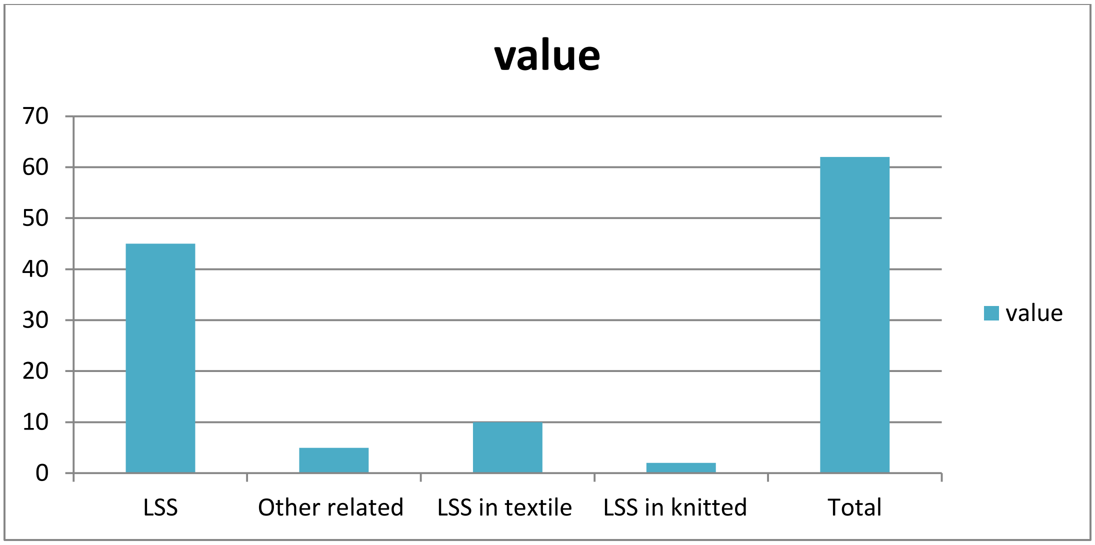


Figure 1: Literature fields

Table 5: Literature summary based on their objectives

| | Author | | | | | | |
|---|---|---|---|---|---|---|---|
| | Hibarkah KURNIA, Choesnul JAQIN, Humiras Hardi PURBA Implementation of the six sigma approach for increasing the quality of formal men's jackets in the garment industry (2022) | KURNIA, Choesnul JAQIN, Humiras Hardi PURBA, Indra SETIAWAN. (2021). Implementation of Six Sigma in the DMAIC Approach for Quality Improvement in the Knitting Socks Industry. Journal of Textiles and Engineer | Roy, H. N., Saha, S., Bhowmick, T. P., & Goldar, S. C. (2013). Productivity improvement of a fan manufacturing company by using DMAIC approach: A Six-Sigma practice. Global Journal of Researches in Engineering, 13(4), 1-6. | Mittal, A., Gupta, P., Kumar, V., Al Owad, A., Mahlawat, S., & Singh, S. (2023). The performance improvement analysis using Six Sigma DMAIC methodology: A case study on Indian manufacturing company. Heliyon, 9, e14625. | Ahmed, T., Toki, G. F. I., Mia, R., Li, J., Islam, S. R., & Rishad, M. M. A. (2022). Implementation of the Six Sigma methodology for reducing fabric defects on the knitting production floor: A sustainable approach for knitting industry. Textile & Leather Review, 5, 223-239 | Jirasukprasert, P., Garza-Reyes, J. A., Kumar, V., & Lim, M. K. (2014). A Six Sigma and DMAIC application for the reduction of defects in a rubber gloves manufacturing process. International Journal of Lean Six Sigma, 5(1), 2-21 | Gupta, N. (2013). An application of DMAIC methodology for increasing the yarn quality in textile industry. IOSR Journal of Mechanical and Civil Engineering, 6(1), 50-65 |

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| Objective | increasing the quality of formal men’s jackets in the garment industry | Quality Improvement in the Knitted Socks | To introduce and implement Six Sigma philosophy in the manufacturing sector of Bangladesh to improve productivity and quality. | implements the Six Sigma DMAIC methodology to reduce the rejection rate of rubber weather strips manufactured by XYZ Ltd. | Aims to reduce fabric defects in the knitting industry, which adversely affect production efficiency. | Reduce product defects in the rubber glove manufacturing process using the Six Sigma methodology, specifically the DMAIC (Define, Measure, Analyze, Improve, and Control) framework. | To reduce defects in the yarn manufacturing process, thereby improving the overall quality of the yarn produced. |

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| Methodology | Define | Identify defect type (CTQ) and dominant defect type and total defect are determined | COPQ(Rp 4,175,000)<br>By identifying cost parameter (Inspection, Defect/scrap, Rework, Return & Training<br>Pareto diagram for determine main defect (hole and loose yarn<br>CTQ to identify type of defect(defect type and total defect are determined | Identified layout and operational inefficiencies.<br>Poor Layout Design.<br>Bottleneck Processes.<br>High Defect Rates.<br>Underutilization of Resources. | Data was collected through discussions with industry officials and secondary sources.<br><br>Problem (rejection rate) and set a target to reduce it to 2% from 5.5%. Major defects included joint cracks and under-fill. | High percentage of B-grade and C-grade knitted fabric due to defects. A team was assembled to work on this issue.<br><br>Production process map also defined | High percentage of defective gloves, particularly leaking and dirty gloves.<br>To reduce the defects by 50 per cent after applying Six Sigma into the gloves manufacturing process<br>Voice of the customer (VOC): Product's quality | Define problem of high defect rates in yarn production, specifically in the winding department. Key metrics, such as the rate of defects and customer requirements, are established.<br><br>SIPOC analysis |

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|---|---|---|---|---|---|---|---|---|
| | Measure | Using four month production report data and defects The sigma level (3.5749) Defect percentage for four month (18.37%) | sigma level(3.7017) the research method takes production report data and defects of 6 month and defect percentage 11.08 | Collected data on production rates, defects, and opportunities for errors.<br>Sigma level 3.7<br>Production 240 pieces per day<br>Line Efficiency : Enhanced 64.31% | Key defects were quantified, revealing joint cracks (25.10%) and under-fills (21.08%) as major contributors to rejections. defectives generated in the two consecutive months. | Data was collected over a week, categorizing fabrics into A-grade, B-grade, and rejected (C-grade). Key metrics included:<br><br>Total fabrics inspected: 22,910 meters<br>Total defects: 8,206 meters<br>Defects per unit (DPU) calculated as approximately 0.358. | Data was collected on defect rates, with a focus on key process variables such as oven temperature and conveyor speed. Initial sigma levels were calculated, revealing a performance level of 2.4 sigma.<br>Uses Pareto chart to identify major defect and defect percentage of each defect is calculated | Data on defects was collected over a specified period, focusing on different types of defects, including stitch defects and their causes. Statistical measures like DPMO (Defects Per Million Opportunities) and sigma levels were calculated to assess the current quality state. |

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| | Analysis | Analysis the data using **p.** control chart to check out of control limit and cause of the problem using fish bone diagram know cause and effect | Fishbone diagram for main defect identification(hole) FMEA to determine risk priority number (RPN) to determine main causative factor for hole problem(defect) | Used cause and effect diagrams analysis tools to pinpoint root causes of defects and inefficiencies. The bottleneck processes have identified named Pressing 1, Pressing 2, Binding, and Grinding. | five major defects as joint crack, under-fill, overflow, pressmark, and dent mark mainly responsible for the high rejection rate of weather strips<br><br>Root causes of defects identified. Significant causes included inadequate work instructions, lack of training, and mold cleaning issues. | Total length of the inspected fabric was 22910 meters and the total length of major and minor faults was 4149 and 4057 meters, respectively. 51% of the defects were related to yarn quality, 30% to machine setting and the rest of the defects came from machine maintenance and material handling using Pareto chart<br>A cause-and-effect analysis was conducted to identify factors affecting fabric performance. The analysis revealed that yarn quality was a significant contributor to defects. | Root causes of defects were identified using cause-and-effect diagrams (5M) and Pareto analysis, revealing that over 60% of defects were due to leaking gloves. | The root causes of defects were identified through tools like cause-and-effect diagrams and Pareto analysis. This phase revealed that the majority of defects were related to yarn quality and machine settings. |

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| | Improve | 5W+1H corrective actions. | Design of Experiment (DoE) | Implemented a balanced layout and reallocated resources to optimize workflow. Considering working distance, type of machines and efficiency, workers who have extra time to work after completing their works, have been shared their work to complete the bottleneck processes. | Revised work instructions, training programs for operators, and installation of flow control valves in molding machines to enhance process consistency | Enhancements in yarn quality control. Improved machine settings and maintenance practices. Training for workers to ensure proper handling and awareness of quality standards. | Experiments were conducted using Design of Experiments (DOE) to optimize process parameters, leading to the identification of optimal oven temperature and conveyor speed. | Solutions were proposed based on the analysis. Key parameters, including machine speed and settings, were optimized to reduce defects. Design of Experiments (DOE) was used to test the effectiveness of changes. |

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|---|---|---|---|---|---|---|---|---|
| | Control | Control P-Chart to check with the previous. | SOPs, One Point Lesson (OPL), Work Instructions (WI), and other documents.<br>For handling of corrective action hole problem | Standard Operating Procedures (SOPs)<br>For Performance Monitoring | Regular training and updated documentation to prevent regression to old practices. | Execute Failure Modes and Effects Analysis (FMEA) to monitor potential defects and ensure ongoing improvements. | control charts, were established to sustain improvements<br>Line chart and boxplot chart representations | Statistical process control using X-bar and R-chart<br>Design the speed limits<br>Inspection procedure using check sheet<br>SOP. |
| Utilized analysis tool | Pareto chart for main defect<br>Fishbone diagram for cause of main defect<br>p- control chart to check the boundary | | Pareto chart for main defect<br>Fishbone diagram for cause of main defect<br>FMEA for risk priority number | cause and effect diagrams analysis tools to pinpoint root causes of defects and inefficiencies | Pareto chart for main defect<br>Cause and effect diagram for root cause | FMEA for monitoring<br>Pareto chart for identifying defect cause<br>Cause and effect diagram to identify root cause | Cause and effect diagram for root cause identification and Pareto chart for major defect identification | Cause and effect diagram for root cause identification and Pareto chart for major defect identification |

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| Result or improvement | Sigma level from 3.57 to 3.78<br>Defect percentage from 18.37% to 10.27%, | COPQ<br>Rp 3,335,000<br>The improvement effects increase the sigma level by 7% from 3.7017 to 3.9614. At the same time, improvement defects can reduce defects before improvement is 11.08% and after improvement is 5.54%. | Production Increase: From 240 to 312 units per day. Line Efficiency: Enhanced from 64.31% to 83.60%.<br>Sigma Level: Improved to 4.3 from 3.7 | Rejection rate reduced from 5.5% to 3.08%, achieving a significant cost saving of Rs. 15,249 per month. Sigma level improved from 3.9 to 4.45, indicating enhanced process capability. rejection was reduced from 153 pieces to 68 pieces | Increase in the sigma level from 3.5 to 4.0. Profit per annum was increased to 2378 US dollars.<br><br>Significant reduction in rejected fabrics was noted, with improved production efficiency. | Reduction in defects by 50%. The sigma level improved from 2.4 to 2.9. Defects per million opportunities (DPMO) decreased from 195,095 to 83,750.<br>Defect percentage decreased from19.51 to 8.38, 7.32 to3.88and 3.42 to 2.44 leak, miscellaneous Total improve from 30.25 to 14.7 | The implementation of the DMAIC methodology led to significant improvements in yarn quality: The sigma level increased from 3.81 to 4.5.<br>The percentage of defects was substantially reduced, demonstrating the effectiveness of the Six Sigma approach in enhancing manufacturing processes. |

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| Gaps | Not verified root cause.<br>-Not use lean tool for improvement of efficiency and affectivity production process<br>- not include quality improvement methodologies<br>Not integrating lean method. | -Not verified the root cause.<br>-Not include quality improvement methodologies<br>-Not integrating lean method for improvement of efficiency and effectively production process<br>-Not Proposing a framework for continuous improvement | Uncertainties in the verified and reliability of the sampled data.<br>These were based on the assumption .As the main purpose of this research is to increase productivity, it has been tried to achieve this by improving the level of sigma | Focus on Quantitative Data<br>Not integrating lean method.<br>Not verified the root cause.<br>Not integrating lean method for improvement of efficiency and effectively production process | Focus on only defect, not exploration of other factors impacting overall productivity.<br>Does not explore type of defect.<br>Shallow in problem definition in defining phase<br>-Not verified the root cause.<br>-Not include quality improvement methodologies<br>-Not integrating lean method for improvement of efficiency and effectively production process<br>-Not Proposing a framework for continuous improvement | Focus on Specific Defects.<br>Does not fully address how these improvements affect overall operational efficiency, including production cycle times beyond defect reduction. Not verified the root cause. | Focus on single defect<br>And does not address productivity.<br>Not verified the root cause.<br>Not integrating lean method for improvement of efficiency and effectively production process |

## 2.6. Gaps of literature

The literature reviewed indicates that numerous studies have focused on the implementation of Six Sigma in the manufacturing sector, primarily aimed at reducing waste, particularly defects. However, most of these studies do not address productivity and efficiency within the production process. While some articles provide quantitative data on defects, they often fail to incorporate other quality improvement methodologies that could enhance their findings. This highlights the detrimental effects of excessive waste on manufacturing standards. Among the 10 pieces of literature directly related to textile industries, only two pertain specifically to the knitting industry, reflecting a lack of research in this area. A systematic evaluation of the literature reveals that several articles have inadequate reviews, unclear problem definitions, unverified root causes, and limited integration with functional departments, alongside superficial analyses. Furthermore, the potential integration of Six Sigma with other methodologies, such as Lean Manufacturing, is not explored, which could provide valuable insights. In response to these gaps, the researchers propose a framework aimed at addressing the identified issues at ERCO Textile and Garment PLC.

# CHAPTER THREE

# 3. RESEARCH METHODOLOGY

## 3.1. Methodology

The author used the Systematic Literature Review (SLR) method in this study. SLRs are essential to the advancement of knowledge in many different sectors. A Systematic Literature Review is an independent research project rather than a summary of the body of existing literature. Usually, this approach is used to advance knowledge, present up-to-date data, compile pertinent research, address certain research problems, and evaluate theories and hypotheses. (Alie, S., & Sarjono, H., 2022).

Before beginning the problem-solving process, it is imperative to establish the research approach. It guarantees that the procedure is carried out in a controlled and targeted manner, making it easier to analyze current problems (Kholil, M., Haekal, J., Suparno, A., Rizki, M., & Widodo, T., 2021). An initial study of the knitted floor section, backed up by pictures, is part of the research technique. In order to greatly improve quality and productivity in the knitting industry, the study chose to use the DMAIC approach inside the Six Sigma framework. Only information from the plants was gathered, and management supplied secondary data unique to the knitting division. This data made it possible to pinpoint a number of problems with the knitting department's quality and productivity. The collected information was arranged to facilitate additional research and analysis.

To effectively implement Six Sigma, it is essential to follow the DMAIC approach step-by-step, as inadequate analysis could lead the process astray, deviating from the primary goal of improvement (Roy, H. N., Saha, S., Bhowmick, T. P., & Goldar, S. C., 2013)

## 3.2. Framework of Research

To get a general idea of the flaws, a first evaluation is conducted. Based on this evaluation, a problem statement is created with the goal of applying Lean Six Sigma techniques to increase the production and quality of knitted fabric produced by ERCO Textile PLC. Starting with the initial evaluation and observations and ending with the final findings, the research framework describes the study's development. It demonstrates the procedures for gathering and analyzing data as well as the instruments used for enhancement.

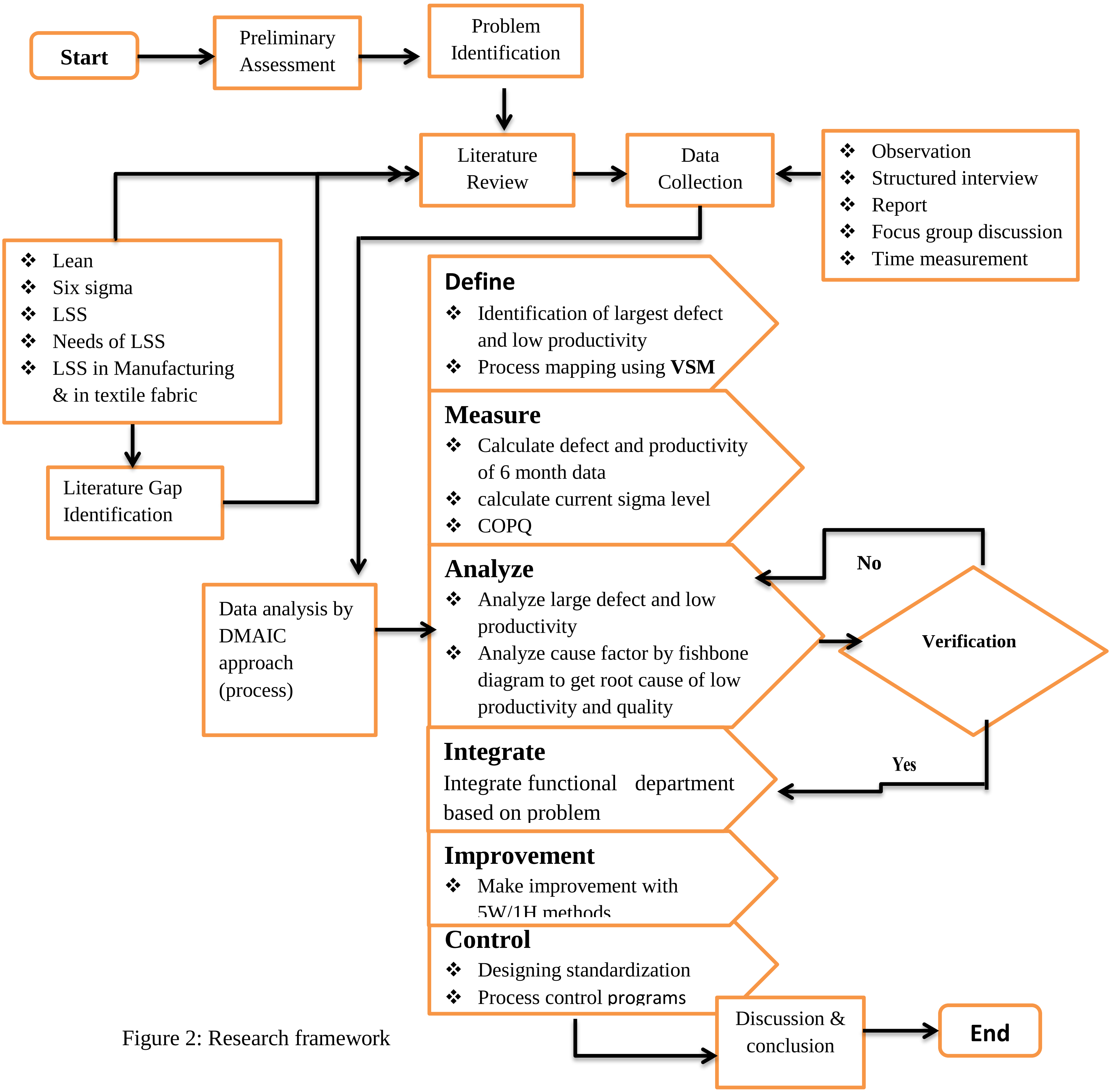



Figure 2: Research framework

### 3.3. Ethical Considerations

Prior to commencing data collection, ethical approval was secured from the College of Technology and Built Environment, and supportive letters was provided to data sources within the study area. The research objectives were clearly communicated to the selected company, ensuring that they have the option to withdraw if they feel uncomfortable during the participation process. All data acquired from the case company, as well as any related information, will be kept confidential. The researchers will emphasize the confidentiality of key information at the outset of each interaction.

### 3.4. Data Collection

This study employs both qualitative and quantitative data collection methods, utilizing primary and secondary data sources. Primary sources encompass direct observations, semi-structured interviews, and time measurements. Furthermore, secondary data is collected from a range of literature, journals, reviews, and reports supplied by the company.

**Reviewed Literature:**

The literature review extensively analyzes papers, reviews, journals, case studies, and reports to gain a comprehensive understanding of the research topic. It emphasizes lean manufacturing, Six Sigma, the importance of their integration, their application in textile manufacturing, and relevant prior studies. This analysis uncovers gaps in the existing literature, pointing out areas that require further investigation and highlighting the importance of this specific study.

**Observation:**

This section examines observed variables, including process organization and prioritization, production flow, value stream maps, types of defects, professional roles, defect percentages, and layout. After monitoring these variables, a value stream map and SIPOC analysis are created to illustrate and document the product or supply flow, identifying areas of value addition and defect occurrence. Tools such as video cameras and stopwatches are utilized to observe specific variables.

**Interview structure:**

A semi-structured interview, informed by the literature review, is planned to address the study's first two objectives. The interview is divided into two parts:

Designed for management personnel, this section aims to gather general information about the factory, including its existing system structure and the type of product manufactured.
Targeted towards quality and production supervisors and operator, this section explores potential areas of waste and gathers data on defect rates and down time in production process.

**Reports**

In this part data are reviewed from quality inspection and productivity records in order to check the type of defect existed and the frequency of each defect happened. Additionally to get cause of low productivity factors and other numerical values like number yarn breakage per unit time

**Time measurement:** a measurement of the time taken for each step, activity, or element of the process is conducted using a stopwatch to identify bottlenecks, areas of waste, and opportunities for improvement. This allows for the calculation of value-added time, non-value-added time, and cycle time within the production process. The primary objective of this time study is to analyze the efficiency of the knitting production process, enabling optimization, cost reduction, and enhanced overall productivity.

**Discussion of Focused Group:**

Following the semi-structured interview, a focused group discussion is conducted. The primary goal of this discussion is to identify the causes of defective products using quality data provided by the factory, which includes potential causes, and to ascertain the genuine or root cause among these. The discussion involves key participants such as quality and production deputy managers, the operational manager, the production planner, quality and production supervisors (from the knitting, washing, and garment sections), as well as mechanics and operators.

#### 3.4.1. Analysis of Data

Data analysis involves inspecting, cleaning, transforming, and modeling data to uncover valuable insights, draw conclusions, and facilitate decision-making. The DMAIC approach will be utilized for this analysis, organized as follows:

Phase 1: Define: The "Define" phase is the first step in the DMAIC cycle for initiating change. During this stage, the total number of issues to be addressed is identified and prioritized. A clear understanding of the project helps the team visualize and simulate the processes involved. This clarity also facilitates a better comprehension of procedural specifications and customer requirements. Consequently, the problem statement, project scope, and objectives are established. The lean tools to define the problem are Pareto to identify the biggest defect and

VSM to provide an overview of the whole process, beginning and ending with the customer, and analyze what is required to meet quality standards.

| Phase | Steps | Way, methods or tools to perform each steps |
|---|---|---|
| **Define** | Understand customer and business requirements | **Voice of Customer (VOC)** to gathering insights and feedback about quality and productivity problem of knitted fabric in knitting department from customers about their needs and requirement, preferences, and experiences through interviews and feedback forms. In this stage I have to gather insight and feedback from quality inspection department, dying and garment department using type form of feedback form. The focus group includes supervisor production head and operator from each department (knitting, dying and garment) Number of issues to be addressed is identified and prioritized. |
| | complete charter | In this step clearly define Purpose: problem statement, project scope, objectives, Stakeholders and Resources are established. |
| | Complete high-level as is process map | In this stage I have to define the process map from supplier to customer. Clearly define the supplier of knitting production department, the type of input that required or using, what the production process(step)look like, the type of output from the production process and who is the customer (internal or external) |

Phase 2: Measure: The second stage in the DMAIC cycle is "Measure." At this point, there is no need to alter the procedures yet. Instead, the existing processes are standardized before initiating the improvement cycle. The issues identified during the Define phase are examined to uncover their root causes. This is accomplished using process maps and flowcharts, which offer detailed explanations and weightings for better understanding. A check sheet for data and a Pareto chart will be used to examine the frequency of problems or causes.

| Phase | Steps | Way, methods or tools to perform each steps |
|---|---|---|
| **Measure** | Identify what to measure (quality product amount and | Measure the amount of quality product in inspection and calculate Cost of poor quality (COPQ) cost that incur in production process based on collected data<br>Cost related failure scrap, loss of low selling price<br>Sigma level |

| | | |
|---|---|---|
| | productivity) | Measure the amount of productivity<br>Value Stream Map (VSM)<br>Identify Value-added and non-value-added activities with lead time and process cycle time |
| | Plan and collect data | Collect 6 month productivity and quality problem data of the produced fabric using systematic sampling by reviewing from recorded data. |
| | Determine baseline performance | Showing trends or patterns of poor quality and low productivity problem from the collected data using run chart and calculate percentage of good product using yield. |

Phase 3: Analyze: The third stage of the DMAIC cycle is "Analyze," which is closely linked to the measurement process. In this phase, the data gathered during the Measure stage is re-assessed to uncover various potential triggers, allowing for the extraction of more accurate and insightful information. The main goal is to identify the root causes of inefficiencies and poor quality based on the current data. Tools such as Pareto charts and Fishbone diagrams are utilized to aid in this analysis. A Pareto chart is used to analyze the most significant causes of poor quality and low productivity, while a cause-and-effect diagram is created through brainstorming in a focused group to identify the primary causes. After confirming the root cause, its validity must also be verified.

| Phase | Steps | Way, methods or tools to perform each steps |
|---|---|---|
| Analysis | Identify performance gaps | In this step the type of defect and root cause and potential root cause of poor quality and low productivity of knitted fabric Determined and categorized. |
| | Ascertain critical root causes: | Identify most significant problem using **Pareto Chart** and to get minimum critical root cause, Using cause and effect diagram in order to focus efforts on addressing the few critical root cause and to Prioritize solutions. |
| | Verify root causes. | Confirming of the root cause and its impact that identified using Pareto chart to become common consensus with management of the factory by presenting the issue for them by **signature and stamp** |

**Phase 4: Verification:** DMAIC, a fundamental problem-solving methodology in Six Sigma (Define, Measure, Analyze, Improve, Control), offers a structured approach to identifying and addressing organizational challenges. It enables teams to systematically enhance processes, resulting in improved quality, lower costs, greater efficiency, and optimized customer satisfaction. The process includes defining the problem, collecting relevant data, analyzing that data to identify root causes, implementing targeted improvements, and establishing controls to prevent recurrence.

Neglecting the Verification phase is a significant error in problem-solving efforts. Verification is the rigorous process of confirming that a proposed solution effectively addresses the identified issue. This involves controlled testing and evaluation to ensure the solution's effectiveness, suitability, and overall impact. Without Verification, organizations risk implementing ineffective solutions that waste resources and may lead to new problems.

Verification is essential in problem-solving, ensuring that the chosen solution is not only effective but also feasible and acceptable to all stakeholders. It ensures that the selected approach is genuinely the best option for long-term success.

Specifically, verifying the identified root causes is crucial. This means confirming that the factors believed to drive the problem are accurate and supported by evidence. This requires thorough investigation, including data collection, detailed analysis, and possibly controlled experiments to validate the root causes. This verification step is vital for ensuring that corrective actions are precisely targeted, effective in resolving the core issue, and preventing its future recurrence. It's about treating the underlying problem, not just the symptoms.

**Phase 5: integration:** Integrating systems functional departments across the entire value chain production process requires a holistic approach. It's about creating seamless connections and collaborations between all functional departments, ensuring that quality and productivity are optimized at every stage.

It encompasses the production process of the value chain and other department for common improvement and sustainability by integrating Data and Information Flow Connecting data sources across different departments to provide a unified view of the production process.

It includes production process value chain functional department or service and other supportive functional system in the organization.

Planning Integration (across all departments): Coordinate production schedules and resource allocation across all departments to meet customers demand.

Human Resource (HR) Integration (across all departments): Ensure the organization has the appropriate personnel with the necessary skills to facilitate improvements in quality and productivity.

Technology Integration (across all departments): Leverage technology to link and automate various elements of the textile and garment production process.

Supply Chain Integration (across all departments): Work closely with suppliers to guarantee the timely delivery of high-quality raw materials and components.

Data Integration and Information Flow (across all departments): Connecting data sources across different departments to provide a unified view of the production process. It includes Centralized Database, Automated Reporting, Real-time Monitoring and ERP (Enterprise Resource Planning) System.

**Process Integration and Standardization (across all departments):** Streamlining and standardizing processes across different departments to eliminate redundancies and improve efficiency. It includes Standard Operating Procedures (SOPs), Process Mapping**,** Cross-Functional Teams.

Skipping integration phase in problem solving effort is critical mistake. It is used to create clear communication where the problem happens and how the problem resolved and what thing required resolving the problem and who resolve the problem.

Integrating functional department in production or service sector has the following advantage:

- Reduced defects, enhanced consistency, and greater customer satisfaction.
- Streamlined processes, reduced waste, and improved efficiency.
- Lower defect rates, reduced material waste, and improved resource utilization.
- Streamlined design and production processes.
- Real-time visibility into all aspects of the operation.
- Increased employee involvement, empowerment, and recognition.
- Superior quality, lower costs, faster response times, and greater innovation.

Thus, incorporating the Integration phase is crucial to the problem-solving process, as it ensures that the solution is effective, practical, and acceptable to the organization or service sector. This approach fosters the development of a more efficient, responsive, and customer-oriented organization.

**Phase 6: improvement**: This stage in the DMAIC cycle is "Improve." During this phase, the most effective solutions identified to improve quality and productivity and address issues related to malfunctioning machines and workforce efficiency. In this step, 5W/1H is used. Which means (what, who, where, when, why, and how): what the problem is, why it occurred, how to solve it (a countermeasure), when to implement the countermeasure, where it is implemented, and who takes action. The proposed solutions must demonstrate significant improvements based on the data gathered in the Measure phase.

| Phase | Steps | Way, methods or tools to perform each steps |
|---|---|---|
| Improve | Generate, prioritize and select solution. | Her based on verified root cause, prioritizing the potential root cause that will be addressed is selected and specific solution to tackle the problem is selected. In order to tackle the selected potential root benchmark problem solving technique is implemented by comparing one's performance, processes, or products against the standards. Additionally 5W/1H, training and 5S lean methodology is implemented to organizing and standardizing the workplace enhances productivity and reduces waste. |
| | Pilot solution | Based on the identified problem in Pareto chart in analysis phase and root causes of the problem in fishbone diagram the countermeasure are performed to reduce its problem based on the prioritized root causes |
| | Validate impacts of solution | Checking and confirming the implemented solution is useful or beneficial or not by comparing the past and the present that is fixed. It is performed by Measurement System Re-Analysis (MSA) of the process outcomes or results after pilot the solution implemented and compare with the past analysis. Conforming What seems like to the outcome and result is there any significance difference between the past process and the present process regarding to cost of poor quality and productivity. |

**Phase 7: control:** The final stage of the DMAIC cycle is "Control." After identifying the issue and formulating the problem statement, processes are evaluated, preliminary data is reviewed, and final corrective actions are implemented to strengthen the system. The primary role of this stage is to ensure that the improvements are effectively integrated into the process. Statistical Process Control (SPC) is a key tool used in this phase, providing real-time alerts to management about whether the process remains under control. Additionally, neighboring Lean methodologies, such as 5S and Kaizen, can also be applied to enhance this process.

| Phase | Steps | Way, methods or tools to perform each steps |
|---|---|---|
| **Control** | Institutionalize the solution | Maintaining of Improved quality and productivity performance and future process performance by integrated improvements into the process using Standard Operating Procedures (SOPs). Statistical Process Control (SPC) is employed for a process remains under control.<br>Ensure that processes are carried out uniformly, reducing variability and errors.<br>Additionally, neighboring Lean methodologies, such as 5S and Kaizen.<br>And monitor the sustainability of this improvement using control chart<br>❖ np Chart<br>❖ p Chart<br>❖ c Chart and<br>❖ u Chart<br>Lastly share document as reference for the factory<br>Provide materials for serve as a reference for existing staff.<br>Provide document best practices |

Table 6: Analysis used for research

| S/N | Tools | Analysis of Inputs | Imperative | Expected outcome |
|---|---|---|---|---|
| 1. | Pareto analysis | Pareto chart | To identify critical main problem | Determination of Major defect %age |
| 2. | Fishbone diagram | FGD result, interview and VSM | To identify critical root cause certain problems | Root cause of the major problem |
| 3. | SIPOC | Observation of production processes, interview results from management and staff, and feedback from company reports and questionnaires. | To illustrate a system (including the inputs and outputs of processes, products, and suppliers) | Problem area identification |
| 4. | Risk matrix | Cause of the problem | To identify the cause that has major risk level | Major risk cause of the problem |
| 5. | Time measurement | Time measurement with a stopwatch. | To know activities time taken | Average cycle time and average work process |
| 6. | VSM | Time of study | To understand the wasted time from VA and NVA times | VA,NVA, cycle time |
| 7. | Control chart | np Chart and p Chart | To monitor sustainability | Reduced variability and error |
| 8. | SOP | Time study, quality result | To assess the capability of the process both before and after improvements. | Process variation , defect percentage and productivity percentage |

### 3.4.2. Data verification

The results from the Fishbone diagram reveal potential root causes that need to be verified for authenticity. This verification process involves conducting a gemba walk, implementing a data collection plan, and performing thorough analysis. The objective of verification is to confirm the root causes before dedicating resources to countermeasures and solutions. Once the root causes are confirmed, improvement activities can be prioritized based on their impact on the issue.

The verification process includes several key steps:

- ❖ Gemba Walk: This step involves visiting the actual location where the work is performed (the "gemba") to observe the processes directly.
- ❖ Data Collection Plan: A structured plan is created to systematically gather relevant data that will assist in validating the root causes.
- ❖ Data Analysis: After data collection, it is analyzed to identify patterns and correlations.

#### 3.4.3. Discussion, Conclusion and Recommendations

A thorough analysis of the results, a solid conclusion, and practical suggestions for further research are included in the study's concluding sections. In accordance with the DMAIC roadmap and related tools utilized in previous phases, this section shows the findings from the data that was gathered and examined. The purpose of the first stages of DMAIC was to thoroughly identify and analyze the problem using techniques such as cause-and-effect diagrams, Pareto charts, time studies, and Value Stream Mapping (VSM) to quantify the problems. Particularly, time studies provided insightful information about the process's value-added and non-value-added activities. Pareto analysis was used to determine the most important elements causing the observed variances, and control charts were used to evaluate the effectiveness of particular operations. The DMAIC framework's fourth stage foresees the development of an optimal process configuration, which involves lowering waiting times, eliminating bottlenecks, and updating the process map in light of time study data and VSM analysis. The discussion part rationally synthesizes the knowledge acquired by carefully interpreting these findings, taking into account their importance within the larger framework of the research issue, and investigating possible avenues for further investigation. The recommendations section makes suggestions for changes that could be made in light of these discoveries in order to further address the main concerns of the study. These suggestions are supported by the information and analysis provided during the course of the study. The conclusion, which highlights the main conclusions drawn from the data and their implications for the field, provides a final summary of the research's overall contributions.

# CHAPTER FOUR

# 4. DATA PRESENTATION and ANALYSIS

This chapter presents a thorough analysis of the data gathered through multiple methods, such as observations, semi-structured interviews, reports, focus group discussions, feedback questionnaires, and time measurements. The data is summarized and organized clearly, in line with the research objectives, to deliver a solid and insightful analysis.

## 4.1. Background of ERCO Textile and Garment PLC

ERCO Textile and Garment PLC is a knitted textile manufacturing company established in 2002 in Adama, Oromia region of Ethiopia. It is the only textile waste recycling industry in the area. It is a PLC; with primary products include polo shirts, round-neck t-shirts, pajamas, V-neck t-shirts, and more.

## 4.2. Data collection results

Based on the collected data, the results from observations, semi-structured interviews, reports, focus group discussions, feedback questionnaires, and time measurements are presented. Data collection began on February 15, 2017 E.C. The findings from the interviews and feedback questionnaires reveal the types and rates of defects, internal customer complaints, influencing factors on productivity, as well as their frequency and rates.

## 4.3. Analysis of data

As mentioned in the methodology section, the DMAIC technique is a well-known framework that many academics employ when implementing Lean Six Sigma. The researcher analyzed each study in light of its methodological approach and goals, drawing from the literature review that is specifically pertinent to this research case. In the end, the researcher created a customized DMAIC roadmap to address the particular issues raised in the case study. This DMAIC roadmap is crucial for process analysis and improvement in the textile manufacturing industry. As a result, a great deal of data was gathered and analyzed using this methodology, which is shown here.

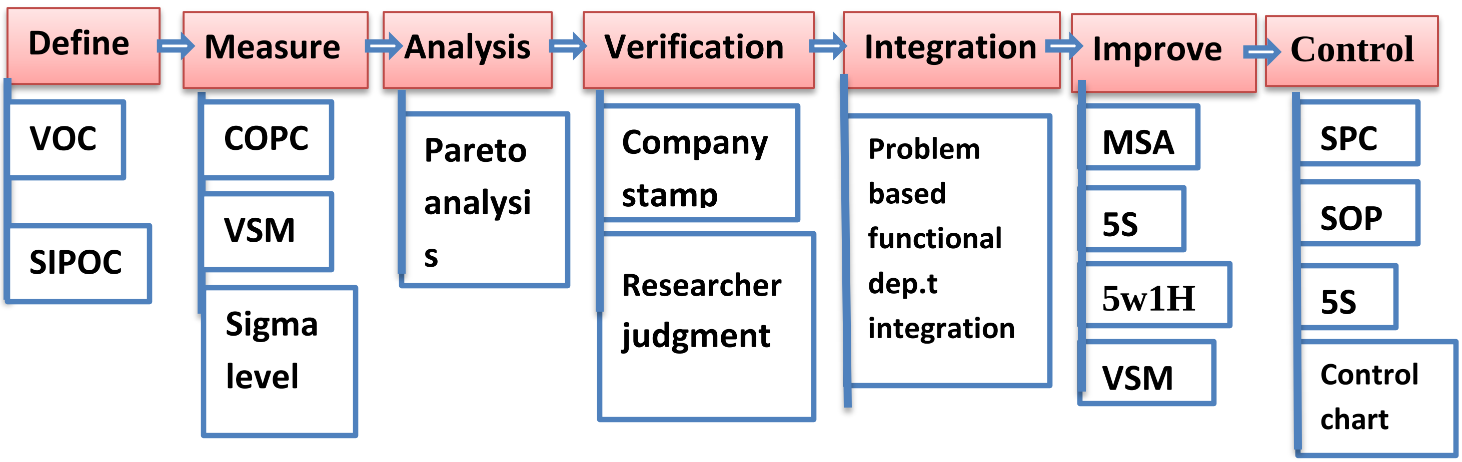



Figure 3: DMAVIIC framework (researcher Analysis)

## 4.4. DMAVIIC ROAD MAP

Building upon the DMAIC (Define, Measure, Analyze, Improve, and Control) framework, this paper introduces a modified DMAIC verification framework, termed DMAVIIC methodology, which incorporates a "verification" and "integration" step creates a DMAVIIC roadmap.

**Define**

It is crucial to specify the relationship between quality and productivity because the study is centered on improving both. The stakeholder (consumer, manufacturer, employee, etc.) determines how subjectively quality and productivity are perceived. Although both high quality and high productivity are frequently regarded as desirable objectives, they are not necessarily seen as being directly proportionate or interchangeable. A lot of stakeholders believe that a well-made product is of superior quality. Therefore, by clarifying the term and its relationship, one can increase quality and productivity by reducing misunderstandings and identifying the causes of low quality and productivity.

Quality refers to the degree to which the product or service meets the required standards and specifications for its intended use. This encompasses several aspects:

- Physical Properties: This includes characteristics of the product
- Appearance: This covers visual aspects such as the absence of defects and overall aesthetic
- Performance: How well the product performs its intended function.
- Conformance to Standards: Meeting industry standards (like ISO, ASTM) and customer-specific requirements.

Productivity is a measure of the efficiency of production process. It's typically expressed as the output (amount of product produced) per unit of input (resources used).

It is affected by many factors like Production Speed, Machine Efficiency, and Resource Utilization, quality of raw material, Waste amount and Throughput (raw material to product).

Quality and productivity are closely interrelated and often have a complex relationship. While it might seem like pushing for higher production speed always increases productivity, it's crucial to remember that quality is an integral part of the equation. A balanced approach that prioritizes both quality and efficiency is essential for success in production. Focusing on preventing defects and optimizing processes will lead to sustainable improvements in both quality and productivity.

High Productivity does not mean necessarily High Quality. High productivity can lead to high quality if it's achieved through efficient processes, skilled labor, and a focus on defect prevention.

High Quality Potentially High Productivity in the long run it can contribute to high productivity by: Reducing rework and waste, improving customer satisfaction and repeat business, Enhancing the company's reputation and brand image, Creating a more efficient and streamlined production process. Thus, it is essential to maintain quality standards and minimize product defects in the production process in order to maximize productivity.

As discussed in earlier chapters, Lean tools are used in conjunction with Six Sigma's DMAIC approach to improve quality and productivity. The goal of the first step, "Define," is to recognize and describe a problem. At this point, the problem is clarified using tools like SIPOC, process mapping, and Voice of the Customer (VOC). Through interviews and feedback questionnaires, VOC collects consumer wants, preferences, and experiences in order to get insights and comments about quality and productivity issues pertaining to knitted fabric in the knitting department.

In order to determine the types of defects and the reasons behind low productivity, this stage gathers information and input from the knitting production process, quality inspection department, dyeing (washing), and garment department using structured feedback forms and interviews. While SIPOC describes the inputs, outputs, and overall process, the process map aids in visualizing the present production workflow.

To begin the investigation, a focused group was first established with the goal of enhancing productivity and quality. Using secondary data, interviews, and surveys, this team was entrusted with determining the types of product defects and the reasons for low productivity. Following brainstorming, the focus group participants determined five reasons for low productivity and eleven fault kinds that were commonly reported in observations, questionnaires, interviews, and recorded data. In order to guarantee the accuracy of data for detecting and prioritizing issues, the operational manager from the planning department was also included to obtain insights into customer concerns about quality, time to market, and low productivity.

## VOC

As discussed before the customer of the knitting department is processing (washing) and garment department. The researcher takes the internal department of internal customer garment and washing to get their insight and feedback about quality and productivity through interview and questioner to get qualitative data.

The **VOC** (garment and washing) about quality and productivity are Summarized as follows:

**Table 7: summarized VOC**

| Parameter | **VOC** | |
|---|---|---|
| | Processing(washing) | Garment |
| Quality | Due to oil stain on fabric there is additional washing chemical consumption. | There is high rejection rate due to many holes existed on the fabric and shade variation |
| | Shrinkage of fabric during washing in widthwise | There is high pattern rejection due to fabric shrinkage in width wise that does not align with pattern width |
| | An increase washing cycle time to remove oil stain from the fabric due to oil stain. Sometimes even the oil does not remove from the fabric. It needs another cleaning agent, like Detergents & Surfactants | There is high return rate of cloth from the external customer due shade variation and shrinkage during washing |
| | Fabric appearance is become damaged due to log run washing to remove oil stain | High pilling on the fabric surface due to long washing cycle time to remove oil stain |
| | Due to un evenness defect there is shade variation or inconsistency on fabric. | There is high bowing and skew ness effect on the fabric |
| | High pilling on fabric during washing process | Affect production efficiency due mending the defect and replacing the defected one. |

| | | |
|---|---|---|
| | Rejection rate (return to spinning) is significant due to big hole sinker and needle line | |
| Productivity | High downtime of machine due to shortage of fabric from knitting department, even they change production shift from two shift to one shift | High waiting time of fabric from washing and knitting department |
| | Delay to deliver the required amount of fabric to the garment department | Decrease line efficiency and production. |
| | | Delay on time to market,<br>Averagely it takes 1-3 month |

Table 8: Focus group

| s/n | Focus group | |
|---|---|---|
| 1 . | Manager | Operational manager |
| 2 . | Planning | Production planner |
| 3 . | Knitting production | Production head, shift leader, supervisor & mechanic |
| 4 . | Fabric quality inspection | Quality head, supervisor & inspector |
| 5 . | Washing department | Washing head, supervisor and operator |
| 6 . | Garment department | Production head, supervisor quality inspector and operator |

By combining all the above stakeholder‘s saying result, defect type and cause of low productivity, which was mostly occur in the production process, are identified as below.

Table 9: Defect type

| S/n | Defect type |
|---|---|
| 1. | Hole |
| 2. | Big hole |
| 3. | Needle line |
| 4. | Sinker line |
| 5. | Oil stain |
| 6. | Needle broken |
| 7. | Unevenness |
| 8. | Loos yarn(tension variation) |
| 9. | Pilling |
| 10. | Shrinkage |
| 11. | Color inconsistencies |

Table 10: Monthly defect percentage

| s/no | Month | Inspected fabric length (m) | Total defect (m) | %age of defect |
|---|---|---|---|---|
| | June | 62452.8 | 9547 | 15.29 |
| | July | 57843.5 | 8453 | 14.61 |
| | August | 53845.6 | 8257 | 15.33 |
| | September | 55794.3 | 8294 | 14.87 |
| | October | 60457.9 | 8798 | 14.55 |
| | November | 61877.7 | 9241 | 14.93 |
| | Average | | | 14.93 |

Table 11: Productivity factor for knitting department

| s/no | Productivity factor | Productivity |
|---|---|---|
| 1. | Machine efficiency | 75% |
| 2. | Material utilization | 80% |
| 3. | Labor | 60% |
| 4. | Quality Productivity | 65% |

**Table 12:** Productivity report of 6-month of case company

| s/no | Month | Productivity factor | | | |
|---|---|---|---|---|---|
| | | Machine efficiency | Material utilization | Labor | Quality Productivity |
| | June | 74 | 82 | 58 | 67.5 |
| | July | 76 | 81 | 60 | 63.5 |
| | August | 75 | 83 | 62 | 63 |
| | September | 73 | 79 | 63 | 64.5 |
| | October | 74 | 77 | 59 | 66 |
| | November | 77 | 78 | 58 | 65.5 |

The resources utilized in the production process are manpower, machine, raw material (yarn), lubricant (oil and grease) and spare part (sinker, cam, needle, belt, bolt and nut)

| | |
|---|---|
| Project objective | Improve quality and productivity of knitted fabric |
| VOC | Products quality and productivity (for time to market) |
| Project scope | Knitting fabric production section |
| Team member | Management, middle management and operator |
| Expected financial benefits | A considerable cost saving due to defects reduction and increase productivity |
| Expected customer benefits | Receiving the product with the expected quality quantity |

**Production Process Map**

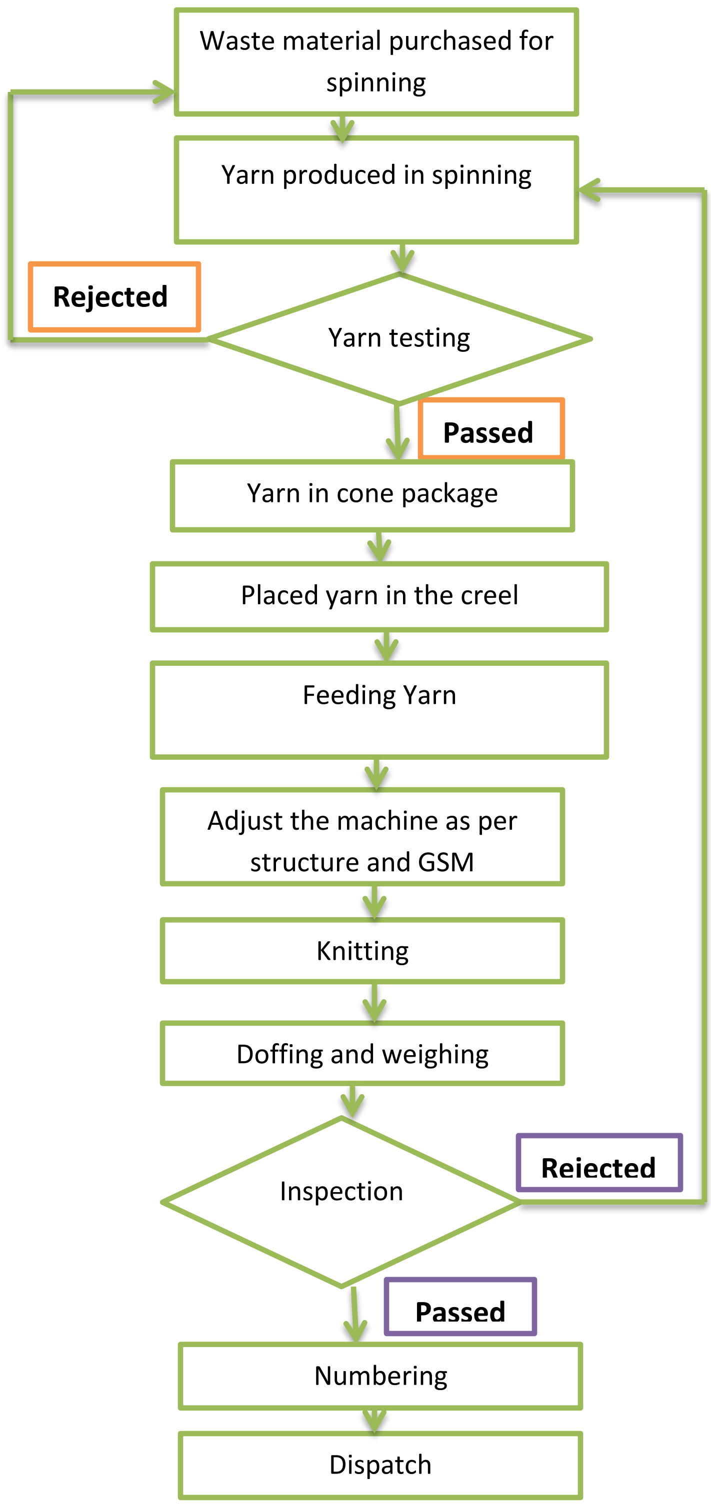



Figure 4: Production process map

**Description of Product Selection**

The company currently manufactures various kind of fabric, including single jersey, double jersey, collars, and cuffs. Given the strong demand for t-shirts, pajama shorts, and jackets, it is crucial to focus on producing fabrics that cater to these popular products.

To effectively meet customer demand, we should prioritize the following:

- Product Selection: Focus on producing single jersey fabric, as it is ideal for t-shirts and pajama shorts.
- Quality Improvement: Implement quality control measures to assure that the fabrics meet high standards, reducing defects and enhancing customer satisfaction.
- Productivity Enhancement: Optimize production processes to boost efficiency, shorten lead times, and minimize waste, enabling us to better meet high demand.

**SIPOC Analysis**: SIPOC is a tool that helps understand the inputs, outputs, and overall process. In this context, it outlines the manufacturing process of single jersey knitted fabric, from inputs to the finished product. The SIPOC analysis offers a comprehensive overview of the entire manufacturing process for single jersey knitted fabric, detailing each step from inputs to the final product. Here's a SIPOC analysis for the manufacturing process of single jersey knitted fabric:

Table 13: SIPOC analysis

| S | I | P | O | C |
|---|---|---|---|---|
| Suppliers | Inputs | Process | Outputs | Customer |
| Fabric structure and pattern analyzer | Raw materials (yarn) | Yarn Preparation: | Finished single jersey knitted fabric (various colors, patterns and structure) | Internal washing and garment department |
| Spinning | Knitting machinery | Coned Yarn loading | Quality assurance and productivity reports | External Apparel manufacturer |
| Raw material store | Lubricant | Knitting: | Fabric specifications for customers | |
| Spare part store | Labor (mechanic & operators) | Doffing and weighing | | |
| | Design specifications (patterns and colors) | Quality inspection | | |
| | Maintenance and quality inspection tool | Packaging | | |

**Measure**

In this stage, measuring the Cost of Poor Quality (COPQ), sigma level, and process cycle time (including both value-added and non-value-added time) is essential. COPQ refers to the costs associated with defects and inefficiencies in the production process. In the context of knitted fabric production, COPQ can be divided into four primary categories:

- ❖ Prevention Costs: Expenses incurred to prevent defects, such as quality training and process improvements.
- ❖ Appraisal Costs: Costs related to measuring and monitoring activities, including inspections and testing.
- ❖ Internal Failure Costs: Expenses resulting from defects identified before delivery, such as rework and scrap.
- ❖ External Failure Costs: Costs arising from defects discovered after delivery, including returns and warranty claims, which can also damage brand reputation and lead to lost future sales.

Steps to calculate COPQ

1) Identify Quality Costs & Collect Data:
2) Calculate Each Cost Component:
    - ❖ Prevention Costs: Total cost of training and process improvements.
    - ❖ Appraisal Costs: Total costs related to inspections and testing.
    - ❖ Internal Failure Costs: Sum of costs for rework and scrap.
    - ❖ External Failure Costs: Costs from returns and claims.
3) Total COPQ Calculation

Based on the gathered data form the company for six (6) the following thing are identified.

Table 14: Quality costing area (issue)

| S/n | Quality cost area | Existing cost | Cost (birr) |
|---|---|---|---|
| 1. | Preventive cost | Steaming of yarn and waxing | 144,000 |
| | Internal failure cost | Re work to spinning and scrap | 90,000 |
| | | Process loss | 2,236,125 |
| | | Down time cost(labor + electric + production loss) | 859,013.75 |
| | | Spare part(needle) | 973,440 |
| 2. | External failure cost | Return and discounted selling | 375,000 |

Therefore the total cost of poor quality is the summation the above quality cost area that means:

Total COPQ =Prevention Costs+ Internal Failure Costs+ External Failure Costs

=144,000+90,000+2,236,125+859,013.75 +973,440+375,000=4,677,578.75 birr

**Sigma level**

Sigma level calculation: Calculating the Six Sigma level involves determining the defect rate of a process and converting that to a Sigma level.

Knowing the DPMO (Defects per Million Opportunities) level is essential for determining the process's sigma level. Here’s how to approach this: First, it’s important to assess the number of defects present in the workplace. Next, identify the opportunities for defects based on the production process.

According to data from the company's quality department, the product undergoes physical quality inspections using an inspection machine for visual assessment. However, before calculating DPMO, certain assumptions must be clarified to distinguish between defects and scrap. This will help eliminate any ambiguity and ensure accurate calculations.

Additionally total opportunity and opportunity per unit must be distinguished and determined.

From the six (6) collected data the opportunity per unit and total production of the single jersey fabric are gathered.

Opportunity per unit =11(type of defect or measurable character to be happened on fabric) Hole, Big hole, Needle line, Sinker line, Oil stain, Needle broken, Unevenness, Loos yarn (tension variation), Pilling Shrinkage, Color inconsistencies

Total produced fabric = 245,652.57 kg

Total opportunity = opportunity per unit* total production= 11*245,652.57 =2,702,178.27

The total number of defect from collected data of 6 month quality report is:

Total number of defect = 44,127.39 kg

Defect Rate (D):

D= (number of defect/total produced fabric)*100 = (44,127.39kg/245652.57)*100 =17.96%

DPMO= [total number of defects / (total product *opportunity per unit)]*$10^6$

= [44,127.39/(245,652.57 *11)] *$10^6$ =179633.33

The DPMO of 179,633.33 is between the range of 193,601 (1.3 sigma) and 161,513 (1.4 sigma), according to Six Sigma tables. Without taking into consideration the 1.5 σ shift, the company's sigma level is calculated to be 1.36 σ by interpolation. Additionally, when taking into account the 1.5 σ shift, the sigma level is 2.32 σ because the DPMO of 179,633.33 falls between the DPMO of 184,108 (2.5 sigma) and 158,686 (2.4 sigma).

When taking into consideration a 1.5 standard deviation shift, the company's estimated sigma level is 1.36, suggesting that the process functions at a low sigma level, which is associated with a higher frequency of errors and deviations. Nevertheless, the sigma level rises to 2.86 with applying the extra 1.5. This improvement signifies that as the process matures, it becomes more capable and shows deviations compared to its initial state without the shift. It's important to recognize that a higher sigma level typically indicates improved process quality and performance.

## Value stream Mapping (VSM):

A lean management tool called Value Stream Mapping (VSM) was created to show, evaluate, and improve the flow of data and objects required to provide a good or service to the consumer. It is a useful tool for businesses looking to enhance customer value, streamline operations, and foster a continuous improvement culture. VSM is a commonly used method for identifying waste across a variety of processes since it clearly illustrates both value-added and non-value-added operations within a process.

Both value-adding and non-value-adding activities are demonstrated in the VSM for the production of single jersey knit fabric. The production head receives the design request at the start of the mapping process, and the product is delivered to the washing department at the end.

1. Waiting Time: Delays caused by waiting for yarn deliveries and the search for trolleys due to their limited availability in production.
2. Long Transportation: Extensive movement of materials from one department to another.
3. Inefficient Setup Times: Long changeover times between different fabric runs
4. Unnecessary Transportation: Moving materials and products between processes without adding value.
5. Excessive Quality sustaining of yarn: Performing unnecessary waxing of yarn

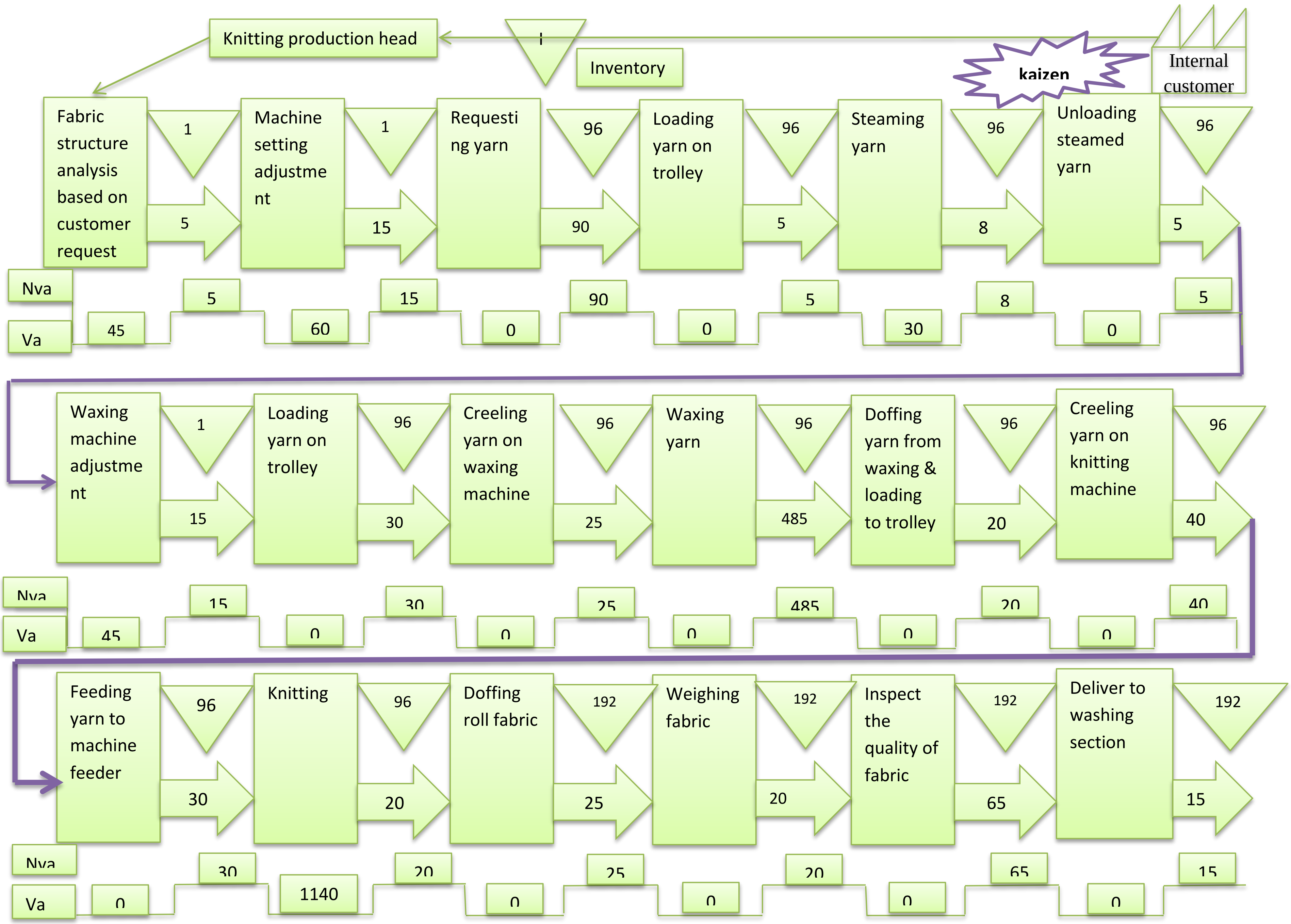

Knitting production head
I
Inventory
kaizen
Internal customer
Fabric structure analysis based on customer request
1
5
Machine setting adjustment
1
15
Requesting yarn
96
90
Loading yarn on trolley
96
5
Steaming yarn
96
8
Unloading steamed yarn
96
5
Nva
Va
45
5
60
15
0
90
0
5
30
8
0
5
Waxing machine adjustment
1
15
Loading yarn on trolley
96
30
Creeling yarn on waxing machine
96
25
Waxing yarn
96
485
Doffing yarn from waxing & loading to trolley
96
20
Creeling yarn on knitting machine
96
40
Nva
Va
45
15
0
30
0
25
0
485
0
20
0
40
Feeding yarn to machine feeder
96
30
Knitting
96
20
Doffing roll fabric
192
25
Weighing fabric
192
20
Inspect the quality of fabric
192
65
Deliver to washing section
192
15
Nva
Va
0
30
1140
20
0
25
0
20
0
65
0
15

Figure 5: vsm

According to the VSM and production process map for single jersey knit fabric production, the current production cycle time is summarized in the following table:

Table 15: Summary of VSM and Time measurement

| S/n | **Summary of Process** | **VAT** | **NVAT** | **Cycle time** | **NVAT** | | |
|---|---|---|---|---|---|---|---|
| | | | | | **Movement** | **Waiting** | **Unnecessary activity for quality sustaining** |
| 1 | Fabric structure analysis based on customer request | 45 | 5 | 50 | 5 | | |
| 2 | Machine setting adjustment | 60 | 15 | 75 | 10 | 5 | |
| 3 | Requesting yarn | | 90 | 90 | 20 | 70 | |
| 4 | Loading yarn on trolley | | 5 | 5 | 1 | 1 | |
| 5 | steaming yarn | 30 | 5 | 35 | | | |
| 6 | Unloading steamed yarn | | 8 | 8 | | | |
| 7 | Waxing machine adjustment | 45 | 15 | 60 | 10 | 5 | 45 |
| 8 | Loading yarn on trolley | | 30 | 30 | 5 | 5 | |
| 9 | Creeling yarn on waxing machine | | 25 | 25 | | | 25 |
| 10 | Waxing yarn | | 485 | 485 | | 5 | 480 |
| 11 | Doffing yarn from waxing & loading to trolley | | 20 | 20 | 2 | 5 | 13 |
| 12 | Creeling yarn | | 40 | 40 | | 2 | |
| 13 | Feeding yarn to machine | | 30 | 30 | 1 | | |
| 14 | Knitting | 1140 | 20 | 1160 | 5 | | |
| 15 | Doffing roll fabric | | 25 | 25 | 3 | | |
| 16 | Weighing fabric | | 20 | 20 | 5 | 2 | |
| 17 | Inspect the quality of fabric | | 65 | 65 | 10 | 5 | |
| 18 | Deliver to washing section | | 15 | 15 | 1 | 2 | |
| Total time | | 1320 | 918 | 2238 | 78 | 107 | 563 |

The table above indicates that non-value-added time includes movement, waiting, unnecessary activities for quality maintenance, and other unproductive times. This assessment is based on time study measurement.

Table 16: coverage of value-added and non-value added time Summary

| Activity | Time / minute | %age |
|---|---|---|
| Non value adding | 918 | 41%% |
| Value adding | 1320 | 59% |
| Sub total | 2238 | |

**Table 17:** coverage of non -value added time

| Non value adding | Tim/ minute | %age |
|---|---|---|
| Movement | 78 | 10.4% |
| Waiting | 107 | 14.3% |
| Unnecessary activity for quality sustaining | 563 | 75.3% |
| Total | 748 | |

According to the table, 59% of the total time is share of value-added, while 41% is non-value-added time. The high percentage of non-value-added time (41% of the cycle time) is not solely due to a lack of attention from workers; some non-value-added activities cannot be completely eliminated. However, waiting times for requested yarn can be reduced, and activities like waxing, which hold significant value, can be eliminated.

Consequently, non-value-added time constitutes 41% of the cycle time in the single jersey knit fabric production process. Additionally, other non-productive time observed in the Gemba (the actual work location) needs to be minimized or removed. Among the non-value-added time, the majority is attributed to unnecessary activities for quality maintenance (75.3%), followed by waiting (14.3%) and movement (10.4%). The findings indicate that non-value-added activities negatively impact the company's productivity, alongside the costs associated with defects in single jersey knit fabric production.

**Productivity measure**

**Machine Efficiency:** Machine efficiency measures how effectively a knitting machine operates compared to its maximum potential.

Machine Efficiency (%) = (Actual Output/Maximum Possible Output) ×100

From the collected data report actual production =245652.57 kg from 6 month and from planning department the attainable (best practice) production is 324569kg

**Machine Efficiency (%) =** 245652.57 kg/324569 kg*100 =75.6%

**Material Utilization:** Material utilization assesses how efficiently the raw materials are converted into finished products.

Material Utilization (%) = (output/Total input) ×100

The input to product 245652.57 kg of fabric uses an input material 307127kg yarn

**Material Utilization (%) =** 245652.57/307127*100= 79.98%

**Productivity of labor:** Productivity labor measures output generated divided by hour of labor.

Productivity of labor =Total Output/Total Labor Hours

Man hour 8 hour and product per shift per labor is 90 kg but the practice is 150kg/8hour

Labor Productivity = 90 kg/8hour = 11.25 kg/hr.

Labor Productivity % =90kg/150kg*100= 60%

**Raw Material Quality Productivity:** how effectively the raw materials contribute to the production of high-quality fabric.

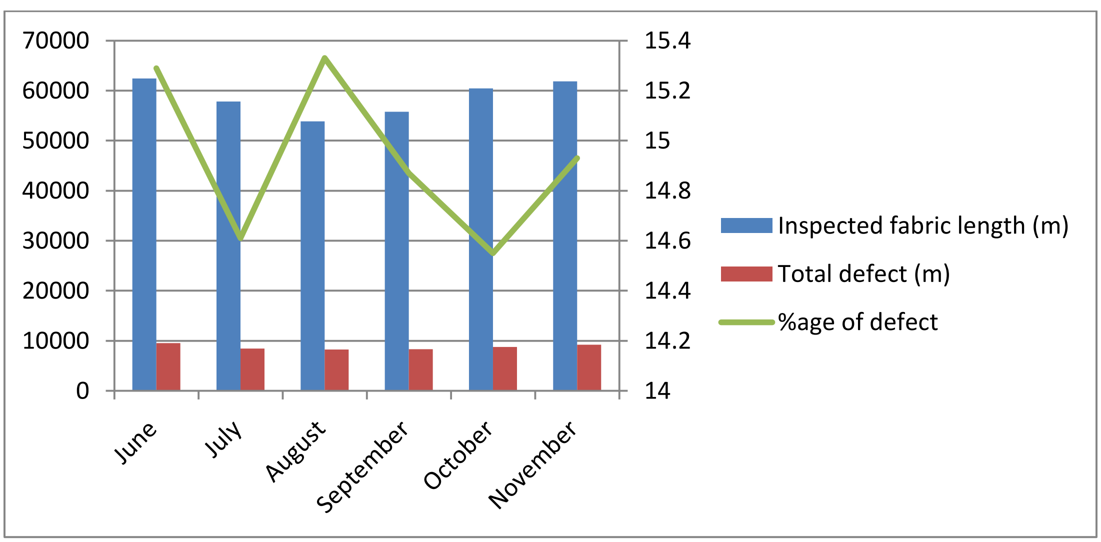
Quality Productivity = (Quality Output / Total produced fabric) × 100

From the above produced fabric, 159674 kg of fabric is with qualified parameter.

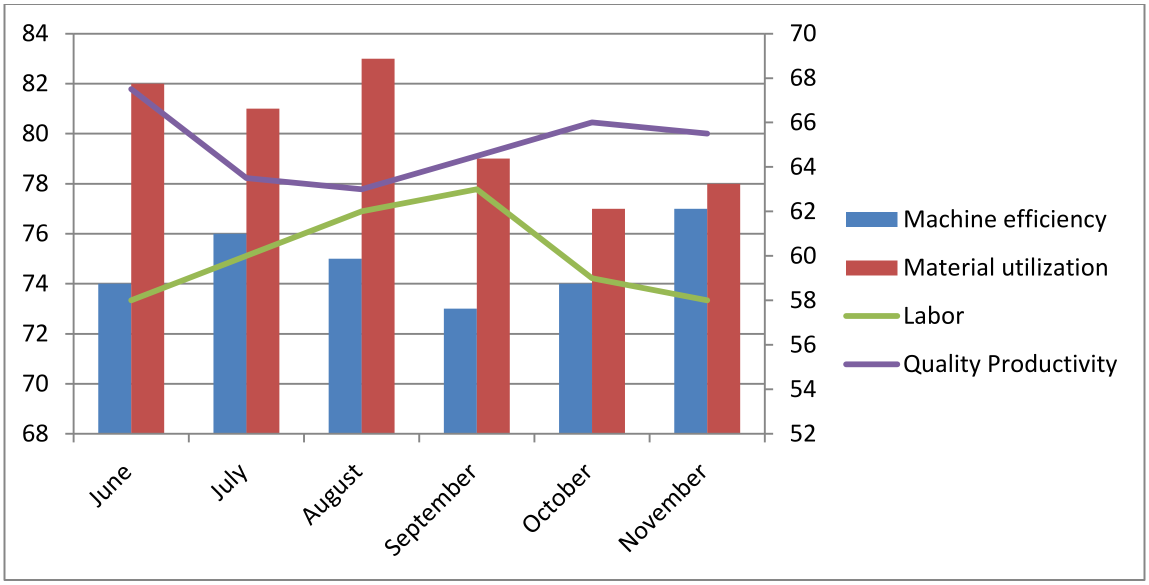
Quality Productivity = Quality Output / Total produced fabric) × 100

159674kg/245652.57kg*100 =65%

## Defect percentage trend




a)




b)

Figure 6: Trends of defect (a) and productivity (b)

**Process capability index analysis (Cp and Cpk)**

Process Capability Analysis for discrete data assesses a process's capability to produce products that achieve requirements using countable data (such as the number of defects). In contrast, Process Capability Analysis for continuous data evaluates process performance based on measurable variables (like length or weight), determining how effectively the process produces products within defined limits.

| sample | Tested fabric | Defect (rejected) | Defect/meter |
|---|---|---|---|
| 1. | 62452.8 | 9547 | 0.153 |
| 2. | 57843.5 | 8453 | 0.146 |
| 3. | 53845.6 | 8257 | 0.153 |
| 4. | 55794.3 | 8294 | 0.149 |
| 5. | 60457.9 | 8798 | 0.146 |
| 6. | 61877.7 | 9241 | 0.149 |
| 7. | Mean μ | | 0.149 |
| 8. | $\delta^2=\sum(\text{Dpmi}-\mu)^2/n-1$ | | 1.076E-05 |
| 9. | $\delta = \text{SQRT } \delta^2$ | | 3.280E-03 |

Fabric rejection

Upper specification limit= 1%=0.01

Lower specification limit= 0.5%=0.005

Cp=(USL-LSL)6δ

Cpk = Min ((USL-μ)/3δ, (LSL-μ)/3δ)    capability index considering mean

Cp & Cpk <1 process is not capable

Cp & Cpk >1 process is capable

Cp=(USL-LSL)6δ=(0.01-0.005)/6*0.00328 = 0.005/0.01968 = 0.254

Cpk = Min ((USL-μ)/3δ, (LSL-μ)/3δ) =min ((0.01-0.149)/3*0.00328, (0.005-0.149)/ )/3*0.00328)

**= min (-0.139/0.00984, -0.144/0.00984) = min (-14.126, -14.634) = -14.634**

A Cp value of 0.254 indicates that the process capability is quite low. Here's how to interpret this value:

Interpretation of Cp = 0.254

Process Capability below Acceptance Threshold:

Generally, a Cp value below 1.0 suggests that the process is not capable of producing items within the requirement limits consistently. A Cp of 0.254 is significantly below this threshold.

High Potential for Defects:

This low Cp indicates a high likelihood of producing defects, as the spread of the process (indicated by δ) is large relative to allowable range between the upper and lower specification limits.

Need for Process Improvement:

Immediate action is required to investigate the sources of variation in the process. This may include analyzing production methods, reviewing equipment calibration, and enhancing operator training.

Specification Limits vs. Process Variation:

The low Cp value suggests that the process variation (6 times the standard deviation) is larger than the allowable range defined by the requirement limits. This indicates that the process needs to be tightened to reduce variability.

A Cp of 0.254 indicates that the process is not capable of consistently meeting quality standards, and significant improvements are necessary to reduce variation and improve capability.

A negative Cpk (Cpk < 0) indicates that the process is not capable of meeting the specification limits. Here's what it means:

Interpretation of a Negative Cpk

Mean outside requirements limit: The mean of the process is outside the allowable specification limits (either above the upper limit or below the lower limit).

High Defect Rate: A negative Cpk suggests a significant number of defects are expected, meaning that the process is producing unacceptable products.

Need for Immediate Action: This situation requires urgent counter measure to control the process. Investigating the causes of variation, identifying sources of defects, and implementing improvements are crucial.

Process Improvement: Focus on process redesign, better quality control measures, and training for operators to ensure that the process can consistently produce within specifications.

Cpk = -14.634, it indicates that the process average is deviate from the requirements limit, resulting in a high likelihood of producing defective items. The goal should be to identify why the mean is so far off and to take corrective actions to realign the process.

## Analyze:

Finding, confirming, and choosing the root causes—as well as possible root causes—for removal is the goal of this stage. Numerous potential explanations for the company's problems are revealed via root cause analysis. Finding the fundamental causes of variances and subpar performance—especially with regard to flaws and low productivity—is the main goal of this phase.

Fishbone diagrams, Pareto charts, and P-Control charts are among the techniques used to help with this analysis. While a cause-and-effect diagram is produced through brainstorming in a targeted group, a Pareto chart is used to examine the main reasons for low productivity and poor quality. Once the underlying reason has been identified, its validity needs to be verified.

In the measure phase of DMAIC, the issues regarding to quality defect and cause of low productivity are selected. Based on that data it can be analyzed as follows by Pareto charts. From the analysis, the defect types which are more effect are selected. Additionally, waiting time is identified as another key issue contributing to variation that requires improvement.

Based on the identified defect and cause of low productivity in define phase with focus group discussion the defect rate and productivity percentage is analyzed as below from quality inspection and production report of company.

## P- Control chart

Control charts can be divided into two primary types based on their measurement of product quality: control charts for variables and control charts for attributes.

**Control Charts for Variables**

Control charts for variables track continuous data that can assume any value within a specified range. These charts assess measurable characteristics of a product, such as weight, length, temperature, or time.

- X-bar: track the mean of a sample over time.
- R Chart: Tracks the range of variation within a sample.
- S Chart: Measures the standard deviation of the process.

**Control Charts for Attributes**

Control charts for attributes monitor discrete data that can be classified into pass/fail or good/bad categories. These charts evaluate characteristics that can be counted rather than measured.

- P Chart: Tracks the proportion of defective items in a sample.
- NP Chart: Monitors the number of defective items in a fixed sample size.
- C Chart: Counts the number of defects in a sample.
- U Chart: Measures the average number of defects per unit, accommodating varying sample sizes.

The researcher has analyzed six months' worth of production reports and inspection reports concerning defects.

| sample | sample size | defect | p | p-bar | UCL | LCL |
|---|---|---|---|---|---|---|
| Week 1 | 10236 | 2158 | 0.211 | 0.214073 | 0.226236 | 0.20191 |
| Week 2 | 10236 | 1925 | 0.188 | 0.214073 | 0.226236 | 0.20191 |
| Week 3 | 10236 | 2412 | 0.236 | 0.214073 | 0.226236 | 0.20191 |
| Week 4 | 10236 | 2359 | 0.230 | 0.214073 | 0.226236 | 0.20191 |
| Week 5 | 10236 | 1953 | 0.191 | 0.214073 | 0.226236 | 0.20191 |
| Week 6 | 10236 | 2247 | 0.220 | 0.214073 | 0.226236 | 0.20191 |
| Week 7 | 10236 | 2675 | 0.261 | 0.214073 | 0.226236 | 0.20191 |
| Week 8 | 10236 | 2457 | 0.240 | 0.214073 | 0.226236 | 0.20191 |
| Week 9 | 10236 | 2489 | 0.243 | 0.214073 | 0.226236 | 0.20191 |
| Week 10 | 10236 | 1994 | 0.195 | 0.214073 | 0.226236 | 0.20191 |
| Week 11 | 10236 | 2548 | 0.249 | 0.214073 | 0.226236 | 0.20191 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Week 12 | 10236 | 1897 | 0.185 | 0.214073 | 0.226236 | 0.20191 |
| Week 13 | 10236 | 2512 | 0.245 | 0.214073 | 0.226236 | 0.20191 |
| Week 14 | 10236 | 1918 | 0.187 | 0.214073 | 0.226236 | 0.20191 |
| Week 15 | 10236 | 1818 | 0.178 | 0.214073 | 0.226236 | 0.20191 |
| Week 16 | 10236 | 2213 | 0.216 | 0.214073 | 0.226236 | 0.20191 |
| Week 17 | 10236 | 2075 | 0.203 | 0.214073 | 0.226236 | 0.20191 |
| Week 18 | 10236 | 1815 | 0.177 | 0.214073 | 0.226236 | 0.20191 |
| Week 19 | 10236 | 1978 | 0.193 | 0.214073 | 0.226236 | 0.20191 |
| Week 20 | 10236 | 1809 | 0.177 | 0.214073 | 0.226236 | 0.20191 |
| Week 21 | 10236 | 2047 | 0.200 | 0.214073 | 0.226236 | 0.20191 |
| Week 22 | 10236 | 2515 | 0.246 | 0.214073 | 0.226236 | 0.20191 |
| Week 23 | 10236 | 2297 | 0.224 | 0.214073 | 0.226236 | 0.20191 |
| Week 24 | 10236 | 2479 | 0.242 | 0.214073 | 0.226236 | 0.20191 |
| total | 245664 | 52590 | 5.138 | | | |
| | | | | | | |
| | | | | | | |
| n | 10236 | | | | | |
| σ | 0.004054215 | | | | | |
| p-bar | 0.21407288 | | | | | |
| q bar | 0.78592712 | | | | | |
| ucl | 0.226235526 | | | | | |
| lcl | 0.201910234 | | | | | |

Total Defective (m): = 52590 m

Total Inspected (m): 10236* 24 = 245664m

Average Proportion Defective (p-bar):

**P –bar** = Total Defective (m)/ Total Inspected = 52590 m/245664m =0.21407288

Standard Deviation (σ) for proportions:

σ = square root (((p- bar (1- p bar))/n) = square root (((0.21407288 (1-0.21407288))/10236) = 0.004054215

UCL =p bar +3 σ =0.21407288 +3*0.004054215 =0.21407288 + 0.012162645 = 0.226235526

LCL = p bar- 3 σ = 0.21407288 -3*0.004054215 =0.21407288 - 0.012162645 =0.201910234

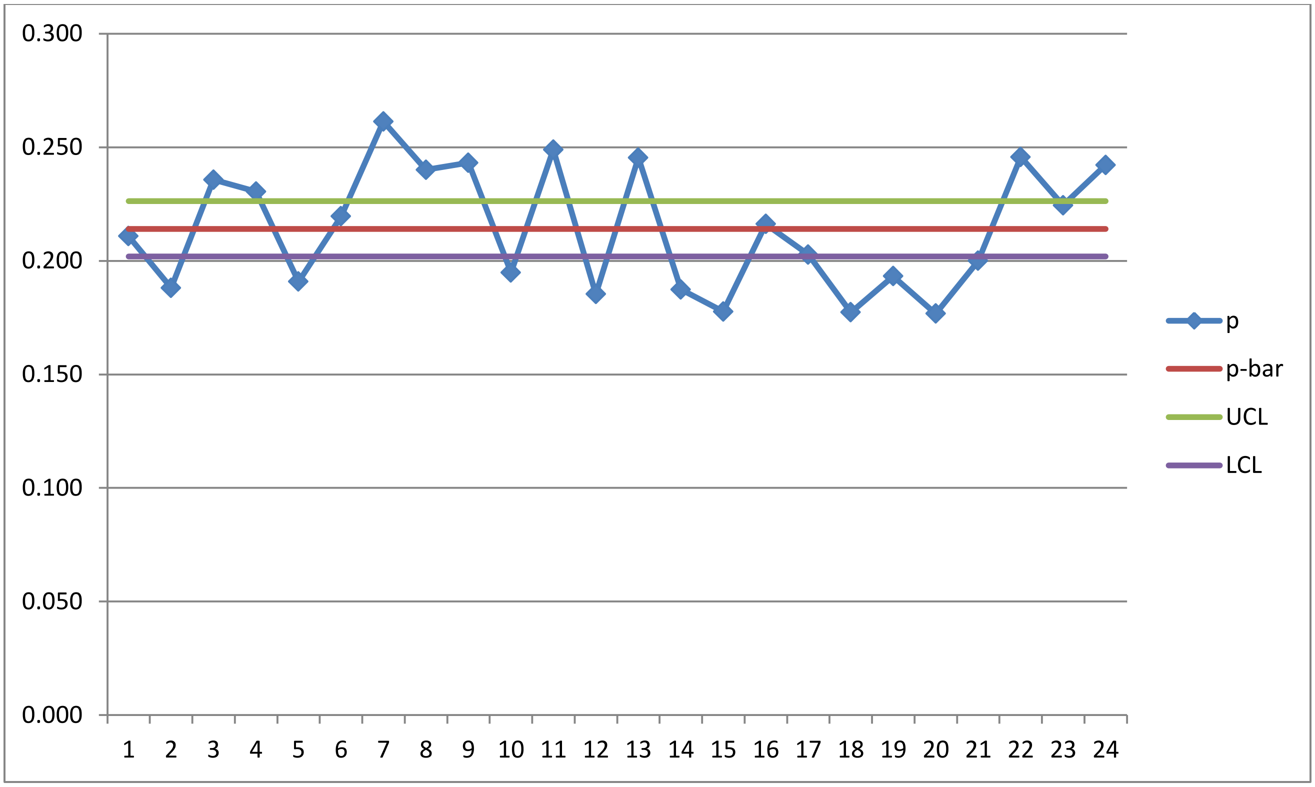



**Figure 7: p- control chart**

The "P Control Chart" presented above offers a statistical analysis of a production process spanning 24 weeks, focusing on ratio of defective things within a manufacturing environment.

This analysis details the P Control Chart for a production process over a 24-week timeframe, specifically tracking the ratio of defective things. Each week maintains a consistent sample size of 10,236 items, with the number of defects varying weekly between 1,809 and 2,675. The proportion of defective items is calculated for each week, ranging from 0.177 to 0.261. The overall average proportion of defects across all weeks is approximately 0.214073, indicating that about 21.41% of the inspected items are defective on average.

**Upper Control Limit (UCL)**: 0.226

this limit represents the maximum acceptable proportion of defects. If any data points exceed this limit, the processes are out of control limit

**Lower Control Limit (LCL)**: 0.202

This limit signifies the minimum acceptable proportion of defects. Data points falling below this limit indicate potential issues within the process.

The total number of defective items over the 24 weeks amounts to 52,590, which is the cumulative count of defects from a total of 245,664 inspected items, calculated based on the number of samples and their sizes.

**Standard Deviation (σ)**: 0.00405: this **σ** measures the ratio of defect variability, with a lower value indicating a more stable process.

**Variability:** The proportions of defects fluctuate weekly, with some weeks (like Week 7) showing significantly higher defect rates (0.261) compared to others (like Week 20, at 0.0.177).

Control Chart Interpretation: from the plotted, most of the weekly proportions fall out the UCL and LCL. Points outside these limits indicate that the process is not stable, and further investigation is needed.

**Stability vs. Performance:**

**Stability**: A process is stable if its variation is consistent over time, indicated by data points within the control limits. This means the process is predictable and operates under normal conditions.

**Performance:** Performance relates to how well the process meets quality standards (e.g., an acceptable defect rate). A process can be stable but still have a high average defect rate (p-bar).

Action Required:

Even the p-bar is not at the desired standard (the acceptable defect rate is lower than the calculated p-bar), it indicates that while the process is stable, it is not performing at the desired quality level.

Actions may be needed to improve the process quality, such as investigating root causes of defects, implementing quality improvement initiatives, or adjusting process parameters.

In summary, most of a process not stable, it requires improvement if the average defect rate (p-bar) does not meet the established quality standards. Continuous monitoring and improvement efforts are essential to enhance both stability and performance.

Control Limits

(UCL): 0.226

(LCL): 0. 0.202:

Weekly Proportions of Defects

Here’s the breakdown of the weekly defect proportions (p) and their relation to the control limits:

1. In Control Limits (between UCL and LCL):

- Weeks within limits: 1,6,16.17.23
- Total weeks in of control: 5 weeks

2. Out of Control Limits (either above UCL or below LCL):
    - Weeks above UCL: 3,4,7,8,9, 11, 13, 22, 24
    - Total weeks above UCL: 9 weeks
    - Weeks below LCL: 2,5, 10, 12, 14, 15, 18, 19, 20, 21
    - Total weeks below LCL: 10 weeks

This analysis reveals that many weeks fall outside the control limits, with several instances where the proportion of defects exceeds the acceptable threshold, indicating potential problems in the production process. The chart shows that most of the p values (proportion of defective items) consistently exceed the control limits, suggesting that the process is likely out of control. This situation indicates the presence of special causes of variation and insufficient process capability. Based on these findings, data analysis and root cause analysis will be conducted to identify the primary issue and its root causes, utilizing tools like the Pareto chart and Fishbone diagram.

**Table 18:** Defect frequency and percentage

| S/n | Defect type | Frequency | Defect %age | Cumulative percentage |
|---|---|---|---|---|
| 1. | Hole | 700 | 35% | 35 |
| 2. | Unevenness (thick and thin place) | 500 | 25% | 60 |
| 3. | Oil stain | 300 | 15% | 75 |
| 4. | Color inconsistencies | 200 | 10% | 85 |
| 5. | Big hole | 100 | 5% | 90 |
| 6. | Needle line | 50 | 2.5% | 92.5 |
| 7. | Sinker line | 50 | 2.5% | 95 |
| 8. | Needle broken | 40 | 2% | 97 |
| 9. | Loose yarn(tension variation) | 20 | 1% | 98 |
| 10. | Pilling | 20 | 1% | 99 |
| 11. | Shrinkage | 20 | 1% | 100 |
| | Total | 2000 | 100% | |

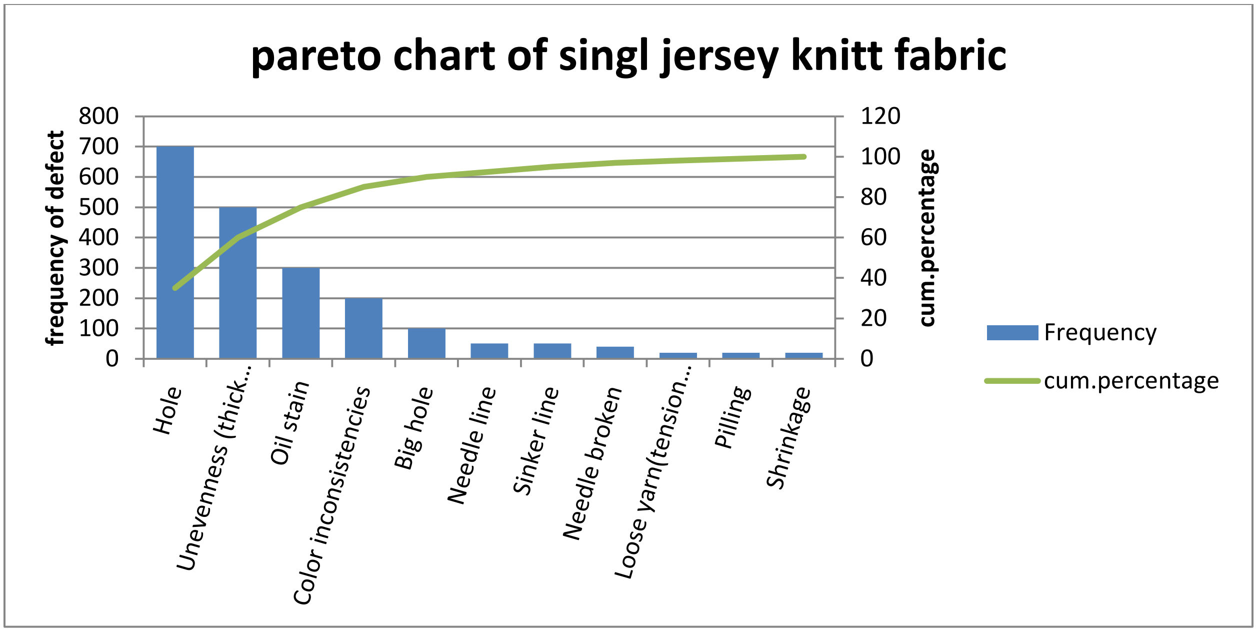



**Figure 8:** Pareto chart of single jersey fabric

According to the Pareto chart analysis of single jersey knit fabric, 75% of the effects arise from 27% of the causes, highlighting the most significant factors in the dataset that should be targeted for improvement efforts. Specifically, these 27% of causes include holes, unevenness (thick and thin areas), and oil stains, which require focused attention for enhancement.

**Fishbone diagram**

The fishbone diagram, is utilized to analyze the causes of problems associated with three primary defect sources in single jersey knit fabric production: holes, unevenness (thick and thin areas), and oil stains.

To determine the defects causes, we conducted interviews and focused group discussions, along with reviewing recorded data on quality and productivity and feedback from questionnaires for process analysis. This collaborative approach enabled us to gather insights from multiple stakeholders, resulting in a thorough understanding of the factors contributing to these issues.

**Analysis of Hole problem**

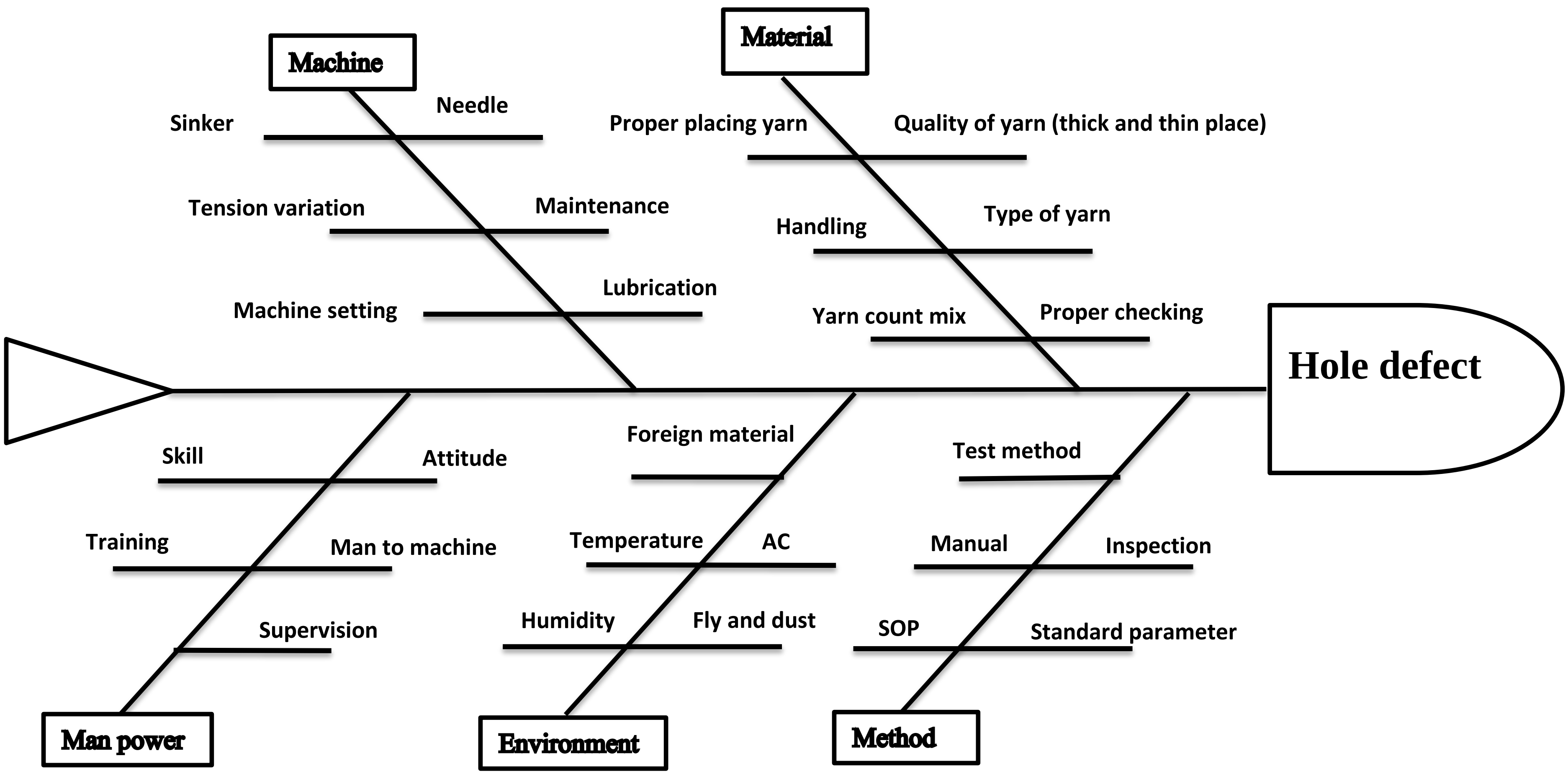



Figure 9: fishbone diagram hole

**Analysis of Unevenness (thick and thin place) problem**

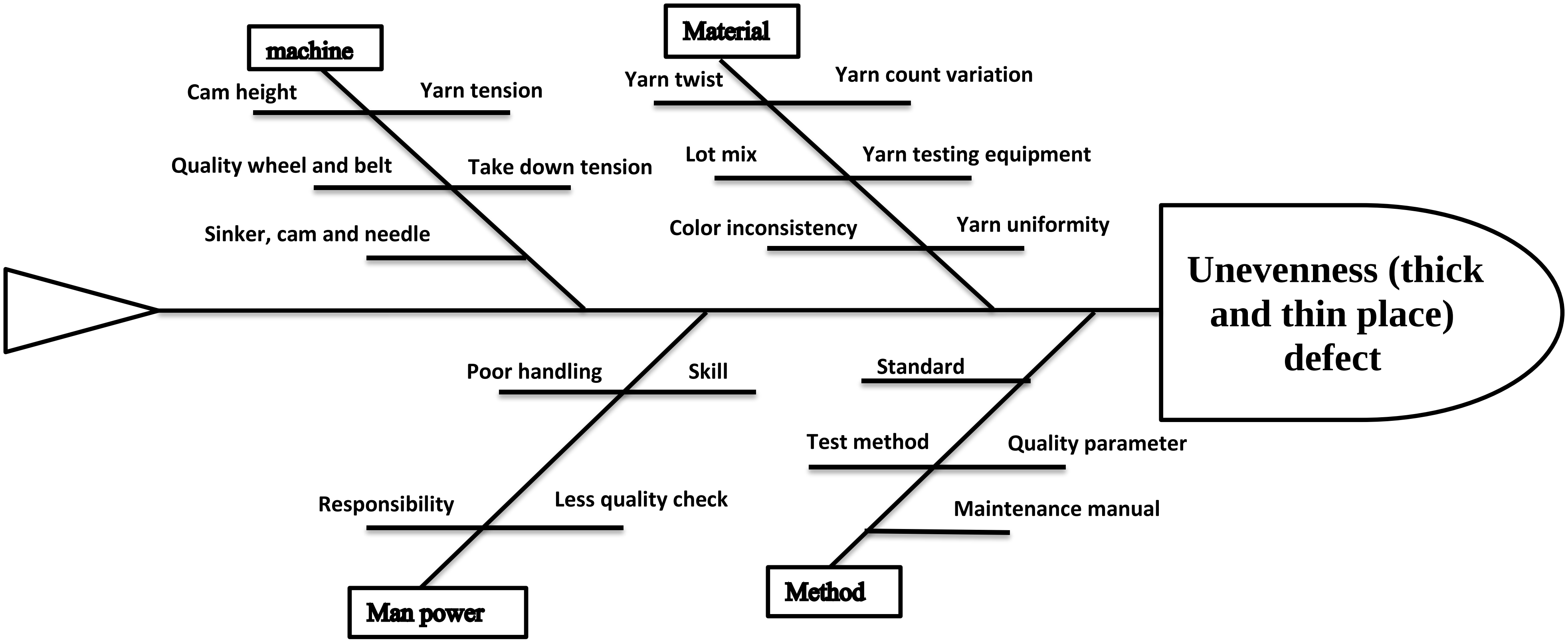



Figure 10: fishbone diagram of unevenness

**Analysis Oil stain problem**

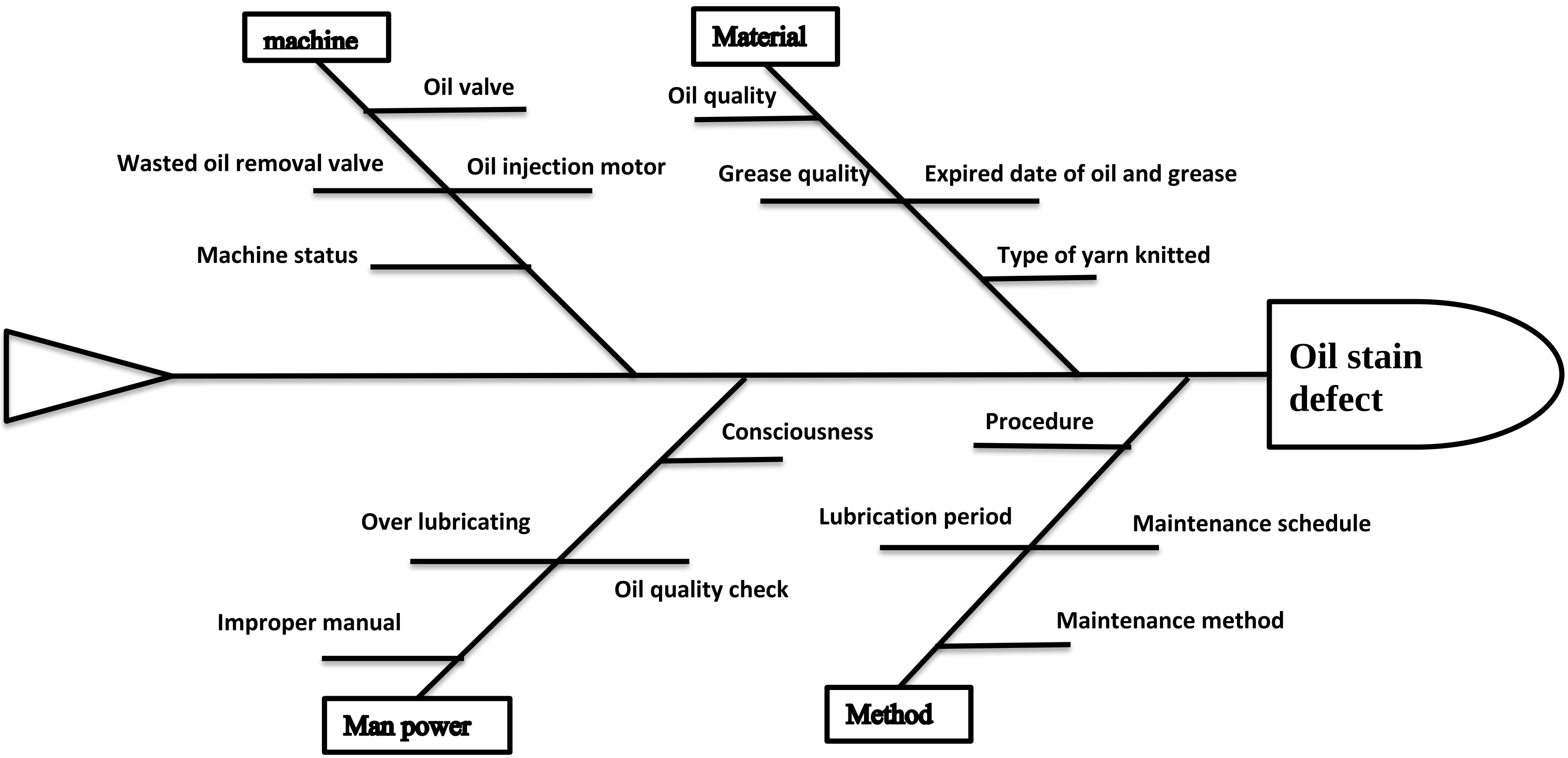



Figure 11: fishbone diagram oil stain

**Analysis of low productivity problem**

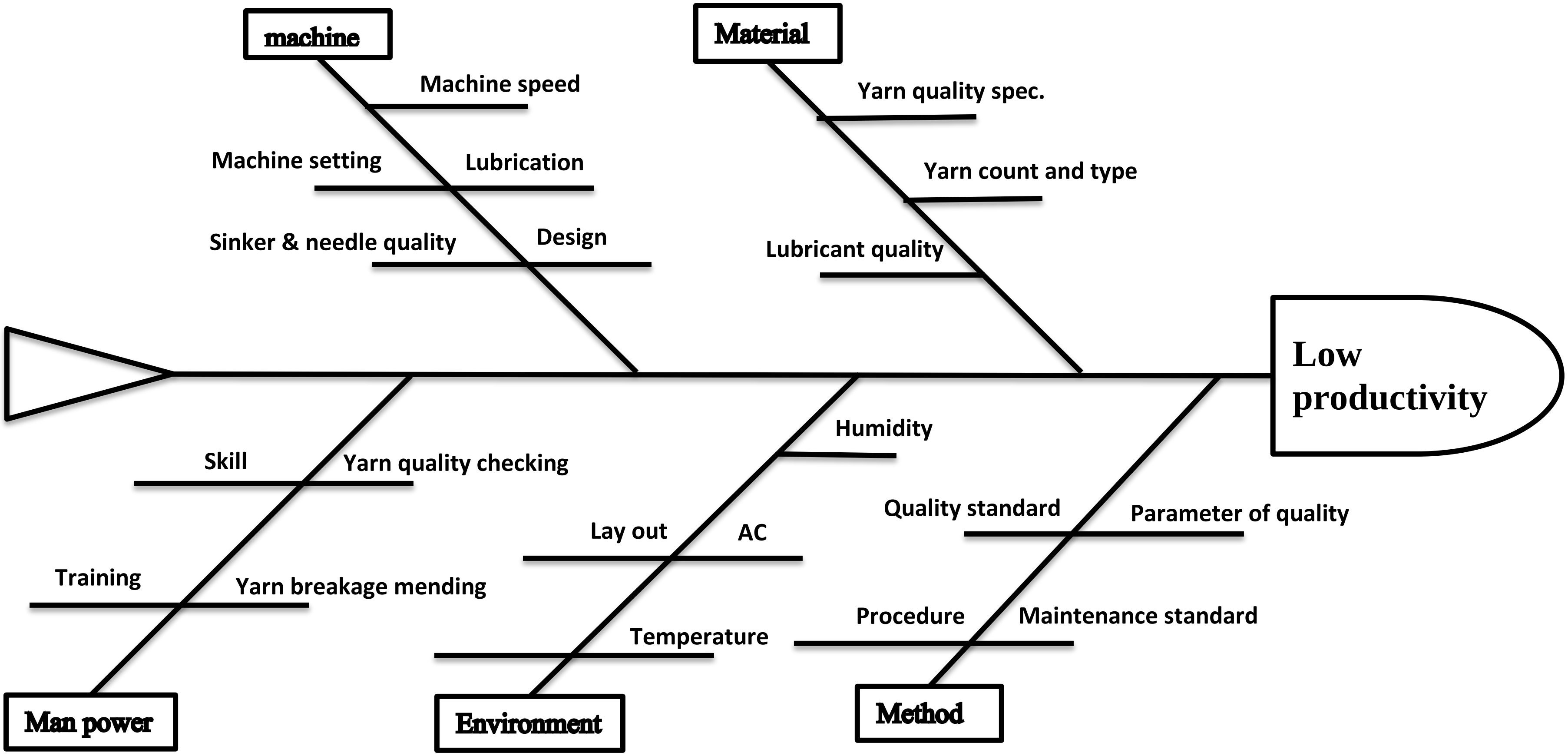



Figure 12: fishbone diagram productivity

**Impact matrix:** The Impact Matrix is a tool designed to evaluate and prioritize issues according to their degree of control and their effect on performance. It helps visualize where efforts should be concentrated based on their risk level. Impact Matrix guides strategic focus on actionable root causes. Together (Pareto chart, fishbone diagram and risk matrix), they enable effective identification and prioritization of the most impactful issues for resolution.

**Table 19:** Risk matrix of single jersey knitted fabric defect.

| Problem | Cause | Likelihood | Impact | Risk level |
|---|---|---|---|---|
| **Hole** | Quality of yarn (thin or thick place) | almost certain | major | high |
| | Yarn count mix | likely | major | high |
| | Yarn lot mix | likely | major | high |
| | Fly and dust (cleaning) | possible | minor | low |
| | Needle damaged | possible | moderate | moderate |
| | Carelessness of operator | possible | minor | low |
| | Yarn tension variation | possible | moderate | moderate |
| | Lubrication | Rare | minor | low |
| **Unevenness** | Yarn twist variation | possible | major | high |
| | Yarn tension variation | possible | moderate | moderate |
| | Yarn count mix | likely | major | high |
| | Yarn lot mix | likely | major | high |
| | Yarn uniformity | almost certain | major | high |
| | Color inconsistency | possible | minor | moderate |
| | Operator carelessness | unlikely | minor | low |
| | Quality parameter and standards | likely | major | high |
| **Oil stain** | Oil and grease quality | likely | major | high |

| | | | | |
|---|---|---|---|---|
| | Expired lubricant | unlikely | moderate | moderate |
| | Damaged oil valve | Possible | major | high |
| | Improper way manual lubrication | Unlikely | major | moderate |
| | Over lubrication | Possible | major | moderate |
| | Maintenance schedule and procedure | Possible | major | moderate |
| **Color inconsistency** | Lot mix of yarn | Likely | major | high |
| | Count mix of yarn | Likely | major | high |
| | Mix plan of fiber or mixing ratio | Likely | major | high |
| | Uniformity of yarn in color | Possible | major | moderate |
| **Big hole (press off )** | Operator carelessness | rare | major | High |
| | Yarn broken | Possible | moderate | Low |
| | Yarn sensor problem | Possible | major | high |
| **Needle line** | Needle damaged (bend) | Possible | major | high |
| | Needle broken | Rare | major | high |
| | Tension variation | Possible | Minor | low |
| | Dust and fly | Likely | moderate | moderate |
| **Sinker line** | Sinker damaged | Possible | major | high |
| | Sinker corrosion | Rare | Minor | low |
| | Dust and fly | Likely | moderate | low |
| **Tension variation (GSM** | Machine setting | Rare | major | Moderate |
| **variation)** | Twist variation of yarn | Likely | major | high |
| | Yarn tension variation | Likely | moderate | high |
| | Fabric takedown tension | Possible | Minor | low |
| **Pilling** | Yarn uniformity (thick and thin place) | Likely | major | high |

| | | | | |
|---|---|---|---|---|
| | Fiber length | Likely | major | high |
| **Shrinkage** | Winding tension | Possible | major | high |
| | Winding angle | Rare | moderate | low |
| | Non-uniform winding across fabric width | Possible | minor | low |

**FMEA (Failure Mode Effect Analysis):**

Potential failure modes of items or processes are identified and evaluated, along with their impact on performance, using a methodical approach. This method helps prioritize risks and carry out remedial measures to improve safety and dependability. It covers certain topics such as anticipated failure modes, consequences and severity, causes, Risk Priority Numbers (RPN), prospective failures, and preventive strategies. In order to do a Failure Mode and Effects Analysis (FMEA), all information pertaining to faults that transpired during the knitting process must be gathered.

S, which denotes severity in this context, represents the effect of a failure mode. The impact is ranked from 1 to 10, where 10 is the highest and 1 is the lowest. O stands for Occurrence, which denotes the failure mode's frequency. It is graded on a scale of 1 to 10, with 10 denoting the highest frequency. D stands for detection, which is rated on a scale of 1 to 10 and evaluates the capacity to recognize the failure mode during process control. Higher scores imply the opposite, whilst lower scores show that the failure mode is readily identifiable.

The mode's overall risk score is represented by the RPN, or Risk Priority Number. While a low RPN implies otherwise, a high RPN indicates that urgent action is required. RPN = S x O x D is the formula used to calculate it, where S stands for severity, O for occurrence, and D for detection.

| Problem | Potential cause of problem | Potential effect of failure mode | S | Potential cause of failure mode | O | D | RPN |
|---|---|---|---|---|---|---|---|
| Hole | Quality of yarn (thin or thick place) | Yarn breakage | 6 | Improper spinning | 4 | 3 | 72 |
| | Mix of yarn count | Yarn breakage and escaping of loop formation | 5 | Negligence of the operator | 4 | 3 | 60 |
| | Yarn lot mix | Yarn breakage and escaping of loop formation | 5 | Negligence of the operator | 3 | 3 | 45 |
| | Fly and dust (cleaning) | Accumulation on sinker and needle | 2 | Fun problem and Negligence of the operator | 2 | 1 | 4 |
| | Needle damaged | Missing of yarn | 4 | Long service time and lubrication | 2 | 2 | 16 |
| | Carelessness of operator | Mixing of yarn in count and lot | 2 | carelessness of the operator | 2 | 1 | 4 |
| | Yarn tension variation | Escaping of loop formation (floating) | 5 | Machine setting | 3 | 3 | 45 |
| | High friction on needle and sinker | Affect needle and sinker movement &become break | 5 | Oil valve problem and Negligence of the operator | 3 | 2 | 30 |
| Unevenness | Yarn twist variation | GSM variation | 5 | Improper spinning | 3 | 3 | 45 |
| | Yarn tension variation | Loop length variation | 4 | Machine setting | 3 | 2 | 24 |
| | Mix of yarn count | Not even appearance and variation of shade | 5 | Carelessness of the operator | 4 | 3 | 60 |
| | Mix of yarn lot | variation of Shade | 5 | carelessness of the operator | 3 | 3 | 45 |
| | Yarn uniformity | Poor appearance on fabric | 3 | Improper spinning | 3 | 3 | 27 |
| | Color inconsistency | Poor appearance on fabric & Shade variation | 4 | Improper spinning | 1 | 3 | 12 |
| | Operator carelessness | Mixed of yarn in count and lot | 2 | Negligence of the operator and unconsciousness | 2 | 1 | 4 |
| | Un fulfilling Quality parameter and standards | Yarn quality failure | 3 | unavailability of standard and parameter | 2 | 2 | 12 |
| Oil stain | Oil and grease quality | Flow out from the machine | 3 | Not Purchasing right quality level lubricant for the machine and needle | 3 | 4 | 36 |
| | Expired lubricant | Decrement of smoothing moving machine part and flow out the machine | 2 | Unavailability of right date lubricant | 1 | 3 | 6 |

| Problem | Potential cause of problem | Potential effect of failure mode | S | Potential cause of failure mode | O | D | RPN |
|---|---|---|---|---|---|---|---|
| | Damaged oil valve | Flow out from the machine | 5 | Maintenance problem | 2 | 3 | 30 |
| | Improper way manual lubrication | Spraying of oil on the fabric | 4 | Negligence of the operator & skill gap | 3 | 2 | 24 |
| | Over lubrication | Flow on the fabric | 5 | Negligence of the operator & skill gap | 3 | 3 | 45 |
| | Maintenance schedule and procedure | Malfunctioning of machine | 1 | unavailability of maintenance schedule and procedure | 2 | 1 | 2 |
| Color inconsistency | Lot mix of yarn | Shade variation | 2 | Negligence of the operator | 3 | 4 | 24 |
| | Count mix of yarn | Poor appearance on fabric & Shade variation | 3 | Negligence of the operator | 2 | 4 | 24 |
| | Mix plan of fiber or mixing ratio | Un uniform yarn in color and evenness | 2 | Unavailability of mix plan in spinning | 2 | 2 | 8 |
| | Uniformity of yarn in color | Poor appearance of fabric and shade variation | 3 | Ring spinning problem | 2 | 2 | 12 |
| Big hole (press off ) | Operator carelessness | Delayed of attending problem | 3 | Unconsciousness of operator | 2 | 1 | 6 |
| | Yarn broken | Needle doesn't form loop | 6 | Uneven yarn and low quality of yarn | 2 | 3 | 36 |
| | Yarn sensor problem | Machine does not stop | 3 | Maintenance problem | 2 | 2 | 12 |
| Needle line | Needle damaged (bend) | Escaping of catching yarn | 3 | Long usage and lubrication | 3 | 2 | 18 |
| | Needle broken | Yarn floating | 4 | Cleaning problem and miss matching yarn count and needle hook | 4 | 2 | 32 |
| | Tension variation | Uneven appearance on vertical | 2 | Machine setting | 2 | 2 | 8 |
| | Dust and fly | Accumulation on knitting zone | 1 | Fan problem and operator negligence | 2 | 1 | 2 |
| Sinker line | Sinker damaged | Uneven appearance on vertical | 3 | Long usage and lubrication | 3 | 2 | 18 |
| | Sinker corrosion | Corrosion mark | 1 | Cleaning and maintenance problem | 0 | 2 | 0 |

| Problem | Potential cause of problem | Potential effect of failure mode | S | Potential cause of failure mode | O | D | RPN |
|---|---|---|---|---|---|---|---|
| | Dust and fly | Accumulation on sinker and pushing of loop to the side | 1 | Fan problem and operator negligence | 3 | 1 | 3 |
| Tension variation (GSM variation) | Machine setting problem | Non uniform loop on horizontal | 2 | Setting standard problem in cylinder and quality wheel | 2 | 2 | 8 |
| | Twist variation of yarn | Non uniform loop on vertical | 3 | Ring spinning problem | 2 | 3 | 18 |
| | Yarn tension variation | Non uniform loop on vertical | 2 | Un equal needle height | 2 | 2 | 8 |
| | Fabric takedown over tension | Fabric shrinkage | 2 | Setting problem | 1 | 1 | 2 |
| Pilling | Yarn uniformity (thick and thin place) | Poor appearance on fabric | 3 | Ring spinning problem | 3 | 3 | 27 |
| | Short Fiber length | Form ball like structure on fabric surface | 4 | Opening and mixing problem on opener | 3 | 1 | 12 |
| Shrinkage | Winding tension | Decrease in fabric width | 3 | Operator carelessness | 3 | 2 | 18 |
| | Alignment of fabric spreader with Winding roller | Fabric bowing and skew ness | 2 | Machine setting problem | 2 | 1 | 4 |
| | Non-uniform winding across fabric width | Non uniform thickness on the fabric | 1 | Machine setting problem and maintenance problem. | 1 | 1 | 1 |

From the above table the higher RPN value shows that, it needs to improvement by taking corrective action for each cause. The potential cause with value of RPN greater than or equal to 18 is needs countermeasure for improvement.

**Analysis Unnecessary activity for quality sustaining**

One of the non- value adding activity is Unnecessary quality sustaining activity that is waxing of yarn which covers major portion of non-value adding activity and cause much movement time from one functional department to another functional department and cause of increasing other waiting time due to engaged of trolley and manpower due to limited number of trolley. Since they have no standards and ideas about which count must be passed on waxing process, they pass the yarn in waxing process that every (any) count of yarn, that results not only time loss but also there is unnecessary cost of power consumption and cost of wax and manpower salary.

**Analysis on Waiting**

Another non-value-adding activity is waiting time, which has several contributors. As noted in the time measurement, non-value-added time often overlaps with movement waste, including waiting for trolleys and searching for free trolleys from other departments (such as washing, spinning, garment, and storage). Waiting time issue addressed assembling essential enough trolleys and repair existing damaged ones according to their demand.

The fishbone diagram identifies potential causes and root causes of the main defect issues and low productivity. However, conducting a "why-why" analysis would be helpful to gain a deeper understanding of these causes beforehand.

**Verification:**

Root cause summary and root causes verification:

First, using information gathered from the quality inspection reports, the Pareto chart was utilized to determine the main flaws. A summary of the root causes was then produced after the identified primary issues' root causes were ascertained with the help of interviews, focused group discussions, and the fishbone diagram. The root cause analysis is described as follows because some situations have common causes that overlap with other cases, and a remedy for one is frequently a remedy for another.

Table 20: summarized root causes

| Types of Defect | Root cause |
|---|---|
| Hole | Quality of yarn (thick place and thin place of yarn in one cone) or unevenness of yarn |
| | Different yarn count mix in production |
| | Damaged needle due to long time working |

| Types of Defect | Root cause |
|---|---|
| | Fly and dust accumulation on knitting zone of sinker, needle and cylinder |
| Unevenness | Yarn twist variation along the feeder and over twist or under twist |
| | Yarn tension variation across the feeder |
| | Operator carelessness |
| | Yarn uniformity i.e. un even yarn throughout the length of yarn |
| | There is no quality parameter and standard for yarn quality |
| | Lot mixing of yarns |
| | Color inconsistency in the lot and across length of one cone |
| Oil stain | Oil and grease quality which does not recommended for knitting machine |
| | Use expired date of lubricant |
| | Damaged oil valve which out flows the oil on fabric |
| | Improper manual oiling on machine |
| | Over lubrication |
| | Maintenance schedule and procedure |
| Low productivity | Low yarn quality i.e. low strength of yarn |
| | High temperature on production room which is cause of yarn breakage |
| | Lack of standard operating procedure |
| | Machine setting i.e. quality wheel, cylinder and take down tension |
| | Operator skill for attending broken yarn |

Along with data analysis, maintenance staff, senior operators, and quality inspectors are essential in determining the underlying causes of issues. But it's crucial to acknowledge that their viewpoints could be shaped by their own prejudices and presumptions. As a result, it is crucial to use interviews to involve a wide range of stakeholders in the problem-solving process, including employees with varying levels of experience, operational managers, planners, quality heads, production heads, supervisors, and internal customers (such as heads and supervisors of washing and garment production). This guarantees that all points of view are taken into account, resulting in the most accurate and thorough investigation of the primary issue and its underlying causes.

Furthermore, using data and other impartial information sources can support the validity of the underlying issues that people have recognized. Higher-level management has verified the main flaws and underlying causes. Additionally, before putting countermeasures in place, these reasons were confirmed by thorough visual inspections, random sampling, and Gemba walks, with additional backing from a management verification letter.

ERCO Textile

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SAMSON CHERNET (ERCO TEXTILE AND GARMENT

Date ---20/03/2025
Liyew workie
Assistant Researcher

**Subject: Validation of Defects and cause of low productivity in Single Jersey Knit Fabric**

**Dear liyew**

This letter serves to validate the quality and productivity issues identified in the single jersey knit fabric following our recent evaluation. The major defects noted include holes, unevenness, and oil stains and cause of low productivity includes machine efficiency, labor productivity, material utilization and raw material quality productivity.

Our validation process involved visual inspections and collecting samples from multiple batches. The results showed that of the samples were affected by the stated defect issues and cause of low productivity which were documented through photographs and user testimonials.

The presence of these defects and cause of low productivity poses a risk to product quality and customer satisfaction. I recommend implementing immediate corrective measures and a review of our quality control protocols.

Should you need further clarification or additional information, please do not hesitate to reach out.

Sincerely,

Senay Mehari
Deputy General Manager / Operation
ERCO textile and Garment /Samson Cherenet
Phone: 251 11 663 40 81

ERCO TEXTILE AND GARMENT : TEL.No +251-221-12-52-30/31, +251- 12-43-23, Email: ------

**Integration:**

Integrating systems means creating a cohesive and interconnected environment where all elements work together to optimize quality and productivity. It's about breaking down silos and fostering seamless communication and collaboration across all stages, from design to delivery.

Therefore, based on the identified main problem in Pareto analysis and root cause of main problem in fishbone diagram, where the problem happen, how the problem happen, who is responsible and required things for solving problem are identified and determined.

Apart from this, to be the solution is effective and efficient and to create responsiveness, integration of department based on problem and root cause is summarized as follows by merging issues.

Table 21: Summarized issue and concerning department

| S/n | Issue | Concerned department |
|---|---|---|
| **1.** | Yarn quality | Operational manager, spinning, planning, knitting production, and procurement. |
| **2.** | Machine setting | Knitting, planning, maintenance department and technical department |
| **3.** | Lubrication quality | Procurement, planning, technical department and maintenance department |
| **4.** | Man power skill and attitude | Human resource, knitting production department and planning |
| **5.** | Environment | Technical department, knitting production, planning |
| **6.** | SOP, standard, procedure, parameter and maintenance schedule | Operational manager, planning and knitting production |

## Improvement:

The fourth phase of DMAIC focuses on improvement. During this phase, existing defect types are identified, and their root causes are examined using tools such as the Pareto chart and fishbone diagram. Countermeasures are then devised for each root cause to reduce variation and defects. The implementation of these countermeasures is detailed using the 5W1H method, which covers who, what, when, where, why, and how, ensuring clarity and effectiveness throughout the process.

**Table 22: Why Why Analysis**

| Problems | Why 1 | Why 2 | Why 3 | Why 4 | Why 5 |
|---|---|---|---|---|---|
| Hole | Quality of yarn (thick place and thin place of yarn in one cone) or unevenness of yarn | Spinning does not maintain quality of yarn | Machine setting and quality of fiber problem | Fiber quality | No standard form and mix plan of for spinning |
| | Different yarn count mix in production | put the yarn on the creel without care | Yarn not put in separate way | Negligence of the employee | There is no kaizen |
| | Damaged needle | due to long time working | Not properly lubricate | No schedule and Oil problem | No SOP |
| | Fly and dust accumulation on knitting zone of sinker, needle and cylinder | Machine fan fun problem and not cleaned | Operator carless ness | Lack of soft skill and technical training | Lack of training schedule |
| unevenness | Yarn twist variation along the feeder and over twist or under twist | Due to mixed of deferent lot and count | Spinning machine setting problem | Not use yarn twist parameter standard | Prepare yarn twist parameter standard |
| | Yarn tension variation across the feeder | Machine does not set in proper way | Skill gap and mechanic negligence | Training and parameter not available | Standard parameter setting. |
| | Operator carelessness | Skill gap and attitude problem | Training not given | No training schedule | Prepare training schedule skill development |
| | Yarn uniformity i.e. un even yarn throughout the length of yarn | Spinning machine problem | Fiber quality problem | Waste mixing problem | Set and prepare mix plan |
| | There is no quality parameter and standard for | Quality parameter and standard not known | Yarn quality parameter and standard not well defined and set with | No technical skill and knowledge | Give training and prepare standard and parameter |

| | | | | | |
|---|---|---|---|---|---|
| | yarn quality | | numerical value | | |
| | Lot mixing of yarns | Yarn not sorted based on count, color and yarn type | Operator carelessness and skill gap | Soft skill training not given and 5s and kaizen not implemented | Give training and implement 5s and kaizen |
| | Color inconsistency in the lot and across length of one cone | Color mix and lot mix | Mixing of waste problem and machine setting | No standard mix plan | Prepare mix plan and set standard |
| Oil stain | Oil and grease quality which does not recommended for knitting machine | Procurement problem | Not now the quality of oil and grease for knitting machine | No specification for oil and grease for the machine | Prepare specification for grease and oil that recommended |
| | Use expired date of oil | Not available oil that is not expired and operator carless ness | Procurement and negligence of operator | Finance problem and training gap | Plan budget for oil and give training |
| | Damaged oil valve which out flows the oil on fabric | Maintenance problem and inventory problem | No schedule maintenance and purchasing problem | Skill gap off mechanic and budget | Fill by training and purchase the new one and replace |
| | Improper manual oiling on machine | Not follow SOP and standards | There is no SOP | Skill gap for preparing SOP | Preparing SOP and follow up it |
| | Over lubrication | Oil and grease viscosity problem, operator carless ness and no schedule of manual lubrication | Low viscos oil and grease and negligence schedule by operator | Purchase problem and attitude gap | Prepare specification and follow schedule lubrication |
| | Maintenance schedule and procedure | No maintenance plan and schedule | Not prepared | Skill gap | Give training and prepare maintenance schedule and procedure |
| Low productivity | Low yarn quality i.e. low strength of yarn | Low strength of yarn | Machine setting problem | No standard RKM of yarn fiber quality problem | Set standard RKM of yarn and prepare mix plan of fiber production in waste recycling |

| | | | | | |
|---|---|---|---|---|---|
| | High temperature on production room which is cause of yarn breakage | The room is not humidify | Not spry water on the room or no AC | | Spray water in the room or install AC in the room |
| | Lack of standard operating procedure | Not prepared yet | | | Prepare SOP and follow properly |
| | Machine setting i.e. quality wheel, cylinder and take down tension | No standard setting and carelessness of mechanic | Skill gap of mechanic | | Train the mechanic and prepare standard procedure |
| | Operator skill for attending broken yarn | Skill gap | | | Train the operator in class and on job |

Table 22: 5W1H of the improvement

| What? Types defect | Why? Root cause | How? Counter Measure | How should it be done | Where? Should it be done? | Who? Should be responsible? | When? should it be Done |
|---|---|---|---|---|---|---|
| Hole | Quality of yarn (thick place and thin place of yarn in one cone) or unevenness of yarn | Prepare yarn quality parameter | Set the machine according to parameter and follow up | Spinning production department | Spinning production head | 10-feb-2025 |
| | Different yarn count mix in production | Use 5s and | Sort the yarn based on the yarn count, color and yarn type | Knitting production and spinning production | Knitting and spinning production supervisor and operator and researcher | 10-mar-2025 |
| | Damaged needle due to long time working | Prepare maintenance schedule standard | Maintenance the machine based schedule and standard | knitting production | Knitting machine maintenance and supervisor | 2-Apr-2025 |
| | Fly and dust accumulation on knitting zone of sinker, needle and cylinder | Prepare maintenance schedule | Clean the machine using air based on schedule | Knitting production | Operator and mechanic | 2-Apr-2025 |
| Unevenness | Yarn twist variation along the feeder and over twist or under twist | Prepare yarn quality parameter | Set the machine according to parameter and follow up | Spinning production department | Spinning production head | 10-feb-2025 |
| | Yarn tension variation across the feeder | Set the machine needle height equal | Use the yarn tension setting standard according to yarn count and twist | In knitting machine of knitting production | Mechanic and researcher | 15-feb-2025 |
| | Operator carelessness | Prepare training | Give training soft skill | Knitting | The researcher | 19-feb- |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | and quality maintenance | production | | 2025-28-feb-2025 |
| | Yarn uniformity i.e. un even yarn throughout the length of yarn | Prepare yarn quality parameter | Set the machine according to parameter and follow up | Spinning production department | Spinning production head | 10-feb-2025 |
| | There is no quality parameter and standard for yarn quality | Identify yarn quality parameter and standard | Prepare yarn quality parameter and standard | Knitting production | Knitting production head and researcher | |
| | Lot mixing of yarns | Use 5s and kaizen | Sort the yarn based on the yarn count, color and yarn type | Knitting production and spinning production | Knitting and spinning production supervisor and operator and researcher | 10-mar-2025 |
| | Color inconsistency in the lot and across length of one cone | Prepare raw material mix plan | Sort the raw material according to yarn type, color and quality | Spinning production department | Spinning supervisor and production head | 13-feb-2025 |
| Oil stain | Oil and grease quality which does not recommended for knitting machine | Set quality standard specification for oil and grease | Purchase according to the standard specification | Procurement | Purchaser and mechanic | 15-feb-2025 |
| | Use expired date of oil | Change the oil that is not expired | Check the expired date of oil | knitting production | Knitting mechanic and store keeper | 16-feb-2025 |
| | Damaged oil valve which out flows the oil on fabric | Change damaged oil valve | Remove the damaged oil valve and fix new one | knitting production | Knitting mechanic | 15-feb-2025 |
| | Improper manual oiling on | Follow sop and | Preparing SOP and | Knitting | Researcher and | 5-mar- |

| | | | | | | |
|---|---|---|---|---|---|---|
| | machine | standards | Standard | production | operator | 2025 |
| | Over lubrication | Lubricate based on schedule and standard | Prepare lubrication schedule | Knitting production | Operator and researcher | 5-mar-2025 |
| | Maintenance schedule and procedure | Prepare maintenance schedule based on production and yarn type | Perform maintenance based one the prepared standard | Knitting production | Researcher, mechanic and production supervisor | 23-mar-2025 |
| Low productivity | Low yarn quality i.e. low strength of yarn | Prepare yarn quality parameter | Set the machine according to parameter and follow up | Spinning production department | Spinning production head | 11-feb-2025 |
| | High temperature on production room which is cause of yarn breakage | Humidify the production room | Spry water on the production room | Knitting production | Knitting production supervisor and mechanic | Depends on |
| | Lack of standard operating procedure | Prepare SOP | Preparing SOP and follow properly | Knitting production | Operator and researcher | 10-Ap-2025 |
| | Machine setting i.e. quality wheel, cylinder and take down tension | Set the machine properly | Setting the machine based on standard and fabric structure and quality | Knitting production | Mechanic and researcher | 22-feb-2025 |
| | Operator skill for attending broken yarn | Train the operator | Prepare training session and give training on job and class | Knitting production | HRM and researcher | 19-feb-2025-28-feb-2025 |

The improvement stage is a vital part of the DMAIC framework, focusing on implementing actionable changes to address the identified issues. During this phase, gathering feedback is crucial for continuously evaluating the effectiveness of the implemented solutions. After generating potential solutions and identifying root causes, the next step is to validate these causes to confirm their significance.

Once the root causes are confirmed, the most effective solutions are selected based on thorough data analysis. This is followed by creating a comprehensive implementation plan to ensure the chosen solutions will be effective. Tracking the progress of these solutions is crucial, as it enables necessary adjustments and refinements to ensure that the desired outcomes are met.

**TRAINING**

Training given under the topics of raw material utilization and material handling in knitting section for 17 (11 female and 6 male) workers from different positions (like team leader, operator, and maintenance person and quality inspection. Basic content of the training was:

| s/n | Training type | Duration | Date |
|---|---|---|---|
| 1. | Mix plan | 2.5 day | 5-7-feb-2025 |
| 2. | Fabric realization | 3 day | 12-14-feb-2025 |
| 3. | Quality control in knitting | 4.5 day | 6-10-mar-2025 |
| 4. | Factor affects raw material utilization | 2 day | 15-16-feb-2025 |
| 5. | Cause of hard wastes, invisible loss and control methods | 2.5 day | 1-3-mar-2025 |
| 6. | Cone arrangement according to yarn count and fiber type | 0.5 day | 4-mar-2025 |
| 7. | 4 point grading quality inspection system. | 2 day | 22-23-feb-2025 |
| 8. | Maintenance concepts | 3 day | 18-20-feb-2025 |
| 9. | 5S (first kaizen) and muda(waste) | 3.5 day | 25-28-feb-2025 |
| 10. | Quality standard and parameter | 2 day | 9-10-feb-2025 |

Figure 13:  training for employee

**Implementation of 5S in the Improve Phase of DMAIC**

The 5S methodology is a crucial element of the "Improve" phase within the DMAIC framework. The five pillars of 5S—Sort, Set in Order, Shine, Standardize, and Sustain—aim to create an organized, efficient, and visually controlled work environment. Below is a detailed examination of how these activities were implemented in the workplace and their relationship to DMAIC:

1. **Sort (Seiri)**

The first step involves identifying and separating necessary items from unnecessary ones. A thorough evaluation of the workspace was conducted, allowing team members to categorize tools, materials, and equipment. Unneeded items were removed, minimizing clutter and ensuring that only essential items remained accessible. This sorting process laid the foundation for enhanced efficiency by making it easier to locate necessary resources quickly.

Figure 14 yarn stored in wrong manner

Before

**2. Set in order**

After the sorting was finished, the next step was to organize the remaining items in a logical and efficient way. This involved organizing tools and materials by frequency of use and function. Visual aids, such as labels and color codes, were implemented to ensure that everything had a designated place. This organization not only streamlined workflows but also reduced the time spent searching for items, thereby enhancing productivity.

After

Figure 15 Yarn on skid

**3. Shine**

The Shine phase emphasized cleanliness and maintenance. Regular cleaning schedules were implemented, and team members were assigned responsibility for their respective work areas. This initiative helped identify any equipment issues early on and fostered a sense of ownership among employees. A clean workspace not only promotes safety but also contributes to a positive work environment, reinforcing the commitment to quality.

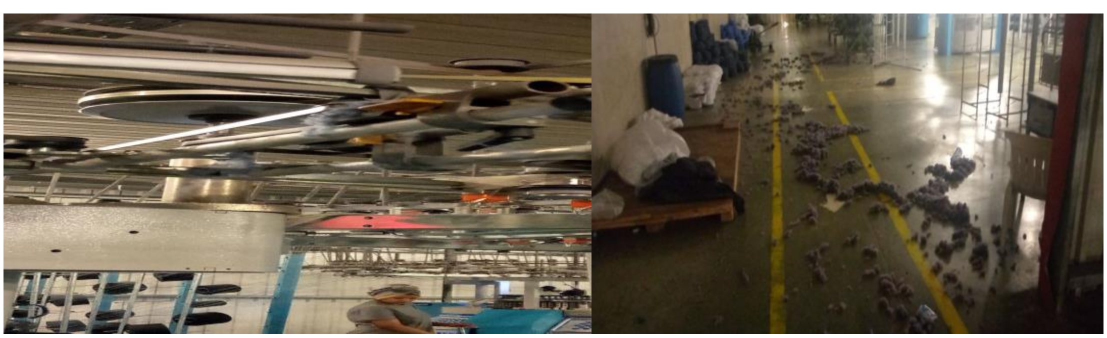


**Figure 16** cleaning of dust from machine

4. **Standardize:**

Standardization was introduced to guarantee consistent adherence to the practices established in earlier steps. This included developing clear Standard Operating Procedures (SOPs), checklists, setting Key Performance Indicators (KPIs), and forming Cross-Functional Teams. Guidelines were also created to maintain organization and cleanliness, along with visual management tools like signs, labels, and color-coded systems to clarify and make standards easily accessible. Training sessions were held to inform employees about the significance of these standards and how to uphold them. By implementing uniform practices, the organization aimed to ensure long-term sustainability of improvements.

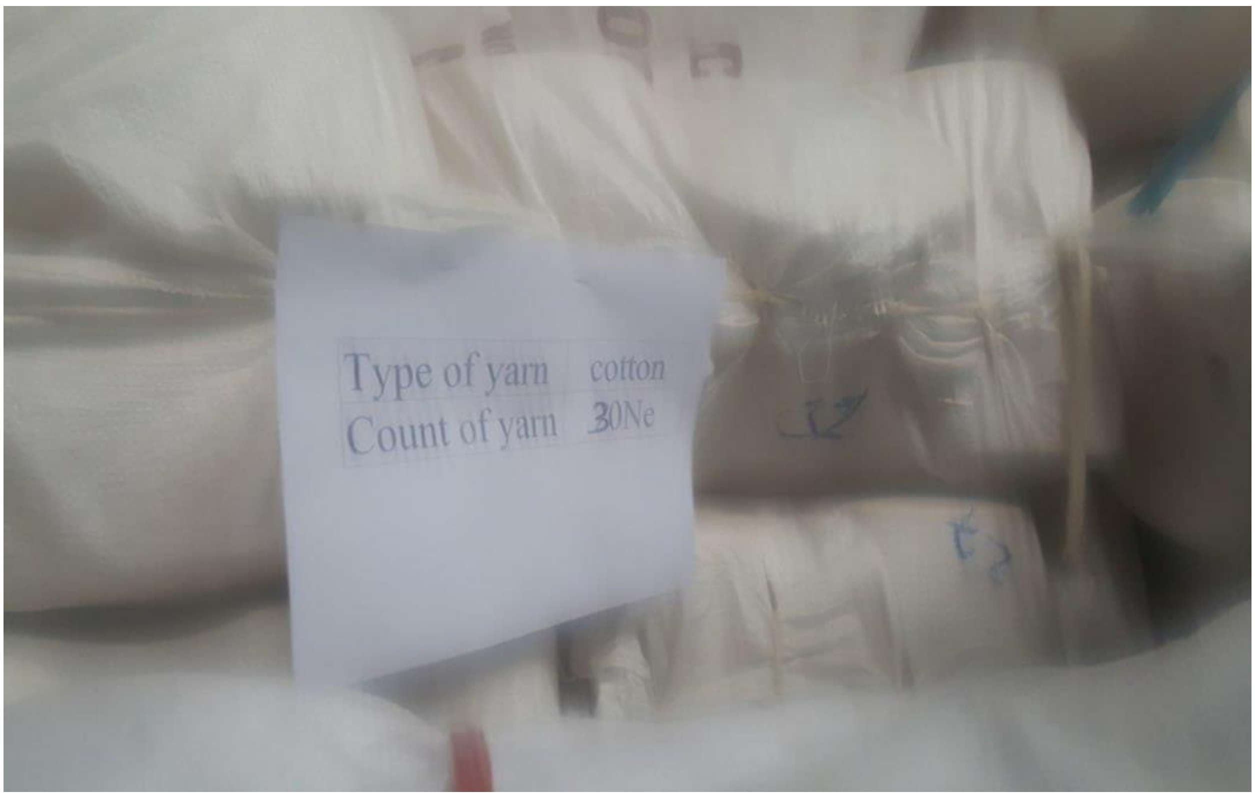



**Figure 17:** labeling of items

5. **Sustain (Shitsuke):**

The final step focuses on sustaining the improvements achieved through continuous commitment and discipline. Regular audits and reviews were planned to evaluate compliance with the 5S practices. Feedback mechanisms were implemented to promote ongoing improvement and to tackle any challenges that emerged. By cultivating a culture of accountability and discipline, the organization sought to ensure that the benefits gained from 5S would be preserved. Standard

Operating Procedures (SOPs) were adhered to, and adherence to these procedures was practiced and assessed as part of the improvement process.

## Improved COPQ

After implementation of countermeasure  based on the identified costing issue or are the cost of poor quality is decreased from 2,338,789.38to 1,386,000.06 with the difference of 952,789.32 birr. This reduction implies that countermeasure is effective by removing unnecessary costing issue.

**Table 23:** improved cost of poor quality

| S/n | Quality cost area | Existing cost | Before Cost (birr) of 6 month | After Cost (birr) of 3 month |
|---|---|---|---|---|
| 1. | Preventive cost | Steaming of yarn and waxing | 144,000 | 43274 |
| 2. | Internal failure cost | Re work to spinning and scrap | 90,000 | 30000 |
| | | Process loss | 2,236,125 | 778061.25 |
| | | Down time cost(labor + electric + production loss) | 859,013.75 | 141304.81 |
| | | Spare part(needle) | 973,440 | 243360 |
| 3. | External failure cost | Return and discounted selling | 375,000 | 150000 |
| Total | | | 4,677,578.75 for 6 month and 2,338,789.38 for 3 month | 1,386,000.06 |
| Difference | | | 2,338,789.38-1,386,000.06=952,789.32 | |

Thus, the total cost of poor quality is the sum of the aforementioned quality cost areas. In other words:

Total COPQ = Prevention Costs + Internal Failure Costs + External Failure Costs.

=43274+ (30000+778061.25+141304.81+243360) +150000 = 1,386,000.06

**Improved Defect percentage single jersey knit fabric**

Based on measuring of system re analysis, after implementation of corrective action the defect rate of single jersey knit fabric dropped from 17.96% to 9.72%. This significant reduction indicates that the intervention successfully addressed the root causes of the defects.

**From 3 month quality report:**

Total produced fabric = **123826.28 kg**

Total number of defect **= 12031.85 kg**

Total opportunity = opportunity per unit* total production= 11*123826.28 =1362089.08

Defect Rate (D):

D= (number of defect/total produced fabric)*100 = (12031.85/123826.28)*100 =9.72%

DPMO= [total number of defects / (total product *opportunity per unit)]*$10^6$

= [12031.85/ (123826.28 *11)] *$10^6$ =8833.4

Using Six Sigma tables, a DPMO of 8,833.4 falls between a DPMO of 9,322 (2.6 sigma) and 6,934 (2.7 sigma), indicating a company sigma level of 2.68 σ without accounting for a 1.5 σ shift. Additionally, this DPMO is also situated between 10,724 (3.8 sigma) and 8,197 (2.9 sigma), resulting in a sigma level of 3.83 σ when considering the 1.5 σ shift.

Prior to implementing corrective actions, the defect rate for single jersey knit fabric was 17.96%, meaning 18 out of every 100 units produced were defective. After the countermeasures were applied, this rate significantly dropped to 9.72%, indicating that approximately 10 out of every 100 units were now defective. This substantial reduction demonstrates the effectiveness of the corrective actions in enhancing product quality and productivity.

The successful identification and resolution of the root causes of defects resulted in a marked decrease in the number of defective single jersey knit fabrics produced. Based on the data, we can confidently conclude that the intervention effectively reduced the defect rate and improved overall quality and productivity.

Furthermore, the sigma level increased from 1.36 to 2.68 without accounting for a 1.5 sigma shift, signifying a more consistent and reliable process operating within a narrower range of acceptable variations. When the 1.5 sigma shift is taken into account, the sigma level rose from 2.32 to 3.83, further highlighting significant improvements in reducing variations and increasing stability in the production process.

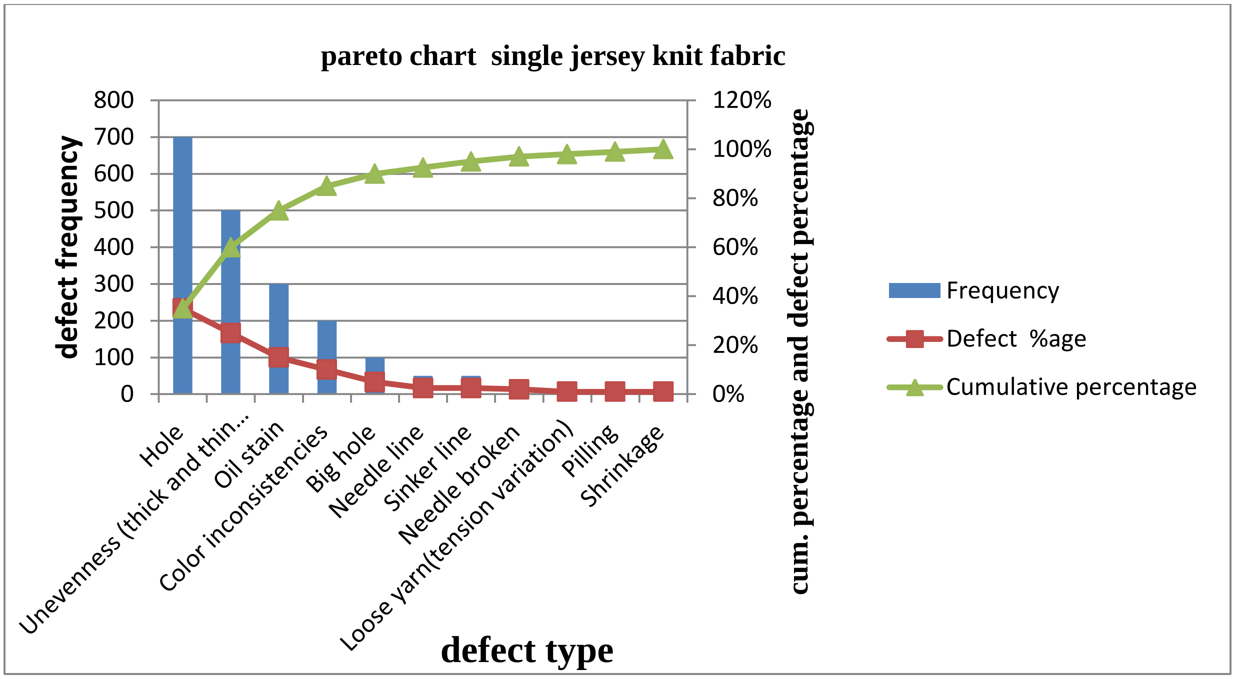
**Improved Defect types Frequency and its percentage single jersey knit fabric**

Following a thorough quality inspection conducted over three months after implementing improvements, there has been a significant reduction in both the frequency and percentage of defect types in single jersey knit fabric. This positive change is a direct result of the corrective actions taken to address the identified root causes and their corresponding countermeasures.

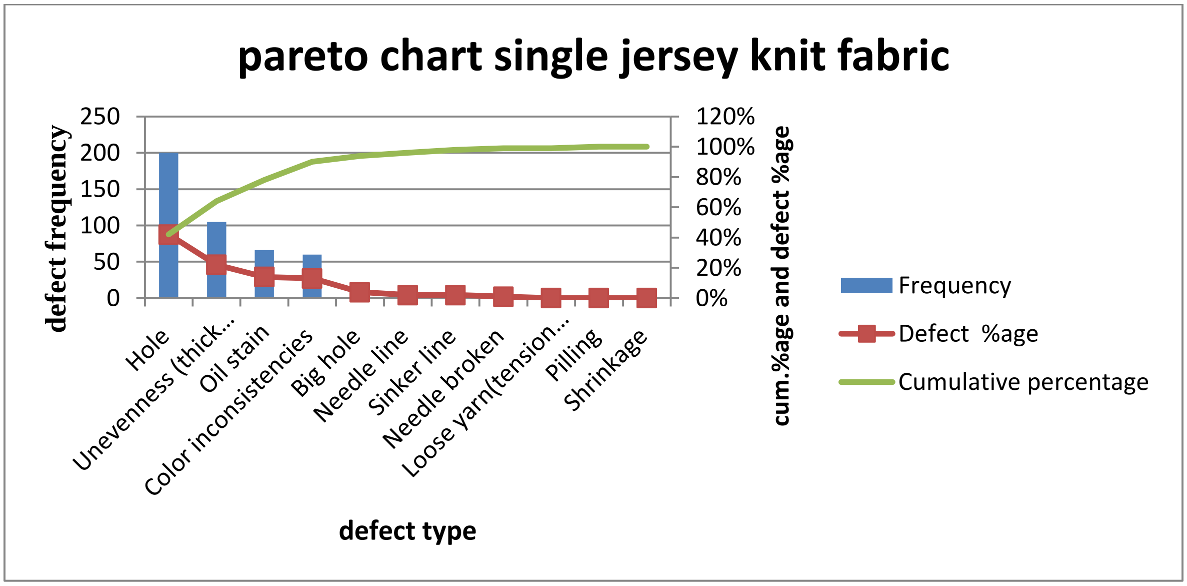
The data indicates that the focused efforts to rectify the issues have led to enhanced product quality. By systematically tackling the root causes of defects, we have not only minimized the occurrence of defects but also improved overall production standards. This improvement underscores the effectiveness of the interventions and highlights our commitment to continuous quality enhancement in the manufacturing process of single jersey knit fabric.

**Table 24:** Improved Defect types Frequency and its percentage single jersey knit fabric

| | | Before improvement | | | After improvement | | |
|---|---|---|---|---|---|---|---|
| S/n | Defect type | Frequency | Defect %age | Cumulative percentage | Frequency | Defect %age | Cumulative percentage |
| 1. | Hole | 700 | 35% | 35 | 200 | 42% | 42% |
| 2. | Unevenness (thick and thin place) | 500 | 25% | 60 | 105 | 22% | 64% |
| 3. | Oil stain | 300 | 15% | 75 | 66 | 14% | 78% |
| 4. | Color inconsistencies | 200 | 10% | 85 | 60 | 13% | 90% |
| 5. | Big hole | 100 | 5% | 90 | 19 | 4% | 94% |
| 6. | Needle line | 50 | 2.5% | 92.5 | 11 | 2% | 96% |
| 7. | Sinker line | 50 | 2.5% | 95 | 9 | 2% | 98% |
| 8. | Needle broken | 40 | 2% | 97 | 3 | 1% | 99% |
| 9. | Loose yarn(tension variation) | 20 | 1% | 98 | 2 | 0% | 99% |
| 10. | Pilling | 20 | 1% | 99 | 2 | 0% | 100% |
| 11. | Shrinkage | 20 | 1% | 100 | 1 | 0% | 100% |
| | Total | 2000 | 100% | | 478 | 100% | 100% |




Before improvement




After improvement

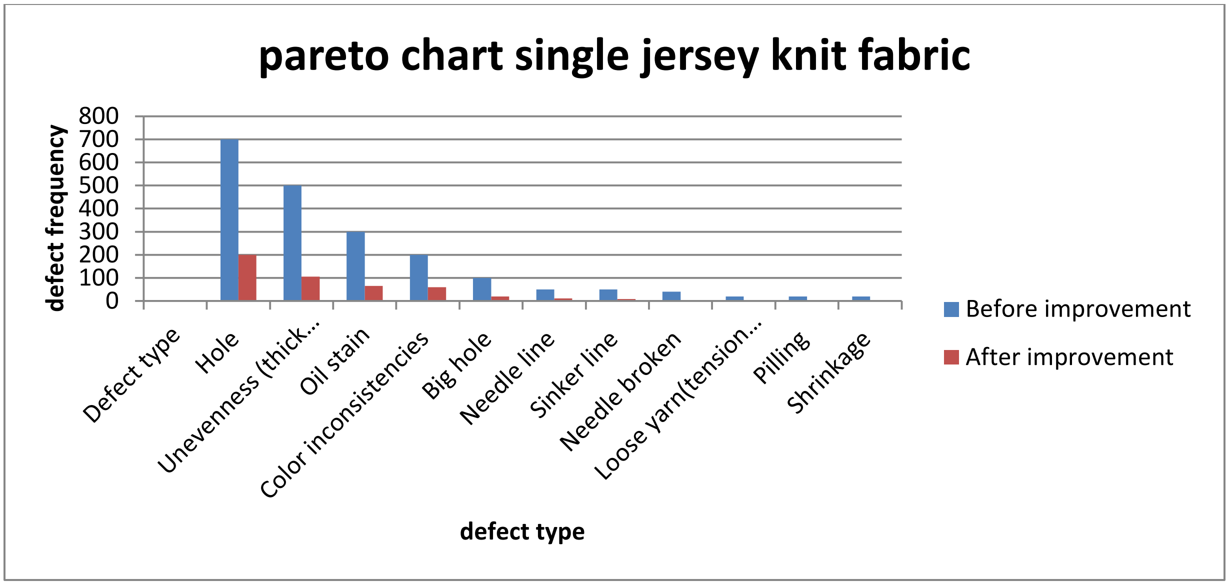



Figure 17 Pareto chart single jersey knit fabric

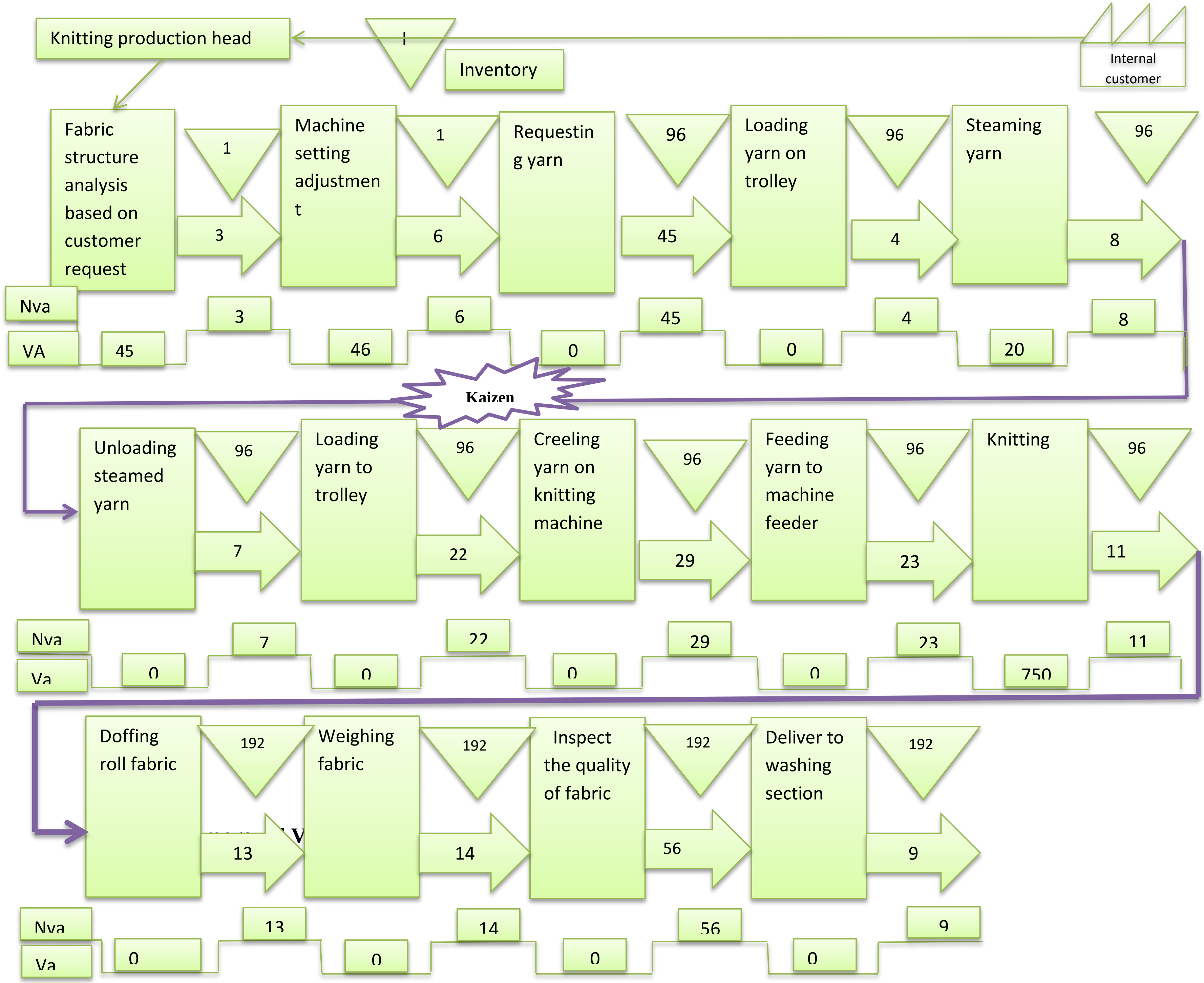
From the above chart, even if there is an improvement of defect frequency still the main problem from Pareto chart analysis of single jersey knit fabric 78% of problem come by 27% of the reason, which is the most significant factors in a dataset, to focus on further improvement efforts. That means the 27% cause are hole, Unevenness (thick and thin place) and Oil stain which needs to be focused for further improvement effort.

**Improved Value Stream Map for Single Jersey Knit Fabric Production**

Enhanced value stream map for single jersey knit fabric production results from, identifying and addressing wasteful steps within production processes. By prioritizing corrective actions for each identified waste—without relying on automation—we achieved notable improvements in efficiency and effectiveness.

The countermeasures implemented specifically targeted issues such as the waxing of yarn and excessive waiting times during knitting and transportation. The cost implications of wax use were significant, prompting a focused effort to reduce unnecessary expenses.

This research emphasized easily achievable solutions to remove waxing step and minimize waiting and transportation times while also enhancing productivity. By streamlining these processes, we not only reduced costs but also improved overall production efficiency. The revised value stream map reflects these changes, showcasing a more efficient workflow that prioritizes value-added activities and eliminates non-essential steps, ultimately leading to better results in fabric production.



Knitting production head
I
Inventory
Internal customer
Fabric structure analysis based on customer request
1
3
Machine setting adjustment
1
6
Requesting yarn
96
45
Loading yarn on trolley
96
4
Steaming yarn
96
8
Nva
VA
45
3
46
6
0
45
0
4
20
8
Kaizen
Unloading steamed yarn
96
7
Loading yarn to trolley
96
22
Creeling yarn on knitting machine
96
29
Feeding yarn to machine feeder
96
23
Knitting
96
11
Nva
Va
0
7
0
22
0
29
0
23
750
11
Doffing roll fabric
192
13
Weighing fabric
192
14
Inspect the quality of fabric
192
56
Deliver to washing section
192
9
Nva
Va
0
13
0
14
0
56
0
9

Based on the enhanced VSM and production process map for single jersey knit fabric production, the improved production cycle time (value-added time) is summarized in the following table:

Table 25: value stream mapping and Time measurement after improvement Summary:

| S/n | **Process summary** | **VAT** | **NVAT** | **Cycle time** | **NVAT** | |
|---|---|---|---|---|---|---|
| | | | | | **Movement** | **Waiting** |
| 1. | Fabric structure analysis based on customer request | 45 | 3 | 48 | 3 | |
| 2. | Machine setting adjustment | 46 | 6 | 52 | 4 | 2 |
| 3. | Requesting yarn | | 45 | 45 | 30 | 15 |
| 4. | Loading yarn on trolley | | 4 | 4 | | 1 |
| 5. | steaming yarn | 20 | 8 | 28 | | |
| 6. | Unloading steamed yarn | | 7 | 7 | 1 | 2 |
| 7. | Loading yarn to trolley | | 22 | 22 | 5 | 3 |
| 8. | Creeling yarn on knitting machine | | 29 | 29 | 4 | 2 |
| 9. | Feeding yarn to machine feeder | | 23 | 23 | 1 | |
| 10. | Knitting | 750 | 11 | 761 | 5 | |
| 11. | Doffing roll fabric | | 13 | 13 | 3 | |
| 12. | Weighing fabric | | 14 | 14 | 3 | 1 |
| 13. | Inspect the quality of fabric | | 56 | 56 | 10 | |
| 14. | Deliver to washing section | | 9 | 9 | 1 | 2 |
| Total time | | 861 | 250 | 1111 | 70 | 28 |

The above table non value add time of unnecessary quality sustaining process is totally removed after countermeasure was taken which is a nonproductive time.

Table 26: value-added and non-value added time after improvement summary

| | Before improvement | | After improvement | | Improved time |
|---|---|---|---|---|---|
| Activities | Time/minute | %age | Time/minute | %age | |
| Non value adding | 918 | 41% | 250 | 22.5% | 668 |
| Value adding | 1320 | 59% | 861 | 77.5% | 459 |
| Total | 2238 | | 1111 | | 1127 |

By minimizing movement time, eliminating unnecessary activities related to quality maintenance, reducing waiting times, acquiring additional trolleys, maintaining existing ones, and reorganizing the steamed yarn storage area, we effectively reduced time wastage.

The analysis data clearly compares activity and time measurements before and after the improvements. The cycle time decreased from 2,238 minutes to 1,111 minutes, resulting in a significant reduction of 1,127 minutes.

Moreover, the time allocated to value-adding activities decreased from 1,320 minutes to 861 minutes, reflecting a reduction of 459 minutes. This shows that the improvements directly influenced the efficiency of value-adding activities.

Training employees and utilizing higher quality yarn also contributed to these advancements. Additionally, non-value-adding activities were reduced from 918 minutes to 250 minutes, resulting in a decrease of 668 minutes. This significant improvement was achieved by eliminating unnecessary activities related to quality maintenance, along with associated movement and waiting times.

Overall, the process improvements have led to a substantial reduction in both non-value-adding and value-adding activities through targeted countermeasures, resulting in a more efficient production process for single jersey knit fabric.

Table 27 : improved non value added time

| | Before implementation | | After implementation | | Improved in minute |
|---|---|---|---|---|---|
| Non-value adding | Time/minute | %age | Time/minute | %age | |
| Movement | 78 | 10.4% | 70 | 71.4% | 8 |
| Waiting | 107 | 14.3% | 28 | 28.6% | 79 |
| Unnecessary activity for quality sustaining | 563 | 75.3% | 0 | 0% | 563 |
| Total | 748 | | 98 | | 650 |

The comparison of non-value-adding activities, specifically movement and waiting times, indicates an increase in their percentage of the total value after the improvements. However, there has been a decrease in the total time spent on these activities. This reduction is primarily due to the complete removal of unnecessary activities related to quality maintenance, such as waxing, which did not adhere to the established standards for specific yarn types and counts. From the above non-value adding time, unnecessary activities related to quality maintenance totally removed from the process of value stream mapping because it is unnecessary process for the current production process which has significant improvement about 563 minute and secondly waiting time 79 minute improvement. This shows that countermeasure that is taking is more efficient and effective.

**Productivity improvement**

**Table 28:** Productivity improvement

| | Before improvement | | | | After improvement | | | |
|---|---|---|---|---|---|---|---|---|
| | Actual | Monthly | Maximum out put | Monthly max | Actual | Monthly | Maximum out put | Monthly max |
| Production | 245652 | 40942 | 324569 | 54095 | 123826 | 41275.3 | 324569 | 54095 |
| Machine efficiency | 75.6% | | | | 76.3 | | | |
| Material Utilization | 79.98 | | | | 82.24% | | | |
| Labor Productivity | 60 | | | | 72.22 | | | |
| Raw Material Quality Productivity | 65 | | | | 70.8 | | | |

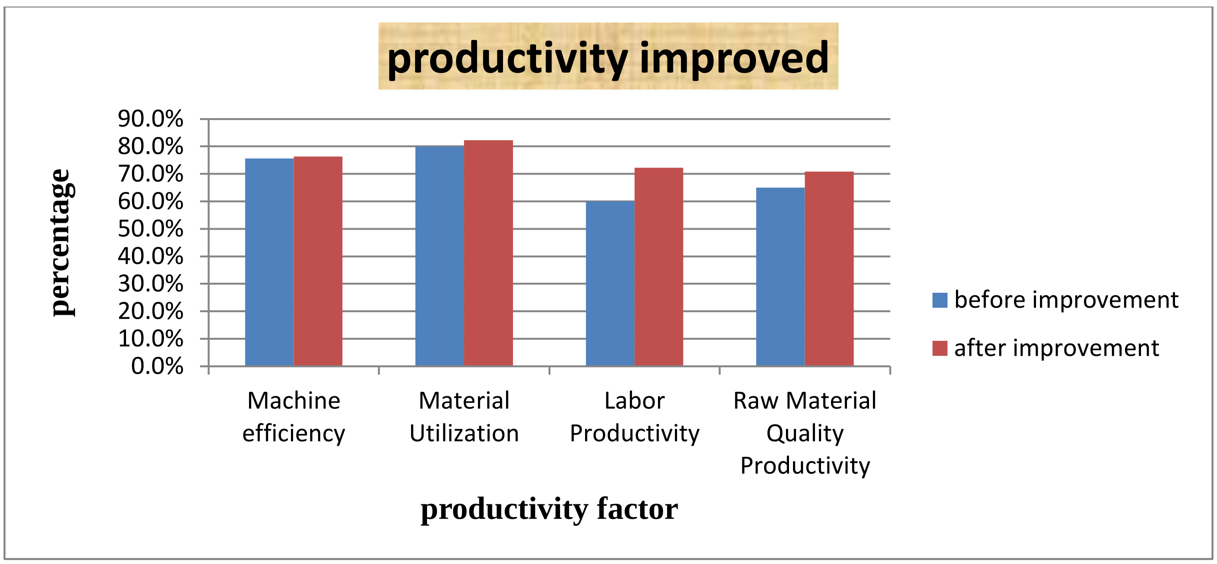



**Figure 19** Productivity improved

**Machine Efficiency:**

Machine Efficiency (%) = (Actual Output/Maximum Possible Output) ×100

Production after improvement =123826 kg from 3 month and from planning the attainable production is 324569 kg

**Machine Efficiency (%) =** 41275.3 kg/54095kg*100 =76.3%

**Material Utilization:**

Material Utilization (%) = (Used output/Total input) ×100

The input to product 123826 kg of fabric uses an input material 150563.5 kg yarn

**Material Utilization (%) =** 123826/150563.5 *100= 82.24%

**Labor Productivity:** Labor

Labor Productivity=Total Output/Total Labor Hours

Man hour 8 hour and product per shift per labor is 130 kg but the best practice is 180kg

Labor Productivity = 130kg/8hour = 16.25 kg/hr.

Labor Productivity % =130kg/180kg*100= 72%

**Raw Material Quality Productivity:**

From the above produced fabric, 87678 kg of fabric is with qualified parameter.

Raw Material Quality Productivity = Quality Output / Total produced fabric) × 100

87678kg/123826.5*100 =70.8

The comparison of productivity improvements—encompassing machine efficiency, material utilization, labor productivity, and raw material quality—reveals significant gains post-improvement. However, the enhancement in machine efficiency was modest due to issues with yarn quality, leading to increased breakage when operating at high RPM. Machine efficiency rose from 75.6% to 76.3%, representing a 0.7% increase, which, while positive, indicates that further improvements are necessary, particularly in yarn quality.

The countermeasures implemented had a notable impact on labor productivity, largely attributed to the soft and technical skills training provided to employees. Additionally, material utilization and raw material quality productivity saw significant increases of 2.26% and 5.8%, respectively.

Overall, while there have been improvements across machine efficiency, material utilization, labor productivity, and raw material quality, there remains ample opportunity for further enhancements. Focusing on improving raw material quality and continuing employee training will be crucial for increasing overall productivity and efficiency.

## Improved process capability index

| sample | Inspected fabric | Defect (rejected ) fabric | Defect/meter |
|---|---|---|---|
| 1. | 49281.3 | 4803 | 0.097461 |
| 2. | 49217.4 | 4769 | 0.096897 |
| 3. | 48913.2 | 4753 | 0.097172 |
| 4. | Average | | 0.097177 |

| | | |
|---|---|---|
| 5. | Variance ($\delta^2$)=∑(Dpmi- μ)2/n-1 | 7.96171E-08 |
| 6. | Standard deviations (δ) | 0.000282165 |

Fabric rejection

Upper specification limit= 1%=0.01

Lower specification limit= 0.5%=0.005

Cp=(USL-LSL)6δ

Cpk = Min((USL-μ)/3δ, (LSL-μ)/3δ)    capability index considering mean

Cp & Cpk <1 incapable process

Cp & Cpk >1 capable process

Cp=(USL-LSL)6δ=(0.01-0.005)/6*0.000282165 = 0.005/0.00169299= 2.9533

Cpk = Min ((USL-μ)/3δ, (LSL-μ)/3δ) =min ((0.01-0.097177)/3*0.000282165, (0.005-0.097177)/ )/3*0.000282165)

=min (-0.087177/0.000846495, -0.092177/0.000846495) = min (-102.9858, -108.8923) = - 108.8923

If you find that the Cp is positive while the Cpk is negative after corrective actions have been implemented, this situation indicates specific issues with the process:

Interpretation

Positive Cp:

A positive Cp value signifies that the potential capability of the process—reflected by the spread of the process in relation to the requirement limits—is satisfactory. This implies that if the process were centered within the limits, it would be capable of producing acceptable products.

Negative Cpk:

A negative Cpk value means that the average process is still outside the specification limits. This shows that, despite improvements, the process is not producing within acceptable limits, leading to defects.

Implications

Process Centering Issue: The corrective actions may have improved the variability of the process (indicated by Cp), but the mean of the process is still misaligned.

Need for Further Adjustments: Additional corrective actions are needed to shift the process mean into the acceptable range defined by the specification limits.

Focus on Centering: Investigate the reasons for the continued misalignment of the process mean. This may involve recalibrating equipment, retraining personnel, or revisiting process design.

While the positive Cp indicates potential, the negative Cpk signals that further adjustments are necessary to ensure the process operates within specification limits. Continued efforts should focus on centering the process to improve overall capability.

When comparing two Cp values—Cp = 0.254 and Cp = 2.9533—after corrective actions have been implemented, here's what you can conclude:

Interpretation of Cp Values

**Cp = 0.254**:

This number shows the process is not capable of consistently producing items with limits. It suggests a high potential for defects due to significant variation relative to the allowable range.

**Cp = 2.9533**:

This value indicates a very capable process. A Cp value significantly greater than 1.0 suggests that the process variation is much smaller than the allowable range, implying a low likelihood of defects.

Implications

**Effective Corrective Actions**: The transition from a Cp of 0.254 to 2.9533 indicates that the corrective actions taken were effective in significantly improving the process capability.

**Process Improvement**: The new Cp value of 2.9533 suggests that the process is now well within acceptable limits and capable of producing high-quality products consistently.

**Focus on Monitoring**: While the process is now capable, ongoing monitoring and control are essential to maintain this level of performance and to ensure that any future variations are promptly addressed.

The improvement from Cp = 0.254 to Cp = 2.9533 reflects successful corrective actions that enhanced the process capability..

## Control

In the framework of DMAIC, the control phase is essential for maintaining and sustaining the improvements made during the process. This phase emphasizes monitoring results, (SOPs) documenting, offering training, and promoting development skill through statistical process control.

During the measuring phase, existing problems were quantified, leading to a detailed analysis in the analysis phase. Several issues contributing to defects and low productivity in the production process of knitting were identified, including:

- ❖ Poor raw material quality
- ❖ Unnecessary quality maintenance practices
- ❖ Absence of standardized operating procedures and quality parameters

- ❖ Use of expired lubricants
- ❖ Prolonged use of sinkers and needles beyond their service life
- ❖ Waiting times for trolleys due to shortages and engagements with other departments
- ❖ Lack of scheduled maintenance
- ❖ High temperatures and inadequate relative humidity (RH)
- ❖ Disorganized workspaces due to insufficient implementation of 5S principles
- ❖ Ineffective manual oiling systems
- ❖ Damaged oil valves
- ❖ Operator carelessness
- ❖ Lot and count mixing
- ❖ Absence of protective covering for the final products

These factors collectively contribute to quality defects and diminished productivity, stemming from a lack of defined technical parameters for each process, including work, maintenance, and operational procedures. Additionally, there is a need for better management of process variations and enhanced supervision.

Establishing precise standards and parameters at every stage of the production process, as well as clear operational, maintenance, and working procedures, is essential to filling up these gaps. The results of this investigation will be handled by developing thorough SOPs, standards, and parameters that serve as organizational norms. These SOPs will guarantee that all staff decisions, actions, and handover formats are executed efficiently, consistently, and methodically. Through training on 5S concepts, the implementation of visual management techniques, regular performance reviews, and the encouragement of a culture of sustainable change, this supports the last phase of the 5S process, maintaining progress.

Furthermore, controlling processes will be evaluated using Statistical Process Control (SPC) charts. Specifically, u charts will be utilized to track the average of defects, R charts will monitor the range of variations, and root causes analysis will help identify underlying issues. This structured approach ensures that improvements are not only achieved but also sustained over time, leading to long-term operational excellence. Utilized u chart for controlling average

Table 29: Number of defect per day after improvement

| Sample | Number of defect | (Ui) = number of defect/ n | U bar= total number defect/total number of sample unit | Ucl=ubar+3*square root of(u-bar/n) | Lcl=ubar-3*square root of(u-bar/n) |
|---|---|---|---|---|---|
| 1. | 30 | 2 | 2.40 | 3.60 | 1.200 |
| 2. | 42 | 2.8 | 2.40 | 3.60 | 1.200 |
| 3. | 29 | 1.9 | 2.40 | 3.60 | 1.200 |
| 4. | 33 | 2.2 | 2.40 | 3.60 | 1.200 |
| 5. | 39 | 2.6 | 2.40 | 3.60 | 1.200 |
| 6. | 35 | 2.3 | 2.40 | 3.60 | 1.200 |
| 7. | 40 | 2.6 | 2.40 | 3.60 | 1.200 |
| 8. | 41 | 2.7 | 2.40 | 3.60 | 1.200 |
| 9. | 31 | 2.1 | 2.40 | 3.60 | 1.200 |
| 10. | 40 | 2.6 | 2.40 | 3.60 | 1.200 |
| 11. | 38 | 2.5 | 2.40 | 3.60 | 1.200 |
| 12. | 37 | 2.4 | 2.40 | 3.60 | 1.200 |
| 13. | 41 | 2.7 | 2.40 | 3.60 | 1.200 |
| 14. | 29 | 1.9 | 2.40 | 3.60 | 1.200 |
| 15. | 33 | 2.2 | 2.40 | 3.60 | 1.200 |
| 16. | 41 | 2.7 | 2.40 | 3.60 | 1.200 |
| 17. | 39 | 2.6 | 2.40 | 3.60 | 1.200 |
| 18. | 32 | 2.1 | 2.40 | 3.60 | 1.200 |
| 19. | 43 | 2.8 | 2.40 | 3.60 | 1.200 |
| 20. | 36 | 2.4 | 2.40 | 3.60 | 1.200 |
| 21. | 27 | 1.8 | 2.40 | 3.60 | 1.200 |
| 22. | 34 | 2.2 | 2.40 | 3.60 | 1.200 |
| 23. | 37 | 2.4 | 2.40 | 3.60 | 1.200 |
| 24. | 41 | 2.7 | 2.40 | 3.60 | 1.200 |
| 25. | 30 | 2 | 2.40 | 3.60 | 1.200 |
| 26. | 38 | 2.5 | 2.40 | 3.60 | 1.200 |
| Total | 936 | | | | |

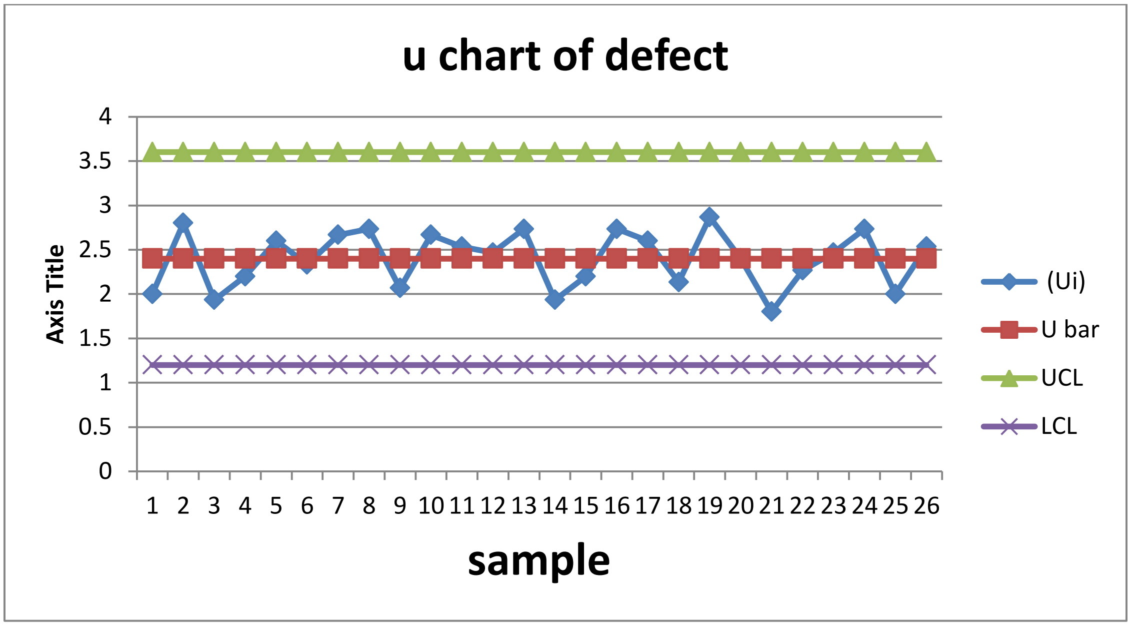



Figure 20 U char of from one month quality inspection report

From the chart the defect per unit is in between of UC and LC limit. Therefore the processes were stable because the defect per unit falls between UCL and LCL.

## Discussion

Numerous factories have found success with the application of LSS techniques, which aid in identifying and measuring production process problems and resulting in increases in profitability, quality, and productivity. Lean Six Sigma offers a robust framework for improving overall organizational performance and process operation optimization. According to the researcher, a textile company may greatly accelerate the development of better manufacturing techniques by putting an LSS plan into place.

With a Sigma level of 3.7, the study by Hibarkah KURNIA (2021) found that the hole was the most critical defect. This problem may have been lessened once the DMAIC approach was put into practice, as evidenced by a decrease in the defect percentage from 11.08% to 5.54% and an increase in the Sigma level to 3.96. Furthermore, with a Sigma level of 3.5, a study by AHMED T et al. (2022) showed that yarn quality was the main contributor to fabric quality problems. This problem was successfully resolved once the DMAIC approach was implemented, resulting in an improvement in fabric production over traditional methods and an annual savings of $2,378 and a Sigma level raise to 4.

These findings imply that the Lean Six Sigma methodology has made it easier to improve process quality performance. However, effectively addressing knowledge, cultural, and human attitude challenges is essential to the successful implementation of Lean and LSS, especially in firms with limited resources (Abu, 2022). Therefore, even if applying lean six sigma yields favorable outcomes, its effectiveness depends on overcoming several challenges. In this research, data on defect types and causes of low productivity were collected through focus group feedback, interviews, and recorded data to identify major defects and their impact on the product. The analysis revealed that the defect percentage for single jersey knit products was 17.96%, with productivity at 70%, indicating a high defect rate and productivity loss in the company. Based on the collected data, the researcher focused on reducing major defects (holes, unevenness, and oil stains) and addressing the causes of low productivity (machine efficiency, labor productivity, material utilization, and raw material productivity).

The DMAIC approach was applied in this study of research. During the define phase, PPM (production process mapping), SIPOC analysis, & VOC assessments were conducted to internalize and Clarify the problems. In the measure phase, the Cost of Poor Quality (COPQ) and its associated costs, the product's sigma level, time measurements, Value Stream Mapping (VSM), and causes of low productivity were quantified and identified.

Through VSM, various non-value-added activities and value-added were recognized, such as waiting time, unnecessary quality maintenance activities, and movement. These issues were attributed to a disorganized work process and insufficient kaizen efforts, including a limited number of trolleys that did not align with their required capacity and activities. Additionally the productivity of labor, material utilization, machine efficiency and raw material quality productivity are calculated. In the analysis phase DMAIC approach the main defect of fabric quality and it possible root cause is identified using Pareto analysis for identifying main defect fabric quality and fishbone diagram for identifying minimal root cause from the listed possible causes to take corrective action. Before going to improvement phase, in this paper I have added verification and integration in the DMAIC approach that was founded research gap, to verify the root causes weather the identified root cause is really exist in the production process or not, through gemba walk, researcher opinion and verification letter and integrating functional departments that is responsible for taking action. Integrating functional departments based on the existed problem and its root cause is an essential approach after verifying or confirming. Improper integration of functional department does not solve the problem from the source, which leads to more crisis and negative impact. Additionally wrong selection of root cause for the identified problem leads to wrong countermeasure and resulting wrong improvement and have negative impact. Therefore, verification of root cause for the identified problem and integrating of right functional department to solve the problem by taking corrective action on the root cause is critical and essential phase that must be incorporated. Integrating of right functional department after validating root causes used to minimize cost, time and increase successful improvement. Therefore, by adding these verification and integration phase in the DMAIC approach, that is known as DMAVIIC approach and resulting significant quality and productivity improvement in the research study. After integrating right functional department, the improvement phase is implemented using by training and 5W1H, 5S and value stream mapping (VSM). Finally, the final phase is control in which is performed by standards, parameters, SOP, kaizen and SPC (control chart) to sustain the improvement by monitoring and evaluating the process.

This study aims to illustrate the effectiveness of LSS within the DMAIC framework by incorporating essential Lean techniques such as VSM, Pareto analysis, Fishbone diagrams, Why-Why analysis, 5S, and production process mapping. The VSM time measure indicated a reduction in both non-value-added and value-added time due to the elimination of unnecessary processes in the production flow and the implementation of 5S, which resulted in increased efficiency.

Cycle time, which is a measure of the overall amount of time needed for a process—was reduced, indicating increased productivity and even less time lost. All things considered, these modifications improved the process by cutting down on both value-added and non-value-added tasks as well as the overall cycle time. Customer happiness, staff morale, and productivity all rise as a result of the production process's overall cycle time decreasing. This outcome is the consequence of a considerable reduction in the overall cycle time (removal of superfluous quality maintenance, reduction of waiting time, and adjustment of value-added activity to the standard).

The study shows how LSS may improve processes by identifying important issues and their underlying causes that are connected to productivity and quality inefficiencies. It Gives precedence to opportunities for improvement, reduction of defects and waste, and addresses the factors contributing to low productivity.

Table 30: Summarized improvement of the research is shown below:

Quality & Productivity

| s/n | Parameter | Before DMAVIIC | After DMAVIIC | Improvement |
|---|---|---|---|---|
| 1. | Defect %age | 17.96% | 9.72% | 8.24% |
| 2. | Cost of poor quality | 2,338,789.38 | 1,386,000.06 | 952,789.32 |
| 3. | Sigma level | 1.36 without1.5 sigma shift and 2.32 with 1.5 sigma shift | 2.68 without1.5 sigma shift and 3.83 with 1.5 sigma shift | 1.32 without sigma and 1.51 with 1.5 |
| 4. | Non-value added time | 918 | 250 | 668 |
| 5. | Value added time | 1320 | 861 | 459 |
| 6. | Cycle time | 2238 | 1111 | 1127 |

| s/n | Parameter | Before DMAVIIC | After DMAVIIC | Improvement |
|---|---|---|---|---|
| 1. | Machine efficiency | 75.6% | 76.3% | 0.7% |
| 2. | Material utilization | 79.98% | 82.24% | 2.26% |
| 3. | Labor productivity | 60% | 72.22% | 2.22% |
| 4. | Raw material quality productivity | 65% | 70.8% | 5.8% |

The comparison in the table above indicates that integrating Lean and Six Sigma within the DMAVIIC strategy yields significant results.

# CHAPTER FIVE
# 5. CONCLUSION AND RECOMMENDATION

## 5.1. Conclusion

Now days high quality product and productivity in the production process is crucial. But In recycling company it is difficult to sustain it quality and productivity because of the material, are loss its physical property and mechanical property as it passed many process before. Additionally there is limitation of technology level to achieve the required quality level as virgin raw material processed. Even if there are many textile industries in Ethiopia still, stick into foreign product importing because of its product quality and addressability to the market. Therefore to become competitive in world market achieving the desired quality level and productivity is critical issue. As result customer is become satisfied and the company develops its brand and leads to sustainable success.

Here based on the analyzed data of the company and conducted problem solving technique many conclusions are sated. During the assessment of the company, several things are identified regarding to quality and productivity. Regarding to quality the assessment covers cost of poor quality, sigma level, process capability index and defect rate of single jersey product and regarding to productivity the assessment covers VSM (none value adding and value adding) cycle time , production process map and cause of low productivity. Based on this assessment the company, has defect rate of 17.96, cost of poor quality (COPQ) is 2,338,789.38 birr per 3 month and it sigma level is 1.36 without 1.5 sigma shift and 2.32 with 1.5 sigma shift. In the value stream mapping the non-value adding, value adding and cycle time 918 minute, 1320 minute and 2238 minute respectively. Apart from this productivity of cause of low productivity are Machine efficiency, Material utilization, Labor productivity and Raw material quality productivity is 75.6%, 79.98%, 60%, 65% respectively. After implementation of suggested solution the defect rate becomes 9.72, COPQ become 1,386,000.06 birr per 3 month and its sigma level increase to 2.68 without1.5 sigma shift and 3.83 with 1.5 sigma shift. Process non-value adding, value adding and cycle time also decreased to 250 minute, 861minute, and 1111minute respectively. And productivity Machine efficiency, Material utilization, Labor productivity and Raw material quality productivity increased to 76.3%, 82.24%, 72.22%, and 70.8% respectively. The Cp (process capability index) is increased from Cp = 0.254 to Cp = 2.9533. This findings shows that the production process (quality and productivity) are improved. These reductions of defect rate and increments productivity give a remarkable customer satisfaction and short time, to market. This remarkable improvement comes from validating root cause and integrating of right functional departments based on the existed problem.

Therefore researcher summarized that, verification of root cause and integrating of right functional department phase are vital to be incorporate in to DMAIC and called it DMAVIIC to become more efficient and effective improvement.

## 5.2. Recommendations

Based on the findings of the research study and the analyzed data, the following recommendations are suggested for the company:

- Maintaining temperature and relative humidity of production process by installing AC in order to improve yarn quality and decrease yarn breakage due to loss of moisture content and safe working environment for employee.
- Mix plan at spinning is necessary to produce qualified yarn product that input for knitting process. The mix plan is based on waste fabric quality like color, fiber type, waste size in or der to minimize color inconsistency, unevenness of yarn and NEP point.
- Schedule training program for employee especially for shop floor because of high turnover in order to make them strong sense of ownership and perform their works based on standard and procedure

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# Annex

Table A: **Sigma level table of DPMO**

| | Without 1.5 sigma shift | | | With 1.5 sigma shift | | |
|---|---|---|---|---|---|---|
| Sigma Level | 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 | | | 0.0004000% | 967 | | |
| 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% |

**DELIVERED STANDARD KNITTING PARAMETERS**

**Table B: YARN PARAMETERS**

| Parameters | 30/1 cotton combed | | 30/1 cotton carded | | 30/1 poly cotton | |
|---|---|---|---|---|---|---|
| | Best | Acceptable limit | Best | Acceptable limit | Best | Acceptable limit |
| Uniformity % | 9-9.5 | 9.7-10.2 | 11.5-12.1 | 12.8-13.5 | 9.5-9.8 | 10.4-10.7 |
| Thin (-50%) | 0 | 3-5 | 16-22 | 50-60 | 2-3 | 7-10 |
| Thick (+50%) | 7-12 | 32-43 | 75-90 | 250-300 | 15-20 | 34-42 |
| Neps (+200%) | 38-47 | 73-88 | 140-175 | 300-380 | 30-45 | 48-58 |
| Hairiness | 4.0-4.4 | 4.6-4.9 | 4.75-5.1 | 5.5-5.81 | 4-4.44 | 4.45-4.8 |
| Tenacity(CN/tex) | 21.8-22.6 | 18.4-18.9 | 16.7-17.6 | 16.2-15.4 | 25.5-24 | 23.4-22.1 |
| Elongation | 6.7-6.9 | 6.2-6.4 | 7.3-7.08 | 6.6-6.4 | 14.7-13.7 | 11.8-11.2 |
| RKM value | 13.7-13.9 | 12.5-12.7 | 11.2-11.4 | 10.1-10.3 | 16.1-16.5 | 15.2-15.4 |

| Count Ne | 20s CH | 30s CH | 40s CH |
|---|---|---|---|
| Count CV% | 0.9 | 1.0 | 1.2 |
| Strength CV% | 4.1 | 4.7 | 5.0 |
| RKM | 16.2 | 15.6 | 18.3 |
| RKM CV% | 7.1 | 8.1 | 8.0 |
| Elongation % | 5.4 | 4.8 | 5.07 |
| Elongation CV% | 4.7 | 6.6 | 8.08 |
| U% | 8.09 | 9.08 | 9.81 |
| Thin Place / KM | 0 | 0 | 1 |
| Thick Place / KM | 4 | 11 | 14 |
| Neps / KM | 6 | 21 | 26 |
| Total Imperfection/KM | 10 | 31 | 41 |

**Table C: STANDARD MATERIAL HANDLING TECHNIQUES**

| S/N | Process | Material | Equipment required |
|---|---|---|---|
| 1. | Yarn from spinning or main stores to knitting department store | Yarn in bags or cartons | Pallet trucks – manual or battery operated |
| 2. | Stores to machines | Yarn cones / cheese | Yarn trolleys |
| 3. | Fabric from knitting machines to inspection machines | Fabric rolls | Manual or pallet truck |
| 4. | Inspection area to grey fabric stores | Fabric in rolls or plaited | Pallet truck or fork lift |

## KNITTING DEFECTS, CAUSES AND REMEDIES

### Table D: Fabric faults related to Yarn

| Description of fault | Causes | Solutions |
|---|---|---|
| Unsettled fabric<br>Local fault corresponding to a portion of yarn having a linear density quite lower or higher than the rest of the yarn | Utilizing yarns with irregularities that exhibit a significant degree of long-term unevenness (thin, thick spots, and neps per km) | Yarn quality control involves measuring the degree of irregularity and imperfection in utilized yarns using the Uster test prior to knitting. |
| Cotton contamination -<br>Dark stains, undetectable on grey cotton fabric and appearing after light dyeing | Contamination of raw cotton by insects laying in the cotton flowers | • Impossible to remove<br>• Laboratory dyeing tests on lab knitted samples before knitting production permit to detect this fault and remove contaminated bobbins |

### Fabric faults related to Knitting machine

| Description fault | Causes | Solutions |
|---|---|---|
| Vertical stripes | Defective needles or sinkers | • Change needles and sinkers after long-term use<br>• Check needle detectors<br>• Use of fabric fault detector |
| Horizontal stripes | yarn consumption are not constant at all feeders | Yarn consumption and couliering readjustment |
| "Fabric spirality." The distortion of simple knitted cloth is known as Wales's courses are not perpendicular. | • An excessive amount of yarn twist;<br>• An excessive number of feeders;<br>• An improper alignment of the machine rotation direction with the yarn twist direction | Reducing the number of feeders;<br>using Z-twist yarn with machines that have needles that monitor rotation;<br>and controlling yarn twist (which should never be greater than tr/m).<br><br>• Fabric spirality is decreased by proper finishing. |
| Dropped stitches -<br>Local column of dropped stitches obtained when presented yarn is occasionally unhooked by needles | • Inadequate or excessively lengthy stitches;<br>• A defective needle latch;<br>• An improperly placed yarn guide<br>• Too high of a take-down<br>• Incorrect yarn threading | • Needle replacement;<br>• Accurate yarn-guide resetting;<br>• Yarn consumption and couriering readjustment<br>Readjustment of the take-down and the dial position<br>Threading the yarn through the appropriate bore; |

| Description fault | Causes | Solutions |
|---|---|---|
| | • An excessively large cylinder-dial distance | utilizing a fabric fault detector; and<br>using a basic needle to repair the stitches |
| Holes -<br>Local holes obtained when yarn breaks during loop formation | • Yarn has weak spots;<br>there are knots in the yarn; and<br>Tension is excessively high.<br>• The yarn is excessively dry;<br>the yarn-guide is not properly adjusted;<br>or the yarn-guide is obstructed by a buildup of yarn hair. | Use of flat knots;<br>regulation of yarn uniformity;<br>correction of yarn consumption and couriering<br>• Humidification of the air<br>• Accurate resetting of yarn-guide<br>• Employing protective filter creel, bobbins, yarn-guide blowing, and yarn with reduced hairiness;<br>• Using a fabric fault detector |
| Yarn hair deposit -<br>Yarn hair and other yarn wastes deposit on needles fabric during knitting | • Inappropriate air blowing<br>• Use of yarn with high hairiness<br>• Different machines working with different yarn types in the same place | • Readjustment of CKM blowing frequency and intensity<br>• Use of yarn having lower hairiness, bobbins and yarn-guide blowing, use of protective filter creel<br>• Machine separation with partitions |
| Knots -<br>Knot appearance on fabric | Inappropriate yarn knotting | • Use of flat knots<br>• Use of fabric fault detector |
| Fabric fall-out -<br>Local dropped fabric obtained when big number of successive needles lose stitches | • Yarn rupture in yarn-guide due to weak places in yarn or yarn hair accumulation<br>• Stitches rupture due to excessive take-down or weak places in yarn<br>• Defective yarn feeder<br>• Yarn tension too high<br>• Yarn-guide not properly set<br>• Defective needles or sinkers | • Yarn control before knitting. Use of yarn having lower hairiness, bobbins and yarn-guide blowing, use of protective filter creel<br>• Take-down readjustment<br>• CKM elements checking<br>• Yarn consumption and couriering readjustment<br>• Precise yarn-guide resetting<br>• Change needles and sinkers after long use<br>• Regular machine cleaning |
| Oil stains -<br>Local lubricating machine oil stains visible after fabric finishing | • Inadequate oil<br>• Defective oiling circuit<br>• Excessive oiling | • Use of adequate oil, respect of oil washing recommendations (temperature, grey fabric storage duration)<br>• Regular oiling circuit checking<br>• Oiling quantity readjustment |
| Missing yarn -<br>Regular absence of yarn | • Yarn rupture in the yarn-guide as a result of weak spots in the yarn or yarn hair accumulation;<br>• Incorrect yarn threading;<br>• A defective yarn feeder | • Yarn management prior to knitting;<br>• Yarn threading through the correct bore;<br>• CKM elements checking. Utilizing protective filter creel, bobbins, yarn-guide blowing, and yarn with reduced hairiness<br>• Frequent cleaning of the machine |

| Description fault | Causes | Solutions |
|---|---|---|
| | | •Using a fabric fault detector |
| Foreign yarn -<br>Regular colour stripes that appear after dying when a foreign yarn different from normally used yarn is accidentally introduced | • Worker's carelessness<br>• Presence of different yarn types having the same color on the same creel | • Worker training to recognize different yarn types<br>• Rigorous yarn sorting and storage |
| Elastomeric mis-plaiting -<br>Regular absence of elastane yarn | • Defective elastane yarn feeder<br>• Elastane roll-guide not properly set | • CKM elements checking<br>• Elastane roll-guide resetting<br>• Use of fabric fault detector |
| Side crease: When a circular knitted fabric tube is wound up, a side crease is formed that becomes fixed quickly and unremovable. This is one of the issues with circular knitted textiles that include elastane. After completion, this error manifests. | • High pressure exerted by take-down rolls on tubular fabric inducing permanent deformation of elastanefibres at fabric sides<br>• Too long tubular grey fabric storage<br>• Use of ordinary take-down devices with elastane plated fabrics | • Use of take-down rolls with movable side rubber rings to avoid pressure on fabric sides<br>• Short grey fabric storage<br>• Use of open-width take-down devices |

**Table E: FOUR POINT GRADING SYSTEM**

| Size of Defects | Penalty |
|---|---|
| 3 inches or less | 1 Point |
| Over 3 inches but not over 6 inches | 2 Point |
| Over 3 inches but not over 6 inches | 3 Point |
| Over 9 inches | 4 Point |

Calculation of Acceptance

Roll Yardage (A)

Total Points (B)

Formula $= \frac{B}{A} * 100$ = points per 100 yards

**Classification**

| Points | Type |
|---|---|
| Below 40 | A |
| 41 – 60 | B |
| 61 – 80 | C |
| Above 80 | Reject |

**Table F: STANDARD OPERATIONAL PARAMETERS**

| KEY PERFORMANCE INDICATORS | BEST PRACTICES |
|---|---|
| Plant utilization | 95% |
| Plant efficiency | 85% |
| Machine productivity/ shift<br>SJ 30/1, 32 GG, 150 gsm | 180 kg |
| Machines per operator | 4 |
| Knitting yarn waste | 0.5 – 1.0% |
| Fabric rejection | 0.5- 1% |
| Needle consumption per machine per day | 4 – 5 |
| Production per needle | 80 – 100 kg |
| Yarn Quality – Uster % | 15% |
| Age of machinery (years) | 10 |
| No. of working days/ year | 350 |
| Training & skill development | 5 |

**Table G: RELATION BETWEEN GSM AND YARN COUNT**

For Single jersey:-

| Fabric GSM(finished) | Yarn Count |
|---|---|
| 130 – 150 | 30/1 |
| 150 – 160 | 28/1 |
| 160 – 170 | 26/1 |
| 170 – 190 | 24/1 |
| 190 – 220 | 20/1 |

For Rib Fabric:-

| Fabric GSM(finished) | Yarn Count |
|---|---|
| 160 – 180 | 34/1 |
| 180 – 200 | 30/1 |
| 200 – 220 | 28/1 |
| 220 – 240 | 26/1 |
| 240 – 260 | 24/1 |

For Interlock Fabric:-

| Fabric GSM (finished) | Yarn Count |
|---|---|
| 190 – 210 | 40/1 |
| 210 – 240 | 34/1 |
| 240 – 260 | 30/1 |
| 260 – 280 | 28/1 |
| 280 – 300 | 26/1 |

Table H: Yarn count and machine gauge

For single jersey fabric

| Machine gauge (Needles/inch) | Yarn count | |
|---|---|---|
| | Ne | Dtex |
| 14 | 8.5/1–14.0/1 | 200 × 2–235 × 1 |
| 15 | 10.5/1–16.5/1 | 150 × 2–200 × 1 |
| 16 | 12.0/1–19.0/1 | 250 × 1–167 × 1 |
| 18 | 14.0/1–23.5/1 | 200 × 1–150 × 1 |
| 20 | 18.0/1–26.0/1 | 167 × 1–122 × 1 |
| 22 | 21.5/1–29.5/1 | 150 × 1–110 × 1 |
| 24 | 23.5/1–35.5/1 | 140 × 1–100 × 1 |
| 26 | 42.0/1–41.5/1 | 122 × 1–84 × 1 |
| 28 | 29.5/1–47.5/1 | 110 × 1–76 × 1 |
| 30 | 35.5/1–59.0/1 | 100 × 1–67 × 1 |
| 32 | 41.5/1–71.0/1 | 84 × 1–55 × 1 |

For fleecy fabric

| Machine gauge (Needles/inch) | Yarn count | |
|---|---|---|
| | Ne | dtex |
| 12 | 2.5/1–9.5/1 | 720 × 2–622 × 1 |
| 14 | 3.5/1–12.0/1 | 620 × 2–500 × 1 |
| 15 | 4.7/1–14.0/1 | 500 × 2–420 × 1 |
| 16 | 6.0/1–16.5/1 | 833 × 1–360 × 1 |
| 18 | 7.0/1–18.0/1 | 660 × 1–300 × 1 |
| 20 | 8.5/1–20.0/1 | 500 × 1–280 × 1 |
| 22 | 10.5/1–23.5/1 | 360 × 1–200 × 1 |
| 24 | 14.0/1–26.0/1 | 300 × 1–167 × 1 |
| 26 | 16.5/1–29.5/1 | 250 × 1–150 × 1 |
| 28 | 19.0/1–35.5/1 | 200 × 1–122 × 1 |
| 30 | 21.5/1–41.5/1 | 150 × 1–110 × 1 |
| 32 | 23.5/1–47.5/1 | 122 × 1–84 × 1 |

For interlock fabric

| Machine gauge (Needles/inch) | Yarn count | |
|---|---|---|
| | Ne | dtex |
| 14 | 12.0/1–16.5/1 | 235 × 1–167 × 1 |
| 15 | 14.0/1–19.2/1 | 220 × 1–150 × 1 |
| 16 | 16.5/1–21.5/1 | 200 × 1–133 × 1 |
| 18 | 21.5/1–23.5/1 | 167 × 1–110 × 1 |
| 20 | 23.5/1–29.5/1 | 150 × 1–100 × 1 |
| 22 | 28.5/1–35.5/1 | 133 × 1–100 × 1 |
| 24 | 33.0/1–41.5/1 | 122 × 1–90 × 1 |
| 26 | 35.5/1–47.5/1 | 110 × 1–84 × 1 |
| 28 | 41.5/1–53.0/1 | 100 × 1–76 × 1 |
| 30 | 47.5/1–59.0/1 | 90 × 1–67 × 1 |
| 32 | 53.0/1–71.0/1 | 76 × 1–50 × 1 |

Table I: KNITTING PROCESS LOSS

| Knitting | Process Loss |
|---|---|
| Greige Yarn-100% cotton | Up to 1% |
| Yarn dyed | 1 to 2% |
| Melange | 1 to 2% |
| Synthetic Yarn | 0-0.5% |

Table J: TYPES OF WASTE

| S/No. | Description | Quantity |
|---|---|---|
| 1 | Humidification waste | 0.0275% |
| 2 | Yarn waste-Due to double yarn, slough -off, nose-stitch | 0.10% |
| 3 | Remnant Yarn on Paper cones due to uneven package weight, improper Yarn Average | 0.35% |
| 4 | Article change, settings cloth | 0.5-1 kg per change |
| 5 | Fabric Pattern change, settings cloth | 4-5 kg per change |

**Table K: MACHINE FULL-SERVICE FREQUENCY**

**For full service**

| S.No. | Yarn type | Machine service schedule |
|---|---|---|
| 1 | 100% Cotton Yarn Knitting | Fabric Knitted between 5000 to 6000 kgs |
| 2 | 100% Synthetics Yarn Knitting | Fabric Knitted between 7500 to 8500 kgs |
| 3 | 100% Yarn dyed Knitting | Fabric Knitted between 5000 to 6000 kgs |

**Partial Service work**

| S/N | Activities | Duration |
|---|---|---|
| 1 | Article change from Yarn dyed Knits to Greige Yarn Knits | Even after knitting minimum 100 kgs |
| 2 | Article change from Melange Yarn Knits to Greige Yarn Knits | Even after knitting minimum 100 kgs |
| 3 | Article change from Melange Yarn Knits to Organic Cotton Yarn Knits | Even after knitting minimum 100 kgs |

Table L: BASIC MACHINE SETTINGS

| SN | Description | Value |
|---|---|---|
| 1 | Cylinder Eccentricity | 0-0.05mm |
| 2 | Cylinder Height variation | 0-0.05mm |
| 3 | Yarn Carrier back surface to Cylinder Needle closed hook | 0.05-0.10mm |
| 4 | Yarn Carrier bottom surface to Sinker Nose Top Surface | 0.05-0.15mm |
| 5 | Yarn Carrier bottom surface to Dial Needle Closed Hook | 0.05-0.10mm |
| 6 | Dial Plate Eccentricity | 0-0.05mm |
| 7 | Cylinder Cam Box Cam-Surface to Needle Inserted in Cylinder tricks | 0.1-0.20 mm |
| 8 | Dial Cam Box Cam-Surface to Needle Inserted in Dial tricks | 0.1-0.20 mm |

Table M: DEVELOPED FORMATS FOR ERCO

| M/C No. | Operator name | Fabric defects | | | | | Weight of fabric | GSM | Total Length | Total Point | Fabric Grade | Four-point Grading system |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Needle Line | Hole | Press off | Oil stain | Other defects | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |

Total length = Weight of fabric in gm* 39.37/fabric width in inch * GSM)

Fabric grade = (Total point/Total length) *100 per yards

Table N: KNITTING WASTE REPORT

| ቀን | ፈረቃ | ገቢክር | የተበላሸክርብ ክነት (kg) | የክርብናኘ (kg) | የባከነጨርቅ (kg) | ጠቅላላብክነት (kg) | የተመረተምርት (kg) | ብክነትመጠንበመቶኛ |
|---|---|---|---|---|---|---|---|---|
| ሰኞ | A | | | | | | | |
| | B | | | | | | | |
| | ድምር | | | | | | | |
| ረቡዕ | A | | | | | | | |
| | B | | | | | | | |
| | ድምር | | | | | | | |
| ማክሰኞ | A | | | | | | | |
| | B | | | | | | | |
| | ድምር | | | | | | | |
| ረቡዕ | A | | | | | | | |
| | B | | | | | | | |
| | ድምር | | | | | | | |
| ሐሙስ | A | | | | | | | |
| | B | | | | | | | |
| | ድምር | | | | | | | |
| አርብ | A | | | | | | | |
| | B | | | | | | | |
| | ድምር | | | | | | | |
| እሁድ | A | | | | | | | |
| | B | | | | | | | |
| | ድምር | | | | | | | |
| W1 | | | | | | | | |
| W2 | | | | | | | | |
| W3 | | | | | | | | |
| W4 | | | | | | | | |
| Monthly | | | | | | | | |
| Total | | | | | | | | |

Prepared By -------------------------------- Approved by:____________________

Signature -----------------------------------

Date------------------------------------------

**Table O: RETURNED BAD/SOFT CONE FROM KNITTING TO REWINDING**

From: knitting Machine
To: Rewinding
Date:

| Date | Shift | Returned cone no. | Cause for return | Action taken | Remark |
|---|---|---|---|---|---|
| ሰኞ | A | | | | |
| | B | | | | |
| | ድምር | | | | |
| ማክሰኞ | A | | | | |
| | B | | | | |
| | ድምር | | | | |
| ረቡዕ | A | | | | |
| | B | | | | |
| | ድምር | | | | |
| ሀሙስ | A | | | | |
| | B | | | | |
| | ድምር | | | | |
| አርብ | A | | | | |
| | B | | | | |
| | ድምር | | | | |
| ቅዳሜ | A | | | | |
| | B | | | | |
| | ድምር | | | | |
| እሁድ | A | | | | |
| | B | | | | |
| | ድምር | | | | |
| WEEK1 | | | | | |
| WEEK2 | | | | | |
| WEEK3 | | | | | |
| WEEK4 | | | | | |
| Monthly | | | | | |
| Total | | | | | |

Prepared By ------------------------------- Approved by: ______________________

Signature ----------------------------------

Date-----------------------------------------

STANDARD OPERATIONAL PROCEDURES FOR KNITTING

1. Turn the power switch “ON” button on the main breaker
2. Clean the machine by air compressor hose before operation
3. Plug the socket and turn the “ON” button on the control panel display
4. Check all machine parts according to design and proper setting
5. Adjust the amount of oil supply to the needle
6. Lubricating
7. Put the sinker, needle and cam with cam holder according to the design
8. Adjust the stich length
9. Threading the yarn through yarn guide and tensioner
10. Adjust the thread tension
11. Adjust the take up roller speed
12. Check the direction of machine rotation, turn the hand wheel by hand to bring the threading yarn inside the cylinder and pulled down the yarn and tight it on the spreader
13. Turn the hand wheel by hand until we get the undamaged fabric
14. Press the yellow color or jog button on the machine
15. Press the green color or start button and jog at the time on the machine to run the machine.

## SAFTEY RULE

1. Never use scrap, long sleeve and do not release your hair if it is long while operate the machine
2. You have to wear safety equipment and ready safety tools
3. Never operate the machine unless it is oil  pan has been filled with oil
4. Keep your finger away from the needle when you turn the power switch “ON” or while the machine is running
5. Open the windows during operation and close them when you finish your work
6. When the operator leaves from the machine, make sure whether the machine is turn OFF or not. If the switch button on turn off and turn off the main breaker switch
7. Clean up the workshop after finish the work every day and keep it up

### Creeling procedure

Creeling the cone on the knitting machine need to follow and control some points

First check the cone free from damaged, soft, unwinding problem, oils and stains

Checks the yarn count and type identify it which is indicated on the cone or bag tag.

Arrange the yarn cone alternatively on the cone holder and leave the space in between the cone and the pole to prevent the entanglement of the nearby cone balloon and breakage yarn due the friction between yarn cone and creel pole.

Finally push the yarn through the yarn tube by the help of air pressure up to the positive feeder in a control manner.

Standard operating procedure (sop) for Raw material utilization and material handling

**Knit Plan**

Check the availability of weekly knit plan. Weekly plan must consist of m/c name, dial/gauge, yarn count, order quantity, sale order and work order number, loop length, GSM

For each work order there must be a batch plan number.

Check the allocation of yarn for each Work order while releasing week plan.

Check yarn stock in hand and prepare yarn requisition against work order quantity.

Check yarn quality as per standard

Check yarn requisition slip to yarn store supervisor signed by knitting manager.

Check yarn requisition consist of machine name, work order number, yarn count and quantity

Get Initial Production Approval

Check setting of cam arrangement in machine based on required fabric structure as suggested by knitting manager and set loop length as confirmed by fabric technologist and maintain all machine setting

Check load yarn cone on creel as per the work order and finish threading action start trial run until 2 meters (approximately) of fabric get produced.

Check first piece approval from QC, by checking loop length, GSM and fabric appearance.

Production Monitoring

Run the machine, cut and doff fabric roll once it reached pre- set revolution.

Follow standard operational procedure for production

Note down revolution counter reading for each machine at the end of each shift

Manpower Allocation and Control

Check man power skill gap and attitude

Check man to machine ratio and their allocation

Follow and control all necessary standard operational procedures (SOPs) for knitting operation

Efficiency & Utilization Monitoring

Calculate knitting efficiency and monitor machine wise.

Calculate yarn realization or raw material utilization on daily basis

Machine Cleaning and Maintenance

Conduct preventive maintenance for each machine once in every two months.

Once for every 2 hrs. Machines& surroundings should clean by air gun by the operator.

Preparing annual maintenance plan/ maintenance flow chart

Start cleaning idle machines in every shift.

**Layout and Material Handling**

Spread poly bags between machines and cover stock yarns based on operators' assignments

Check layout passage with standard

Check availability of handling equipment's and tools

Utilities and Room Condition

Check compressor functionality

Check room temperature and RH.

Recording and Recording System

Prepare new formats for needle breakage, efficiency, daily production and operators' effectiveness

Attend yarn breakage and record cause of breakage.

Check and conducting of recording system of fabric defects if not exist