



Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical & Industrial Engineering

**Quality Enhancement of a Garment Sewing Process
through Six sigma and Failure mode and effect analysis: A
case of Eltex Textile and Garment Factory**

A Thesis Submitted to the School of Graduate Studies of Addis Ababa
Institute of Technology, Addis Ababa University in partial fulfillment for
the Degree of Master of Science in Industrial Engineering

By: Mustefa Mohammed
Advisor: Dr. Kassu Jilcha (PhD)

Addis Ababa, Ethiopia
July, 2023



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“Quality Enhancement of a garment sewing process through six sigma and failure mode and effect analysis: A case of Eltex Textile and Garment Factory”

By

Mustefa Mohammed Mustefa

Approved by the Board of Examiners:

<u>Kessu Dicha (PhD)</u> Advisor Name	 Signature	<u>July 18/2023</u> Date
<u>Gezakegn T (PhD)</u> Internal Examiner	 Signature	<u>July 18/2023</u> Date
<u>Temessen G (PhD)</u> External Examiner	 Signature	<u>July 18/2023</u> Date
<u>Dr. Araya Abera</u> School Dean	 Signature	_____ Date
<u>Dr. Sosina Mengistu</u> Associate Director for PG Program	_____ Signature	_____ Date


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Declaration

I hereby declare that the work which is being presented in this thesis entitled “Quality Enhancement of a garment sewing process through six sigma and failure mode and effect analysis: A case of Eltex Textile and Garment Factory.” is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been duly acknowledged.


Mustafa Mohammed

31 July 2023
Date

This is to certify that the above declaration made by the candidate is correct to the best of my Knowledge.

Passer Sircha (PhD) 

Aug 24/23
Date

ACKNOWLEDGEMENT

I would like to give special thanks to my advisor Dr. Kassu Jilcha, for his valuable comments and full insights as well as to my co-adviser Mehret Getachew for her comments and shaping out the research work. Their effort and guidance helped me to gain more knowledge and skills that is resulted in the development of this little but important paper. I would also like to give special thanks to Mr. Daniel who is the operational director of Eltex Textile and Garment Plc., Bishoftu plant for allowing me to freely conduct my study on sewing quality and for his facilitating role to get the information needed from different work sections. I would also like to thank Mr. Wondimagegn who is the planning head in the same factory. My heartfelt thanks also goes to production manager, sewing in charge, quality and maintenance heads for their wonderful explanation of quality issues and feed backs on this research work. I would also like to thank to all those line supervisors and quality personnel who participated in the development and application of failure mode and effect analysis tool. Last but not least I would like to thank my fellow colleague Mr. Samson Tesfaye for his encouragement and advises during the research work.

ABSTRACT

The Ethiopian Textile and garment sector is one of the top priority manufacturing sectors that is given due attention by the government for its generation of foreign currency and job creation for its increasing population. However, the sector faces challenges related to productivity and quality due to several reasons such as poor work culture, skill gap, inappropriate methods and poor system integration. The objective of this study is to improve quality of a garment sewing process through a continuous quality enhancement model. Previous literature on six sigma frameworks in the garment industry do not take into consideration key performance indicators other than defect per hundred units or percentage defectives, such as efficiency, productivity, and cost per SAM or cost per garment. Similarly most six sigma frameworks are not backed by cost/benefit impact analysis hence this research incorporated key performance indicators along with cost/benefit impact analysis by taking 128,311 samples from five product styles in one of the export based company located outside Addis Ababa. The study included an extensive investigation of secondary data in the form of literature reviews and company quality reports, while primarily data is collected through observation, formal and informal discussions with top and middle management. Secondary data collected from the case company shows an average defects per hundred units (DHU) of 19.7%. Data collected from the case company identified significant out of control situation for polo categories and slight out of control situation for the t-shirt categories. Pareto analysis identified six major defects contributing to 82 % of quality reworks. Furthermore questionnaire is used for conducting failure mode and effect analysis. Root causes identified are prioritized using failure mode and effect analysis and improvement solutions presented. Based on the results obtained from quality enhancement model DHU is reduced by an average 5.3% from the existing 19.7 % to 14.4%. Whereas as efficiency and cost per SAM improved by an average 5.6% and 0.76 Birr respectively. The study demonstrated that continuous quality enhancement model comprising six sigma and failure mode and effect analysis have a strong impact on the financial stability of the company.

Keywords: Quality enhancement, Garment industry, Sewing process, Six Sigma, Failure mode and effect analysis

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LIST OF ABBREVIATIONS

DHU – Defects per Hundred units

DMAIC -Define, Measure, Analyze, Improve and Control

DPMO- Defects per million Opportunities

ETIDI – Ethiopian Textile Industry Development Institute

FMEA – Failure Mode and Effect Analysis

QC- Quality Control

RMG – Ready-Made Garments

SPC - Statistical Process Control

TGIRDC- Ethiopian Textile and Garment Industry Research and Development Center

TQM- Total Quality Management

USD – United States Dollar

Br - Birr

CHAPTER ONE

1. Introduction and Problem Approach

1.1 Introduction

Nowadays quality has evolved to become a strategic importance instead of being a technical issue. Companies compete in the global arena based on their quality of products or services delivered. Quality has significant impact on the reputation, competitiveness and profitability of any organization, as a result, it has got due attention from researchers and industry managers. Quality has different meaning to different user's, quality Guru's define quality as fitness for purpose and conformance to requirements (Hebo, 2022). Quality in the Ready-made Garment (RMG) industry is not different from other industries. The era of fast fashion in the apparel industry has made quality, productivity and on time delivery as factors of competitive advantage.

A study by Bashir et al., (2019) identified cost of quality in the textile and garment sector to be 6.8% of sales, furthermore, the study identified internal failure cost to be the maximum in both textile and garment sectors. The existence of defects in the apparel production makes the company vulnerable to various losses. Defective garments result in either reworks or rejects. Reworks consume resources such as material, manpower and energy and whereas rejects are total loss to the company. If defects are found before shipment, the shipment will be delayed. If defects are found after delivery to the customer, there is a probability of current and future order cancellation. As a result of this quality issues, the risks involved in the export RMG industry is greater. Mahnaz and Ejaz, as cited by Michael and Charles (2017) states that in the apparel manufacturing, a good quality management system should be concerned about the inputs used, the skill of the workers and also should have adequate sewing machines which that use quality threads. All these literature emphasize the importance of right first quality production.

Various tools are developed to improve the quality of a manufacturing process such as quality function deployment, plan do check act (PDCA), failure mode and effect Analysis (FMEA), statistical process control (SPC), and DMAIC (Define, Measure, Analyze, Improve and Control) methodology of Six Sigma. The six-sigma approach is effective for variation control, whereas statistical process control tools such as control chart, Pareto and fish bone diagram are important data analysis tools. The failure mode and effect analysis is a risk prioritization tool.

Quality of a garment sewing process is not well researched area by the academic community. There is also significant quality related problems specifically in the export based local garment factories. The aim of this research is to develop a quality enhancement model that enhances quality of a sewing process.

1.2 Background and Justification of the study

The garment industry is one of the top foreign currency earning and job creation sector for different countries. The export earnings from ready-made garment industry of Bangladesh in 2019 G.C stood at 30.61 Billion USD (Samad et al., 2021). Similarly the Bangladesh ready-made garment industry contributes to 83% of foreign currency earning and created 20 million jobs (Islam, 2017).

Garment industry is one of the most labor intensive industries. As labor costs in developed countries become expensive, the garment industry migrates to developing countries such as Ethiopia in search of cost effective labor. In Ethiopia since 2014, many Industrial parks which produce export garment items are established with the purpose of generating direct foreign currency and creating job opportunities for its increasing population. However, the export earnings from garment industry of Ethiopia in 2021 G.C stands at 181 million USD. The productivity and quality of Ethiopia's garment companies is low compared to global best performers.

Non conformity is one of the great issues that the Ethiopian manufacturing industry faces accounting to 41% of the total export value of the country (Beshah et al, 2015). Based on a survey by Demissie et al (2017), from 11 Ethiopian garment enterprises, the major quality related problems in the garment enterprises are summarized as: poor supplier relationship, lack of proper education and trainings, poor leadership, weak external customer focus, unavailability of self-evaluation techniques, poor quality control, poor quality design, low technological level, lack of teamwork, and lack of recognition activities.

In the garment industry all the processing steps from cutting, and sewing to finishing are responsible for different kinds of defects (Amhed, et al, 2019). However, the sewing section of a garment manufacturing unit contributes to high rate of defects in the garment industries (Bahadir, 2016, Hewan 2017, Kassu et al, 2019, Lemma 2019).

Studies indicate that six sigma has positive and significant impact on enhancing quality of a garment production process. A study by [Hewan \(2017\)](#) implementing 5 phases of the DMAIC methodology of lean six sigma at MAA Garment Company reduced the top sewing defects of a t-shirt production process. A study utilizing the DMAIC methodology of six sigma reduced the defect percentage in the sewing section from 11.229 to 7.604 ([Uddin et al., 2014](#)). Similarly by the implementation of Six sigma in the sewing section of a garment industry, a study found that the percentage of defective items were reduced from 13.42% to 7.26 ([Mirdha et al., 2019](#))

Studies also indicate that SPC has positive and significant impact on enhancing quality of a garment production process. [Linzi et al., \(2018\)](#) in their study implemented statistical process control in the sewing section of Garment industry and managed to improve quality by reducing alteration rates from an average of 9.14% to 6.4 %. A study also showed that by application of SPC tools such as Pareto analysis, root cause analysis and control charts, sewing defects are reduced from 8% DHU to 4% DHU ([Patil, et al, 2017](#)).

Failure mode and effect analysis (FMEA) is a very structured and reliable tool for evaluating product and process failures. It consists of identifying each failure mode, possible causes, probability of occurrence, consequences, and proposes safeguards. [Hannufudin and laksono \(2019\)](#) prioritized 6 critical failure modes out of a total of 14 failure modes identified and reduced defect percentage by 0.7% in a sewing section of a shoes manufacturing plant.

Eltex textile and Garment Plc. is a privately owned apparel manufacturer established in 2004 G.C in Debrezeit, Ethiopia. Currently the company has 11 production lines and employs a total of 550 workers in various sections. Some of the products include t-shirt, jogger, jacket, shorts and polo shirts. The company produces for both local and export market, and hence generates foreign currency for the country. The company faces challenges due to high defective rates of the sewing section specifically to the export products of polo and t-shirts as shown in the following table.

Table 1:1 Preliminary quality assessment

Style: V- Neck M11959M1					
Date checked	Total pieces checked	Total Defects found	Total pass	DHU	Percentage defective (%)
3-30/9/2014	35650	3668	31972	10.288	10.32

Source: Company quality check- sheet (2014-2015 E.C)

1.3 Statement of the problem

Ethiopia is a developing country currently transitioning from an agriculture led economy to industry based economy. The textile and garment sector is one of the development sectors that is given due attention by the government of Ethiopia for its high generation of economic benefits and job creation. As such the manufacturing sector including the textile and garment sector faces different challenges with regards to productivity and quality. However, the sector faces various challenges which can be categorized as internal and external. A study by [Selamawit \(2018\)](#) identified employee turnover, raw material, employee skill, product quality, infrastructure, logistics, marketing and technology as major challenges affecting the production capacity of Ethiopian Garment Industries. Studies also indicated that the Ethiopian Garment industry is characterized by high rate of turnover and absenteeism, Low productivity and poor working conditions ([Demissie, 2021](#)).

Some of Quality performance parameters used in the garment industry include Defects per Hundred units (DHU), percentage defective, first time pass, and cut-to ship ratio. However, the most frequently used quality parameter in garment industries is DHU or percentage defective. According to a study by [Bahadir \(2016\)](#), sewing defects constitute around 65% of total defects in a jeans manufacturing plant. According to a study by [Hewan \(2017\)](#), the sewing section constitutes to 6 % of the total garment reworks, whereas finishing section, Embroidery and printing, and the cutting sections constitute to 3.5%, 2% and 0.5 % reworks respectively. A study also found out that sewing defects contribute to 30.3% of the total garment defects ([Kassu et al, 2019](#)). Hence, the sewing section constitutes the major portion of defects in a garment manufacturing process.

Furthermore, most of the sewing defects are related to machine, material, methods and manpower. A study identified that around 50% of skip stich defects are caused by machine whereas material, method and manpower issues constituted to 25%, 15% and 10 respectively, it also identified equal contribution on the creation of stain spots in the garments ([Muhammad et al., 2021](#)). Textile and garment defects are one of major areas of research by academicians and practitioners around the world. Besides in Ethiopia very little researches have been done to address the issue of high sewing process defects faced by local garment manufacturers.

Analysis of quality reports in sewing section of the case company as shown in the previous section is found to be lower compared to the international benchmarks. Preliminary data of the specified product showed an average of 10.28 defects per hundred units inspected (DHU).

The proportion of defective items also stand at 10.32 %. As a result of the aforementioned quality problems, this research aims to address the following basic research questions.

1.4 Research Question

This research tries to address the following research questions

1. What are the root causes of sewing defects in a garment industry?
2. How do quality issues affect key performance indicators?
3. What are the quality enhancement tools used to enhance quality of a sewing process?
4. How to improve quality of a garment sewing process through continuous quality enhancement model?

1.5 Objectives

The research work have the following general and specific objectives

1.5.1 General Objective:

The general objective of this research is to enhance quality of a garment sewing process through six sigma and FMEA approach.

1.5.2 Specific Objectives:

- ❖ To measure End-table DHU (defects per hundred units) of a sewing process
- ❖ To identify the major sewing process defects and their root causes
- ❖ To assess the impact of quality issues on key performance indicators (KPI's)
- ❖ To develop a model for continuous quality enhancement of a sewing process.

1.6 Scope and limitation of the study

1.6.1 Scope of the study

The study mainly focuses on controlling assignable causes of defects in the sewing process of garment manufacturing so as to find ways of improving sewing quality. From literature identified in the problem statement, most of garment defects occur in the sewing process. Hence, the research focused on the sewing section of a garment factory. The research study was conducted in a locally owned Garment factory near Addis Abba that is engaged in export of apparel products. The research includes 100% export products and does not consider products for local market.

1.6.2 Limitation of the study

One of the limitations of the study was unavailability of continuous data, since export order production is limited in quantity, the data includes products produced in 2014 and 2015 E.C. however data is carefully selected from both years. There are issue with the recording of check sheets by some of end-line quality personnel as there exists missing information, however when conducting this study, completed quality check sheets having full information of defects is considered while taking the sample.

1.7 Significance of the study

The major beneficiaries are the case company in particular and the garment industries in general, since improving quality of production process is one of the core requirements to improve profit margins, attract buyers and stay in the export market. Top and middle management of the company also get awareness about the situation of sewing quality. A document detailing quality status of the sewing section and its impact on company key performance indicators was delivered. The results of the study is expected to benefit the case company by reduction of rejects and reworks and by becoming profitable and competitive.

Local garment factories that have export base have a long-standing problem with regards to productivity, quality and on-time delivery. This research is a case study that shows how an export based local company faces quality related challenges in the sewing process. The study is important as it explores the unexplored and also paves the way for future studies on similar areas, as a result it would become an addition to the existing body knowledge.

1.8 Organization of the Paper

The research was structured and categorized in six main chapters. Chapter one includes an introduction, background and justification as well as problem statements and research objectives. Besides, a brief discussion on scopes, limitations and significance of the research is explained. Chapter two covers a systematic literature review on a wide range of topics related with quality in general and quality of a garment industry and sewing process in particular. In chapter three, the research design approach and methods of data collection, data analysis, and interpretation techniques, determining sampling size, and ethical considerations are discussed. Chapter four of the research includes presentation and analysis of data followed by development of sewing process quality enhancement model in chapter five. Chapter six which presents conclusion, recommendation part of the research based on the results obtained in chapter five. Similarly future research areas are also provided in chapter six.

CHAPTER-TWO

2. Literature Review

2.1 Literature Survey and Data Sources

A review of literature has been conducted on the existing literature to get empirical knowledge and to identifying research gaps for the investigation of this research work. This literature survey covers the concept of quality, Statistical process control, six sigma and failure mode and effect analysis. The reviewed articles are gathered from leading databases such as Emerald, Taylor and Francis, and Google Scholar dated from January 2005 to 2022. The following figure below show the number of reviewed paper and the trend of tools.

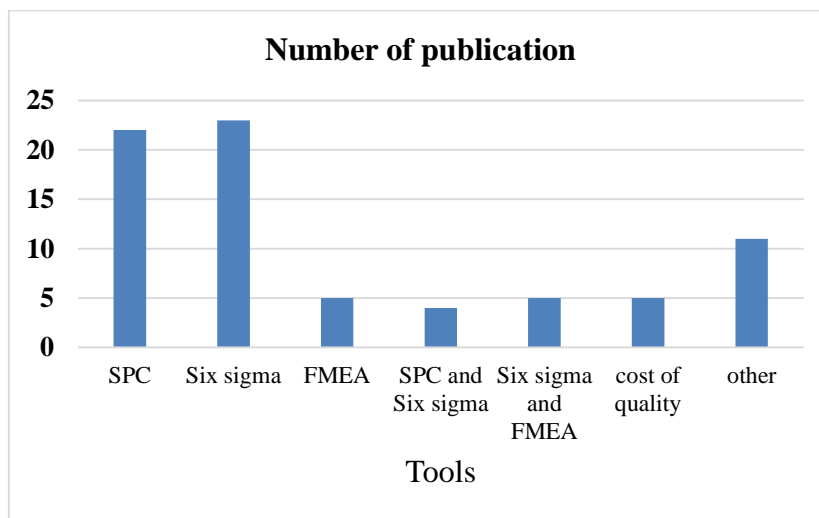


Figure 2.1 number of publications against the quality improvement tools

The types of paper reviewed in this research varies according to journal, conference proceeding and other as shown in the following figure

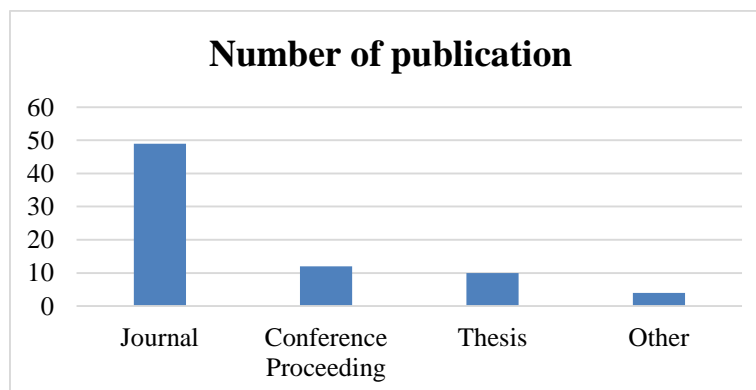


Figure 2.2 number of publication against type of paper

Similarly reviewed papers varies according to their publication dates. The following figure shows that publications related to quality improvement tools such as SPC, six sigma and FMEA publication have increased from 2005 to 2019.

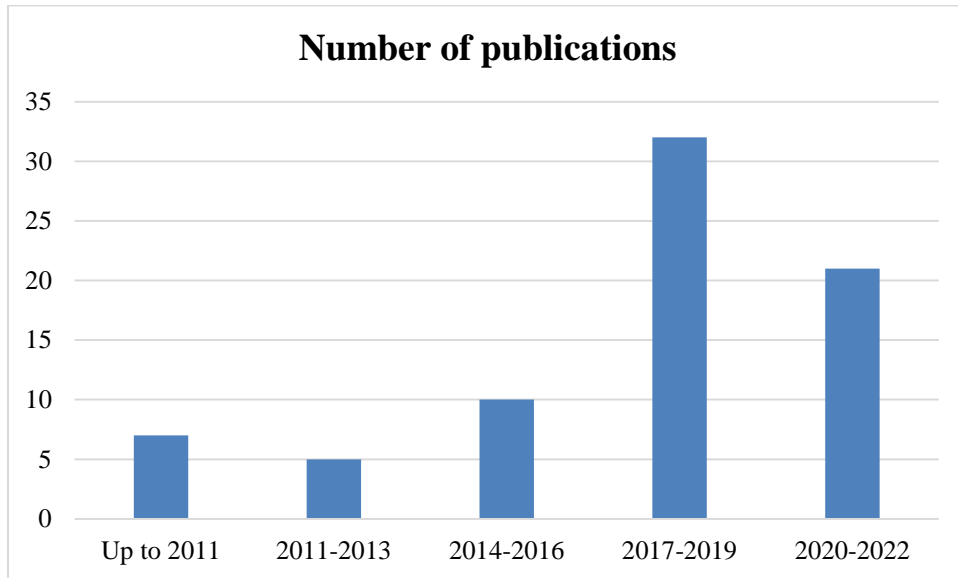


Figure 2.3 Number of publications against years

Similarly, considering the geographical spread of publications, the publications are widespread across America, Africa, Asia, and Europe. In the following figure below the continental spread of publications related with quality improvement tools is provided

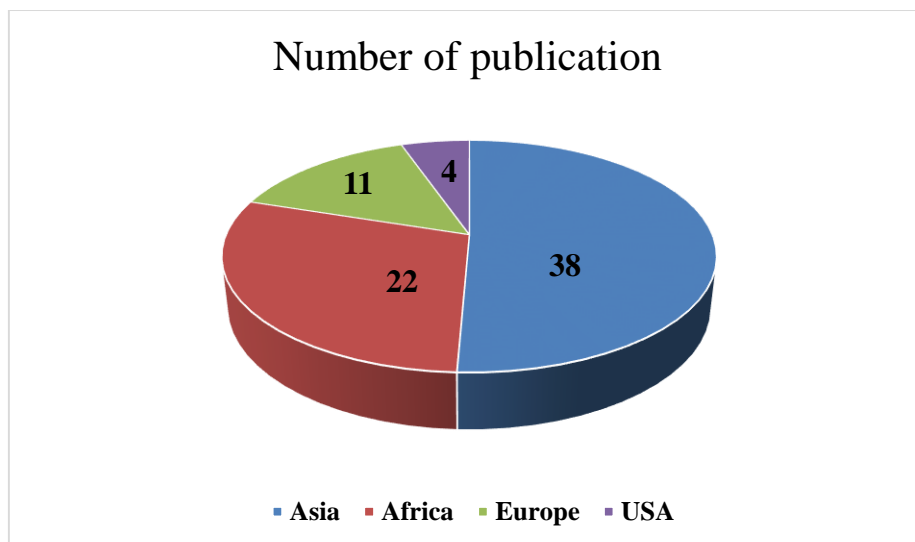


Figure 2.4 Continental spread of publications

2.2 Concept and Evolution of Quality

The term Quality is very common to all industries. Quality can be described as the degree of excellence or conformance to the requirements. According to the online business dictionary quality may be defined in manufacturing, as a measure of excellence or a state of being free from defects, deficiencies and significant variations. [Giovanna Culot, \(2019\)](#) states that Quality can refer to either product (or service) or a process that generates it. As a result there are multiple dimensions of quality. The author discusses different dimensions of product and process quality from the perspective of customers, production personnel, marketing personnel, and also from the views of companies and academician. A simple and more general definition of quality is given in 1974 by Juran as fitness for use ([Habibur Rahman, 2019](#)). Reeves & Bednar, as cited by [Giovanna Culot, \(2019\)](#) states that quality is multi-faceted and is fundamentally context-dependent. It is brought about by a strict and consistent commitment to certain standards that achieve uniformity of a product in order to satisfy specific customer or user requirements.

Since the turn of the 20th century quality improvement has matured significantly. New quality systems have evolved from the foundations of Deming, Juran and the early Japanese practitioners of quality, and quality has moved beyond manufacturing into service, distribution, healthcare, education and government sectors. During the last three decades, simple inspection activities have been replaced or supplemented by quality control, quality assurance and now most companies are working towards Total Quality Management TQM ([Mohammed Mijanur, 2013](#))

[Albert Weckenmann et al., \(2015\)](#) identified four paradigm shifts in the evolution of quality these are product quality, process quality, quality management and total quality management. Product quality came as a result of mass production during the 1900-1940's. Marked by inspection of final products before delivery to the customer, the main aim is to prevent failure of products before delivery there by reducing customer complaints. One of the draw backs of quality inspections is that it address failures or con-conformances after they have already occurred which results in more scraps, consumes manpower resources and results in less company efficiency. During the era of process quality, quality activities are conducted in line with the production process by helping an early identification of failures and prevent waste production thus making the first shift from quality inspection to quality control.

During the Second World War quality control practices have been widely implemented by the US defense (Giovanna Culot, 2019). Tools like statistical process control or SPC which was developed by Shewhart in 1920's and plan do-check act or PDCA, a management tool developed by Deming have been used during this phase. The 1960's marked close cooperation among countries as a result it demanded different markets and hence a different quality perspective creating the second shift of quality management (Albert Weckenmann et al., 2015, Giovanna Culot, 2019). At this stage quality assurance has replaced quality inspection and quality control as a quality management concept evolved this period marked the development of a series of quality standards apart from the extensive application of existing tools.

Quality at the turn of the millennium marked by development of Total quality management concept which identifies the need for the involvement of all employees for the quality of products and services delivered. Total quality management concept also requires the involvement of various stake holders to the design, production and delivery of products and services. Various quality standard systems have been developed during this period such as the ISO (International organization for standardization).

Quality can be defined in different ways depending on who is defining it. Different authors define quality in different ways. As a result the term quality has always been an issue of contention among suppliers, manufacturers and customers. Previous literatures indicate that the concept of quality is evolving from technical perspective to strategic aspect as a result it is linked to key parameters of a business performance.

2.3 Concept of Process Quality

A process is an operation or a series of activities that transform inputs to outputs in the form of goods and services. Sofjan Assauri cited by Octora and Mustafa (2021) states that the production process is a method and technique to create or add to the use of a good or service by using resources such as labor, machinery, materials and funds. Kane (2020) states that Process defects include scrap, rework/repair of products, customer complaints, returns, or repeat services. Continuous improvement of a production process or service is an important aspect for today's organizations to remain competitive in global market. A competitive market environment requires enterprises of various industries to emphasize quality aspects in improving the process, quality and performance of their company. According to Bousdekis et al., (2022).

Product-oriented quality studies the defects on the actual parts and tries to find a solution, while process-oriented quality studies the defects of the manufacturing equipment, and based on those can evaluate whether the manufactured products are good or not. Manufacturing defects can occur either on the product development stage or the production stage. Defects that occur in the manufacturing stage can be detected either during production or at the end of production however, process quality is concerned with identifying those defects at the production process and tries to correct them before they move along the process. By doing so, defects such as reworks, scraps and rejects can be eliminated or minimized. Therefore, process quality tries to address variations that emanate from a manufacturing process. Process variations are deviations from the expected standard. Variations are expected in every manufacturing process however, variations can be either common or assignable. Common variation are chance factors that does not make the process to be unstable whereas assignable variations are special causes and their existence makes the process unstable. All manufacturing organizations process quality makes sure that there are no special causes of variation so that the process remains stable.

2.4 Quality enhancement Tools

There are various quality enhancement tools or methods some of these include statistical process control or statistical quality control, six sigma, Failure Mode and Effect Analysis (FMEA), Taguchi method, Quality function Deployment (QFD) and Design of Experiments. In the following section major quality enhancement tools such as statistical process control, six sigma and failure mode and effect analysis is reviewed.

2.4.1 Statistical process Control (SPC)

Statistical process control includes the Seven Basic Tools of Quality which can be used to analyze and subsequently intervene to eliminate the problems from the production system. The seven basic statistical process controls include check sheets, histograms, Pareto chart, control chart, scatter diagram, process flow chart and root cause analysis.

The seven basic tools of quality are a formalized body of techniques involving tabulating, depicting, and describing data sets to make the quality of the products or services visible. After making the quality of a process visible it is possible to take appropriate actions. Statistical process control (SPC) is an important and powerful technique for the continuous improvement of product and process quality (Jiju et al., 2000). The main purpose of SPC tools is to detect and prevent the occurrence of defects to the products or process

SPC has long been practiced and utilized extensively in the quality aspect of the manufacturing sector (Yunus et al, 2017). Most of the statistical process control tools does not require advanced knowledge and skill to conduct and hence employed by most of the manufacturing industries. According to Montgomery (2005), the main objective of Statistical process control (SPC) is to identify effective factors on quality, monitor manufacturing process and eliminate special causes of variation. Special causes of variations are assignable factors which if eliminated can make the process to be in statistical control. One of the tools to identify special causes of variation and process stability is through control charts. Neyestani (2017), states that control chart powerful tools that identify process variations, Control chart is the most complex statistical tool among the seven basic tools for quality personnel as it requires a special knowledge to calculate the mean, the upper and the lower limits of the characteristics (Abdel-Hamid and Abdelhaleem 2019). Pareto can be employed to prioritize using 80/20 principle, Cause and Effect diagram also called Fishbone diagram shows the root cause of problems generally related to machine, material, method and manpower.

SPC are one of the extensively used quality improvement tools by the manufacturing sector. Isniah and Purba (2021), reviewed literatures on the application of SPC in the manufacturing sector between 2015 -2020 G.C. and identified 15 journals that focus on reducing defects and improving processes in the manufacturing sector. The study also concluded that an objective application of the SPC method can result in the elimination of waste by reducing defects and increasing quality and improving the process. According to Rai, (2008). Statistical process control tools are universal in nature, however their applicability varies from industry to industry.

2.4.2 Six Sigma

Six sigma is developed at the Motorola Company in the mid 1980's, however it is further promoted by General Electric Company in the 1990's (Desai and Aurangzeb, 2016). Six sigma is a powerful variation reduction tool in a manufacturing industry it has been widely used by industries both in the manufacturing and service sector. Six sigma is a quality improvement tool that aims to reduce defect rates to 3.4 per million. However, definitions for six sigma varies, accordingly some define six sigma from the quality and productivity perspective while others define six sigma from the perspective of business performance and excellence (Reosekar and Pohekar, 2014). Since six sigma combines quality improvement with business performance (Jung 2013), its application is increased in the last decades.

Selamat and Fabri (2022), studied 16 manufacturing firms which implemented six sigma in Indonesia and found that six sigma initiatives reduced the defect and hence cost of poor quality is reduced and it brings better process performance. The Six Sigma approach has been increasingly adopted worldwide in the manufacturing sector in order to enhance productivity and quality performance and to make the process robust to quality variations (Desai and Shrivastava, 2008).

Almost all six sigma models uses the DMAIC methodology (Define, Measure, Analyze, Improve, and Control) to analyze processes and to reduce sources of variation that exceed tolerances (Selamat and Fabri, 2022). The DMAIC methodology has also been widely used in the textile and garment industry by academicians and practitioners. (Hewan, 2016, Dinulescu and Dima 2019, Bayu, 2020, Hibarkah et al., 2021, Hibarkah et al 2022). The define phase analyzes the problem and it clarifies the problem. At this stage the objective of the project should be clearly identified and tools such as process flow chart and SIPOC chart (supplier, input, process, output and customer) should be studied (Espadinha-Cruz et al., 2021). The measure phase assess the problem to a measurable parameters such as critical to quality (CTQ). In the analyze phase, the problem that has been measured is analyzed to find out the causes and effects that impact the process. In the improve phase, various improvement tools and techniques are devised so as to improve the existing situation. Finally the control stage makes adjustments and control techniques that aids in continuous improvement of the process.

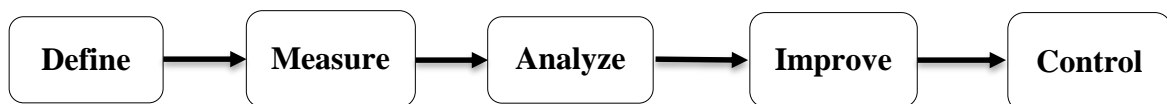


Figure 2.5- DMAIC Methodology. Espadinha-Cruz et al., (2021)

Ali and Sarjono (2022), systematically reviewed 46 literatures that implemented lean six sigma in the textile industry and found that successfully implemented companies have increased product quality, reduced average damage or products defect, increased the efficiency of the process, and reduced costs in the processes of the company. Similarly Citybabu and Yamini, (2022) reviewed The implementation of Lean Six Sigma framework in the Indian context and found that there is a lack of Lean Six Sigma implementation framework for specific industry and critical metrics of evaluation before, during and after implementation. There are some success factors for effective six sigma implementation. The most cited success factor for six sigma include strong top management commitment and involvement, selection of six sigma project, alignment of six sigma objective to corporate business objective, and measurement (Gamal Aboelmaged, 2010).

The same study also identified customer satisfaction as the most cited benefit of six sigma project. Similarly there is lack of adequate literatures that combines six sigma framework with financial performance analysis (Sosnoski, 2014. Mahato et al., 2017, Sandeep et al., 2022, Tribby 2022). Since the outcomes of six sigma implementations such as cost and efficiency determines organizational ability in adopting Six Sigma approach (Lee, 2015), Management’s Intention and Commitment can be brought by the deployment financial impact analysis. In general, six sigma projects have a potential to be a good quality and productivity improvement tools in the garment industry. By combining six sigma with key performance indicators of the factory, the application of six sigma can be a critical quality improvement model for the textile and garment sector in particular.

2.4.3 Failure Mode and Effect Analysis

Failure mode and effect analysis (FMEA) is a very structured and reliable tool for evaluating product and process failures. It consists of identifying each failure mode, possible causes, probability of occurrence, consequences, and proposing safeguards. The application of failure mode and effect analysis dates back to 1949 when the US Army used it in the aeronautic sector in order to solve reliability and safety problems during the design and production phases.

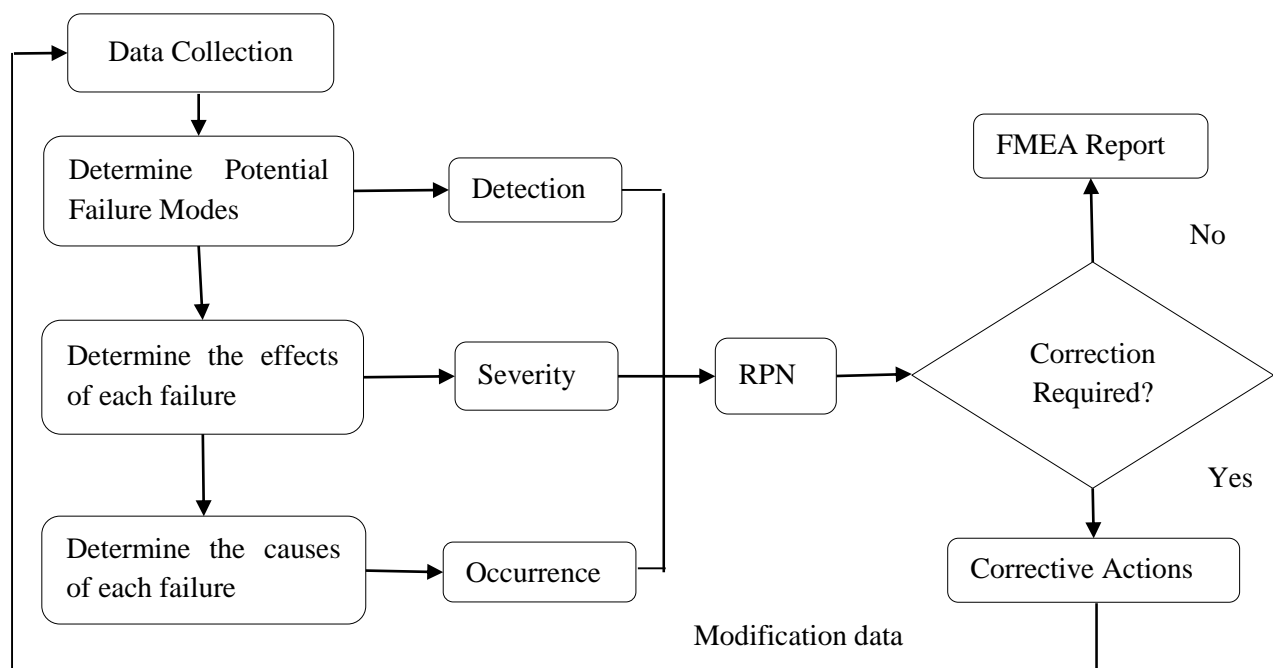


Figure 2.6- Failure mode and effect process. (Paciarotti, et al. 2014)

The rating scales for failure mode and effect analysis usually range from 1 to 5 or 1 to 10, with the highest number representing seriousness of the risk level. The specific rating scales are determined by the organizations or project teams that best suits the analysis.

Hawkins and Wollons, as cited by [Paciarotti, et al. \(2014\)](#) describe FMEA as a good strategy for implementing risk management by providing qualitative and quantitative information about safety and reliability of simple products and complex systems. According to [Hartono et al., \(2021\)](#) Failure Mode and Effects Analysis can identify potential failures and confirm important and significant characteristics to be addressed with design changes, processes, or inclusion of control plan in a process. [Yonas and moorthy \(2014\)](#) conducted machine Failure mode and effect analysis at plastic pipe manufacturing factory and recommended the necessary corrective actions to improve the performance of the process unit. There are few researches conducted through the application of FMEA in the textile and garment industry.

A study by [Bahadir \(2016\)](#) identified 14 potential root cause of failures of a jeans manufacturing plant and identified 6 s as a critical failures by using FMEA. Furthermore FMEA can also be used to identify failures which in some cases can be customized as not being able to meet customer's requirement ([Bethelhem, 2017](#)). Hence FMEA can be used to identify the main factors that satisfy customer needs. A study by [Sissay et al., \(2018\)](#) conducted at the weaving section of a textile factory reduced weaving machines down time from 39% by 14% through the application of failure mode and effect analysis.

In general, the main purpose of failure mode and effect analysis is to identify and resolve products and processes that lead to accidents and incidence of failure. However there is lack of adequate literatures on the applicability of failure mode and effect analysis on the textile and garment sector specifically in the garment sector. Detail review of literatures on the combined application of six sigma and failure mode and effect analysis is given in Appendix 3.

In summary few researches have tried to show six sigma implementations with cost and/or benefit impact analysis ([Desai and Shrivastava, 2008](#), [Gijo, and Scaria, 2010](#), [Jiju et al., 2012](#), [Abhilash et al., 2019](#)). Similarly most six sigma frameworks applied in the textile and garment sector to reduce defects and improve quality only considered Defect per hundred units and/or percentage defective as the sole key performance indicator ([Hewan, 2017](#), [Ahmed et al., 2019](#), [Dinulescu and Dima, 2019](#), [Hibarkah et al., 2022](#)).

2.5 General overview of the Garment Industry

Garment manufacturing is an organized activity consisting of sequential process such as laying, marking, cutting, stitching, checking, finishing, pressing and packaging. Garments are sewn in an assembly line, with the garment becoming more complete as it progresses down the sewing line. Sewing machine operators receive a bundle of cut fabric and repeatedly sew a portion of the garment, passing that completed portion to the next operator. For example, the first operator may sew the collar to the body of the garment and the next operator may sew a sleeve to the body. The garment process starts from the receipt of order confirmation, preparation of job order then to the cutting, sewing, finishing section then to final inspection and delivery to the customer. This labor-intensive process progressively transforms pieces of fabric into designer garments.

Garment industry is one of labor intensive industries in the world as a result productivity of the workforce is critical to the success of factories in this sector. Production process of any business unit is mainly concerned with the creation of product required to satisfy customer need and desires. The most important task for the garments industry is to remain competitive in the global network of apparel suppliers. To achieve this, garment companies should reduce lead time, improve quality and productivity which is important for long-term stability of the industry.

2.5.1 Background and Performance of the Ethiopian Garment Industry

The industrialization of Ethiopian textile industry started in the 1950s. In 1958 Italy constructed the now Bahir Dar Textile Share company as a form of war-reparations. 1961 three Italians established Augusta Garment Company known by its current name as Addis Garment Share Company. Since 1990's with privatization of public enterprises, investments in the textile and garment sector increased (Matebu, 2009). In 2010, the Ethiopian government has designed industrial development strategy giving the textile and apparel sector as one of its top priority sectors. Currently, the government of Ethiopia is making efforts towards realizing a developed and prosperous Ethiopia through its ten years (2021-2030) national development and prosperity plan. The policy has thus identified priority sectors that deserve attention to build the required platform for the industry to play its key role in the economy. The textile and apparel industry is the top priority sector considering its comparative advantage.

Comparative advantages of the Ethiopian textile and apparel industry include: Geographical proximity to potential markets, preferential market access to the United States and European markets. Ethiopia is known to produce quality cottons considered as the white gold. Ethiopia has the second largest population in Africa which has abundant human resource with the furnished industrial parks that are established in the various regions of the country. The other competitive advantages of the Ethiopian textile and apparel sector include its ability to create forward and backward linkages. Therefore, building competencies in these product categories can attract many buyers in the US market. [ETIDI, \(2018\)](#) states that the efficiency of the Ethiopian garment industry is a slow as 40-45% in production. Based on the study the main reasons for decreasing the Ethiopian garment export values were related to the poor production process, product quality problem, lack of skills of the employee & management, low productivity, low employee wage, limited input material, long lead time, poor infrastructure, and lack of integrated system between institutes.

The export share of Ethiopian textile and apparel industry has shown an increase between the years 2016 to 2022 except for the year 2020 which is marked the corona-virus pandemic (Covid-19). Some of export destinations for Ethiopian textile and garment products include USA, Canada, Germany, Italy, and Turkey. In the following table the market trend of textile and apparel products for the last six years from 2016/117 to 2021/22 is shown

Table 2.1 Export Performance of Ethiopian Textile and Apparel Industry

Fiscal Year (GC)	Total Export in (Million USD)
2021/22	181.0
2020/21	140.0
2019/20	171.0
2018/19	153.5
2017/18	109.0
2016/17	89.34

Source: [\(TGIRDC, 2023\)](#)

2.5.2 Quality management in the garment industry

Certain quality related problems, seen in garment manufacturing are, color variations, size variations, sewing defects and finishing defects (Rahman et al., 2009). Garments at the sewing process are checked According to parameters such as thread Tension, stitch per inch (SPI) measurement parameters and attribute qualities such as broken stitch, oil spot, uneven seam etc. Oktora and Mustafa (2021) identified non conformities in the garment factory as Sewing errors, the installation of attributes that are not neat, Color differences/fading colors, Tears and holes in fabrics due to mishandling and Order error. The same study also identified factors that cause non conformity of the company's products which as shirts and pants as Raw Materials, Machine and Equipment, Human Resources, Method and Work Environment.

Mazdul Islam et al., (2012) categorized sewing department defects and identified sewing defects, seaming defects and placement defects that contribute to 20.73%, 14% and 3.37% respectively which combined together resulted in 38.1 % out of the total DHU of 39.22. The remaining defects in the same study are fabric defects and embroidery defects which contributing to 1.02 and 0.10% respectively.

Quality activities in the garment industry are conducted starting from the inspection of fabric rolls using a 4 point or 10 point system. Quality inspection is also conducted during cutting process and after cutting during bundling and sorting process before cut panels arrive for the sewing process. At the end of sewing process there is end-table quality where defect free garment will pass to the finishing section whereas defective garment are sent back to the sewing line for reworks. After finishing, there is a final quality inspection that checks overall garment quality before it is packaged and sent to the finished goods store.

2.5.3 Sewing defects that affect quality in a garment industry

Defect is a vital issue for poor quality products and low production rate. Defect in the garments industry is a common phenomenon that hampers the smooth production flow and rework of defective products have an impact on overall factory performance. According to a study by Mazedul Islam et al., (2012), Reworks increased the cost of the different work categories in the apparel industries between 2% to 30%. Reworks consume resources such as direct labor, material, energy and other indirect resources. Reworks are considered non-productive activities that the customer is not willing to pay. Since garment is labor intensive sector, labor cost is one of the significant cost factors.

A study by [Erol, \(2013\)](#) identified direct labor cost as the second largest cost item after the material and accessory cost. Furthermore the study revealed that labor costs in sewing department were affected mostly by the duration of sewing and efficiency of production process. Hence increased reworks result in increased labor cost. The quality of garments is vital in an increasingly competitive apparel industry. In order to maintain the production of high quality garments and improving productivity in the apparel industry, Minimization of defects is a must in quality and productivity improvement ([Islam, 2017](#)).

Defects in the garment industry arise from the cutting, sewing or finishing sections. Previous literatures have shown that the sewing process has a high share of garment defect ([Hewan 2017](#), [Kassu et al, 2019](#), [Lemma 2019](#)). According to study by [Ahmed et al \(2019\)](#), defects in the sewing section include seam puckering, open seam or broken seam, skip stitch, uncut or loose thread, seam slippage, and needle thread breakage. A study identified that uncut thread and spots, waist belt, bottom hem, side seam and waist belt top stitch as major sewing defects contributing to 80% of all defects in woven pant production line ([Tanvir et al, 2013](#)). According to a study by [Kapuria et al \(2017\)](#), major defects identified in the sewing process which generate 80% defects are broken stich, open seam, pleat, skip stitch, label missing, and point up down.

A study by [Safa Tuna \(2018\)](#), also identified that 78 % of the non-conformance in a garment industry consist of garments out of tolerances and faulty stitches. A study by [Muhammad et al., \(2021\)](#) identified skip stich, stain spot and broken stich as a critical defects in a stitching unit contributing to 65% of all stitching defects using Pareto analysis. A study by [Rahman and Masud \(2011\)](#), also identified oil spot, skip stich and uneven stich as the major causes that contribute to 80 % of overall garment defects.

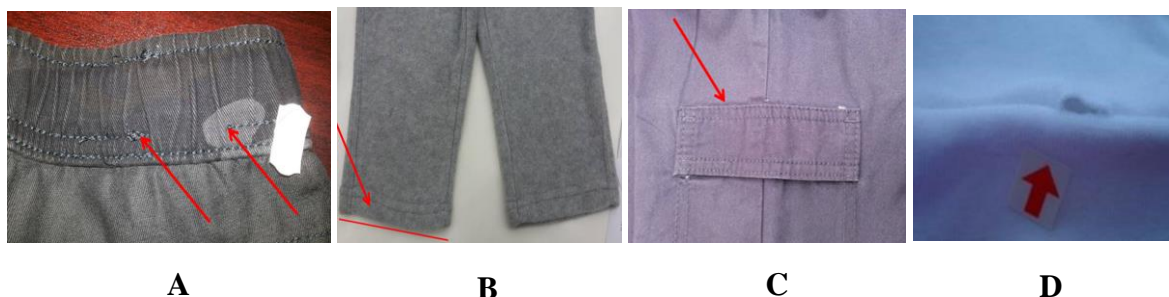


Figure 2.7- Examples of sewing defects (source: ETIDI 2018, Ahmed et al., 2019)

A) Broken stitch B) Shape out C) Unbalanced seam D) Open seam

The causes of defects of a sewing process are mainly related with machineries, manpower, the quality and characteristics of material and the stitching methods. [Chaudhary et al., \(2018\)](#) identified 8 factors that cause sewing damage and defects in the garment industry, these include the characteristics of yarn, fabric, needle, sewing thread, machine parameters, and working methods of the workforce. A study by Carol [Wanjiru Komu, \(2017\)](#) analyzed the impact of employee training, operating procedures, and quality department on relative garment quality in Kenyan small and medium apparel industries. The study identified there exist a positive relationship between these variables and quality of a clothing. Defect minimization is one of the major areas of reducing production cost and improving the quality. It also reduces the cycle time by reducing reworks and finally result in higher productivity ([Uddin et al., 2014](#)). A study clearly indicates that by eliminating non-productive activities like reworks in the apparel industry, time as well as cost are saved by ensuring quality products which has an important impact on overall factory economy ([Mazedul Islam et al., 2012](#)).

Most of previous researches conducted on the garment industry focus on identification of garment defects based on the sources of the departments. Previous researches indicated that sewing defects are the major sources of garment defects and by using statistical process tools analyzed the root causes of major ones. However, the impact of sewing defects on the business performance of the company is poorly discussed and quantitative data regarding key performance indicators is limited in availability.

2.6 Application of Quality Improvement tools in the Garment Industry

Defects in the garment industry arise from the cutting, sewing or finishing sections. Previous literatures have shown that the sewing process has a high share of defect occurrences ([Bahadir, 2016](#), [Hewan 2017](#), [Kassu et al, 2019](#), [Lemma 2019](#)). A study showed that by application of fishbone analysis to a garment defects, reduction of DHU (defect per hundred units) from an existing 7.73 to 5.43 has been achieved ([Miglani, 2018](#)). A study conducted by [Ebeyedengel \(2022\)](#) at a local garment factory showed that by application of Pareto analysis and cause and effect analysis, six major defects that contribute to 81.6% have been reduced by 14.3 to 67.3 %. A study by [Addis \(2019\)](#) also determined the most frequently occurring type of defects using Pareto analysis in a local shoes export factory. According to the study, three type of defects (Skipped stitches, Wrinkle not cut and Thread not cut) are the most frequently occurring defects which accounted for 72% of the total problems in the sewing section.

Most of previous literatures use one or more of the statistical process control tools to address the issues. From most literatures we can observe that sewing defects are analyzed using Pareto graph and fishbone analysis however there is lack of adequate evidence of process stability using different control charts. Control charts have not been widely used to address the process stability based on attribute data. Significant products samples are not taken in previous studies. There is also lack of literatures on developing industry specific quality improvement models. There is lack of literatures on the application of six sigma in the sewing process and the development of six sigma model that incorporates key performance indicators of the sewing process in the garment industry. When it comes to cost analysis of garment reworks due to defects, there are still gaps to quantitatively analyze monetary losses to companies.

In summary there is lack of adequate researches on the combined application of six sigma methodology and failure mode and effect analysis. DMAIC methodology of six sigma is a continuous improvement model that is has been widely accepted by manufacturing and service organizations in the past decades, whereas failure mode and effect analysis is a quality improvement tool that identifies and prioritizes various modes of failures of con-conformities for effective implementation of corrective actions. Failure mode and effect analysis is widely used by industries to improve safety and reduce non-conformities.

The combination of six sigma and failure mode and effect analysis is an innovative method to sort out failures and/or defects, identify and prioritize sources of failures and develop mitigation strategies for effective implementation of corrective actions. Hence this research focuses on applying DMAIC methodology of six-sigma along with failure mode and effect analysis in a local garment manufacturer by developing an effective quality improvement model to enhance quality of a sewing process and there by improve productivity and competitiveness of the company. The research gaps identified in the literature review are summarized in the following table.

Table 2.2: Summary of literature review

No	Author and Date	Title of the research	Tools/ techniques used	Research gap
1	Bahadir 2016	Failure mode and effect analysis an application in jeans production process	Defect check sheet, FMEA, organized FMEA team,	The research identified root cause of critical failures of a jean by using FMEA, considers only a single product
2	Hewan 2017	Minimization of Defects in Sewing Section at Garment and Textile Factories through DMAIC Methodology	Quality check sheet, Observation, questionnaire, brainstorming	Identified root causes of out-of-control situations, but has not developed improvement model for minimizing sewing defects.
3	Kapuria et al., 2017	Root Cause Analysis and Productivity Improvement of An Apparel Industry.	Pareto, 5S, PDCA, root cause analysis using brainstorming	Improved operator efficiency from 45 to 60%. Impact of quality not presented against KPI's.
4	Abteu et al, 2018	Implementation of SPC In The sewing Section of Garment Industry for quality improvement	Quality team, check sheets a mostly SPC tools,	Identified major sewing defects and their root causes, mostly used SPC tools but lacks process capability, KPI and considered a single product.
5	Kassu et al, 2019	The Impact of Quality Control Tools Application on Supply Chain Management	Check sheet, observation, interview, SPC tools	Studied impact of good quality on supply chain. But lacks mitigation strategy or improvement plan.
6	Muhammad et al., 2021	Identification and Analysis of Stitching Defects at the Stitching unit: A Case Study	Pareto chart, Root cause analysis	Identified the critical defects using Pareto and root causes analysis but does not use any quality improvement model.
7	Samad et al., 2021	Analysis of major defects and finding their root causes in a sewing section	Questionnaire, pareto chart, 5Why, RCA	focuses on ergonomic factors by Proposing an ergonomic workstation such as chairs and tables
8	Fandi Achmad et al., 2023	Proposed Design of Sewing Process Improvement to Minimize defect	Fishbone diagram, control charts, brainstorming and questionnaire	Developed a product for defect monitoring. however, the product is applicable for needle control and thread control

2.7 Gap from Literatures

Few researches have tried to show six sigma implementations with cost/benefit impact analysis Similarly most six sigma frameworks applied in the textile and garment sector to reduce defects and improve quality only considered Defect per hundred units and/or percentage defective as the sole key performance indicator. This research considers other key performance indicators such as efficiency, productivity and cost per SAM. It also addresses the root causes of sewing defects by taking a larger sample considering five styles of 128, 311 pieces.

CHAPTER -THREE

3. Research Methodology and Material

3.1 Introduction

End table quality check sheets that is presented in appendix 8, is used for DHU analysis as a secondary data. Formal and Informal discussions is conducted with the factory operational director, production manager, quality control head and sewing in-charge on how quality challenges of sewing section affect performance of the company. Through physical observation of the production line, defects in the sewing section such as broken stitch, shape out, un-balanced seam and open seam have been observed. Furthermore, discussions are held with maintenance team, planning head, as well as line supervisor and quality checkers on quality related problems and situation affecting the sewing process.

3.2 Research Design

The study considers export items of the company such as polo and t-shirt products. The company has good quality record sheets prepared by foreign experts in the past. The research design follows the DMAIC methodology of six sigma. Various statistical process control tools such control charts, Pareto diagram, fishbone analysis is used. The process is examined by using control chart for all five product categories using control charts. The research design includes a procedure for failure mode and effect analysis application. Failure mode and effect analysis is carried out after validation of root causes through discussion with technical personnel. Discussion are mainly focused on validating out of control situations and identifying their sources of variations or root causes. The quality enhancement model that combines six sigma and failure mode and effect analysis is developed after thorough analysis of results and discussions. The model is validated through expert opinions from the case company. Conclusion and recommendations are drawn based on the results of the study.

In summary the research design includes both secondary data in the form of quality audits and primary data that includes observation and discussions. Secondary data from various peer-reviewed journal articles are selected and extensively reviewed. Quality manuals, books and apparel quality standards have been referred.

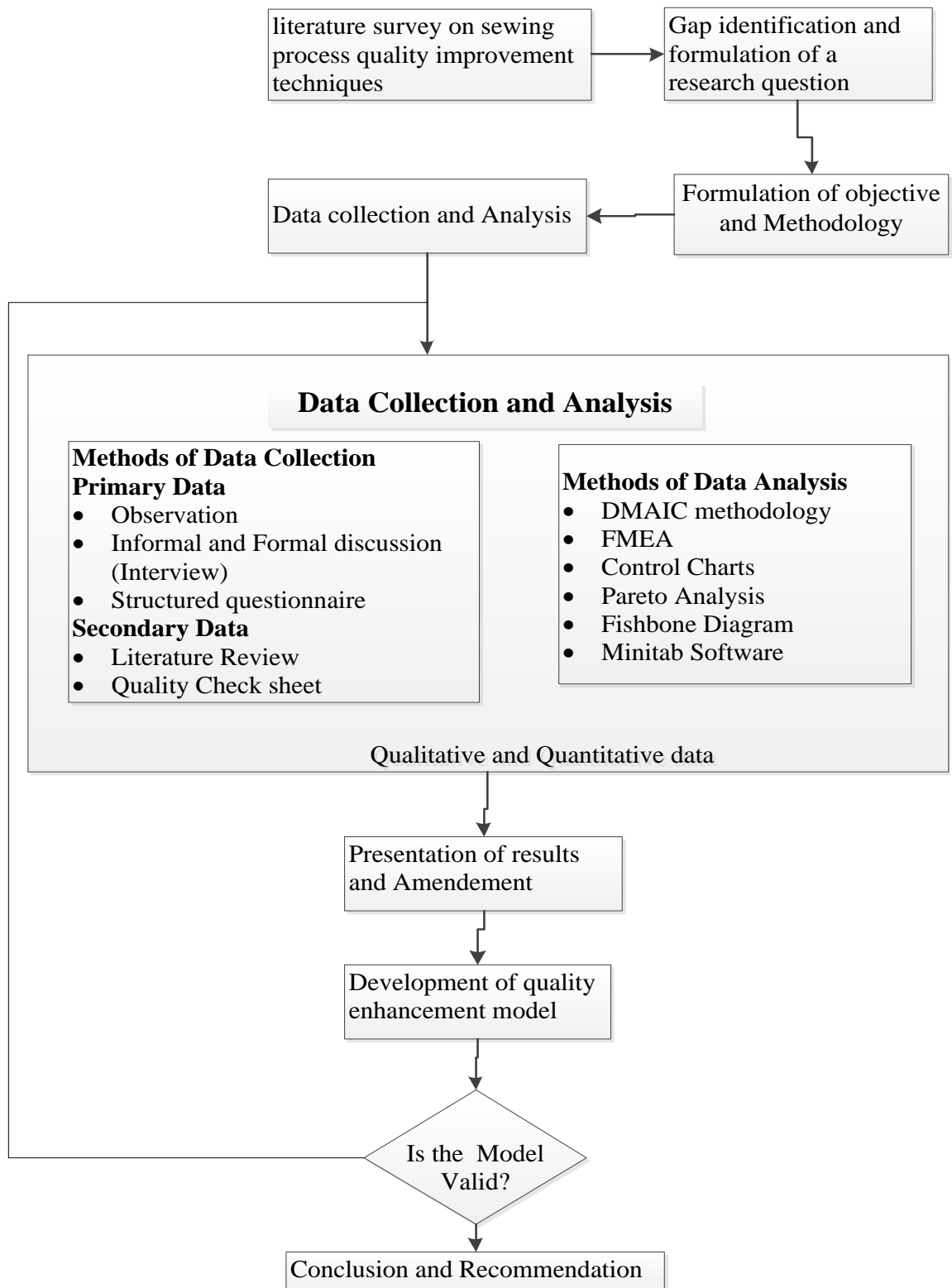


Figure 3.1- General Research approach

3.3 Study Area

The research entitled quality enhancement of a garment sewing process through six sigma and failure mode and effect analysis, a case of Eltex textile and Garment Plc. was conducted at the sewing section of the case company located in Bishofu, Ethiopia. The company established in 2004 G.C., currently has 11 sewing lines and produces different types of garments both for the local and export market as presented in appendix 9. Since export products have a vigorous quality inspection procedure and quality issues, only the export products are selected for this study.

3.4 Population, Sample Size and Sampling Technique

3.4.1 Population

The company employs nearly 550 people in the cutting, sewing, finishing, and embroidery and printing sections as well various administrative section. The sewing section consists of 11 production lines and the top management consist of 1 operational director, 1 sewing manager and 1 planning manager, whereas the middle management consists of 1 quality manager, 1 sewing in-charge, 11-line supervisors and six quality personnel.

3.4.2 Sample Size determination

Formal and informal discussions are held with top management and middle management including operational director, planning head, production manager, sewing in-charge as well as quality in-charge. Semi- Structured interview questions are conducted with operational director and planning head whereas structured failure mode and effect analysis is conducted with purposively selected employees with 100% sample size. Considering the number of line supervisors which is 11 and the number of quality personnel which is 6 totaling 17 people is small, 100% sampling technique is applied for failure mode and effect analysis.

3.5 Methods of data collection

Both primary and secondary data was collected for this study. Primary data is collected through direct observation of the sewing lines followed by informal discussions with quality manager, production manager, line supervisors and operators were conducted. Similarly Formal discussion was conducted on quality issues of the sewing section and to identify root causes of quality problems with top management. Secondary data includes quality check sheet or daily quality audit, standard allowed minute (SAM), machinery list as well as working procedures. Secondary data was also collected in the form of company reports, and international best practices.

3.6 Methods of data analysis

Check sheets are analyzed using U-control chart, Pareto analysis to determine critical defects and operation types. After identification of critical defects, discussions were carried out in order to identify potential root causes. The identified root cause for each defect is analyzed and developed through failure mode and effect analysis tool. The failure mode and effect analysis tool are filled by sewing line supervisors and quality personnel and the analysis of which is done through MS excel. On the other hand, Minitab software was mainly used for secondary data analysis including control chart, and Pareto chart.

3.7 Validity and Reliability

Secondary data obtained from quality check sheet is validated through formal discussion with top management as well as shop floor observation informal discussions with respective production and quality personnel. The FMEA questionnaire is tested with small group of respondents before it is administered to a larger sample.

3.8 Ethical Considerations

Ethical consideration while conducting this research are complied with full effect. The company top management was informed about the nature and scope of the research and received signed cooperation letters from Addis Ababa University. Respondents of Questionnaires have been fully informed about the purpose of the study and the confidentiality of their response.

3.9 Dissemination of Research Findings

The result of this study was submitted and presented for the management of Eltex Textile and Garment Plc. At Bishoftu Plant. The same is presented for Ethiopian Textile and Garment Industry Research and development Center (TGIRDC, formerly ETIDI) as a key area for capacity utilization project. Furthermore the findings of the research work can be made available to online journals and portals such as Google scholar.

CHAPTER- FOUR

4. Data Collection and Analysis

4.1 Company Highlight

Solely owned by Mr. Elias Tesfaye, a visionary and charismatic businessman, Eltex is established in 1995/96 G.C as a small garment house with 12 employees. In 2004/05 G.C, the company reinvented as a knitting fabric supplier and garment factory with a capital of ETB 3 million and 150-200 employees producing different garments for local consumption.

After two decades Eltex now owns a second garment sewing and finishing factory at Debrezeit which started operation in 2010/2011 G.C. the company now has a total capital of 70 million Birr in capital and has over 1,300 employees in both plants. Behind all these success, there are visionary management that have a visions to make the organization one of the top ranked company in Ethiopia. In the Bishoftu plant there are a total of 550 employees with sewing department comprising 375 employees including operators and management.

The factory produces both for the local market and export market. Quality of export items is given due consideration by management as a result a 100% inspection is conducted for the sewing lines and finishing section. Quality assurance is performed at the end of the sewing line to ensure that the garment has been properly assembled and that no garment defects exist. When needed, the defective garments are reworked or fixed at respective workstations. In the sewing process of a garment industry there are two types of quality control practices these are in-line quality control and end-line quality control. During the inline quality control, quality personnel will inspect a sample of random garment from the production line in order to detect and control any defects early. In the end line quality control also known as end table quality, quality personnel will inspect 100 of the products in order to prevent the passing of defective garment to the finishing process. There are also quality inspection conducted in the finishing process. Currently the company employs only end-line quality control for the sewing section. Final quality inspection is conducted both by the company and the buyer, by taking samples based on agreed acceptable quality level (AQL) standard.

4.2 Data Collection

In the following table general information about export order that is delivered in the years 2022 and 2023 G.C is presented for the purpose of understanding information related with the type of products that have been exported.

Table 4.1: Production details

Manufacturer	Eltex Textile and Garment Factory Plc.
Foreign Buyer	XYZ Group
GSM (Gram per Square Meter)	160
Fabric Composition	94% polyester, 6% Spandex
Produced dates	2022 G.C/2014 E.C and 2023/2015
Type of business	FOB (Full on Board)

In order to increase the sample of products that are investigated, all export product items are included in this research. There are a total of five product styles that are produced for export order these are two polo shirts with rib fabric and self-fabric as well as three types t-shirts that are round neck or crewneck with full sleeve, crewneck with no sleeve and V-neck t-shirts. In the following figure some of the export products of the company are presented.




Polo Shirt with Rib Fabric	Polo Shirt with Self-Fabric	Crewneck (Round neck) T-shirt
		
Style Number MLG02MM	Style Number M846	Style Number M11979M1

Figure 4.1 Product styles

The production data consists of two consecutive years in a row include 2022 G.C and 2023 G.C. The order for export items is not a continuous order as a result data is found in different months of the years. Simply the monthly production varies from month to month, the sample taken from each month also varies accordingly. Due to this, the sample taken also includes all those specific production months in order to reflect the pattern of production in a year. While many researches used small sample of products such as [Ahmed et al, \(2019\)](#), [Dinulescu and Dima \(2019\)](#), and [Hibarkah \(2022\)](#) has checked a total 3500, 1385, and 7500 of products.

This research represents 45,117 pieces checked for polo categories and 83,194 pieces for the t-shirt categories with a total of 128,311 pieces being checked. In the following table below total production of export items for the year 2014 and 2015 E.C is presented to verify the sample size of defects taken from the quality department are representative. From the table it is easily understood that the sample size of quality data for polo shirt is 64.8% of total production while the sample size for t-shirt is around 33.4 % of total production. The data pertaining to samples considered for this study is provided in Appendix 1.

Table 4.2: Verification of production and sample

Product/Style		Dates	Total Production	Samples taken	
Polo Shirt	Polo (Rib- fabric)	Miyazia /2014	8,645	4,609	
		Ginbot /2014	19,178	10,853	
		Tahsas /2015	2,273	907	
		Tir /2015	5,580	3,601	
		Yekatit /2015	13,637	11,545	
		Total	49,313	31,515	
	Polo (Self-fabric)	Yekatit /2014	20,319	13,602	
	Total Polo			69,632	45,117
Sampled polo in (%)			64.8		
T-Shirt	Crewneck	Megabit /2014	46,191	4,699	
		Ginbot /2015	46,575	9,539	
		Yekatit /2015	68,055	28,865	
		Total	160,821	43,103	
	Sleeveless crewneck	Yekatit /2014	66,664	19,722	
	V-neck	Ginbot /2014	21,576	20,369	
	Total t-shirt			249,061	83,194
	Sampled t-shirt in (%)			33.4	

4.3 DMAIC methodology of Six Sigma

DMAIC methodology of Six Sigma along is used to enhance the quality of sewing processes. The name DMAIC comes from the initials of each stage define, measure, analyze, improve and control, and each phase is essential for the Six Sigma project to be a successful. In the following sections, the application of six sigma model according to each DMAIC stage is discussed thoroughly.

4.4 Define

This is one of the most critical phases of the entire DMAIC methodology. This phase defines the project by identifying critical customer requirements and linking them to business necessities. The case study selection can be all export products whereas the objective formulation should be described as to reduce sewing process defects from the existing 19.7% to minimum.

4.4.1 SIPOC Diagram

The SIPOC diagram is a tool used by six sigma team to identify all relevant elements of a process improvement before work starts. Supplier, input, process, output, and customer (SIPOC) refers to the technique of analyzing a process relative to these parameters to fully understand their impacts. SIPOC is a high level of process mapping tool that identifies key stake holders, and critical processes involved. Based on the interview result a SIPOC diagram for company is given as follows.

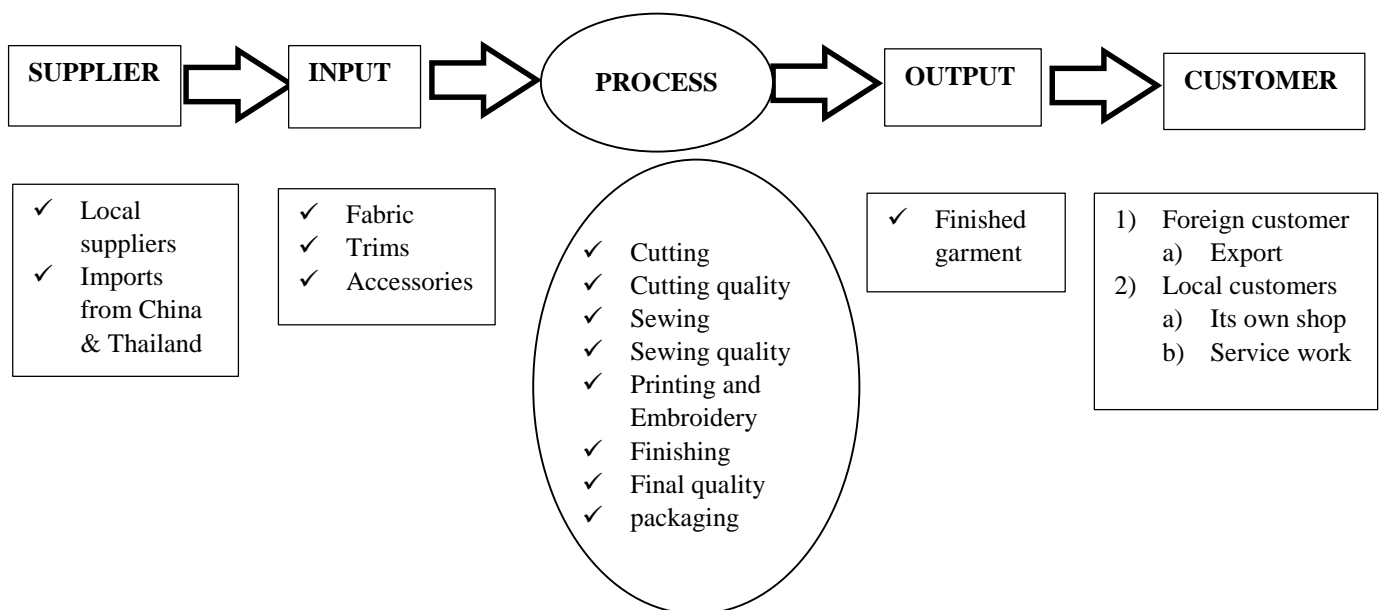


Figure 4.2 - SIPOC Diagram

4.4.2 Production process flow

A process flow chart is a diagram commonly used in industrial engineering to indicate the general flow of processes and machineries. The flow process chart shows the relationship between major equipment of a facility. Merchandiser at the head office receives orders for both local and export works. Agrees about prices, payment modalities and delivery dates. Factory merchandiser contacts suppliers and communicates with planning personnel to get rough estimates of all required inputs. It also tracks and receives incoming shipments. It communicates with planning personnel to get production data so as to arrange future delivery dates and shipments for foreign and local buyers. In the following picture, detail stepwise garment manufacturing sequence in the case company was shown. The company has both sewing line and finishing line inspection personnel which is due to high rate of defects in the garments. After the receipt of the order by head office merchandizer, planning personnel makes operation breakdown, discusses with sewing manager and sewing in-charge to arrange a sewing line. Sewing in-charge with the help of maintenance personnel and operation arranges machine layout and runs sample product. Maintenance personnel arranges machine according to the style of the order. Sewing manager assigns operators based on their expertise of machine operations.

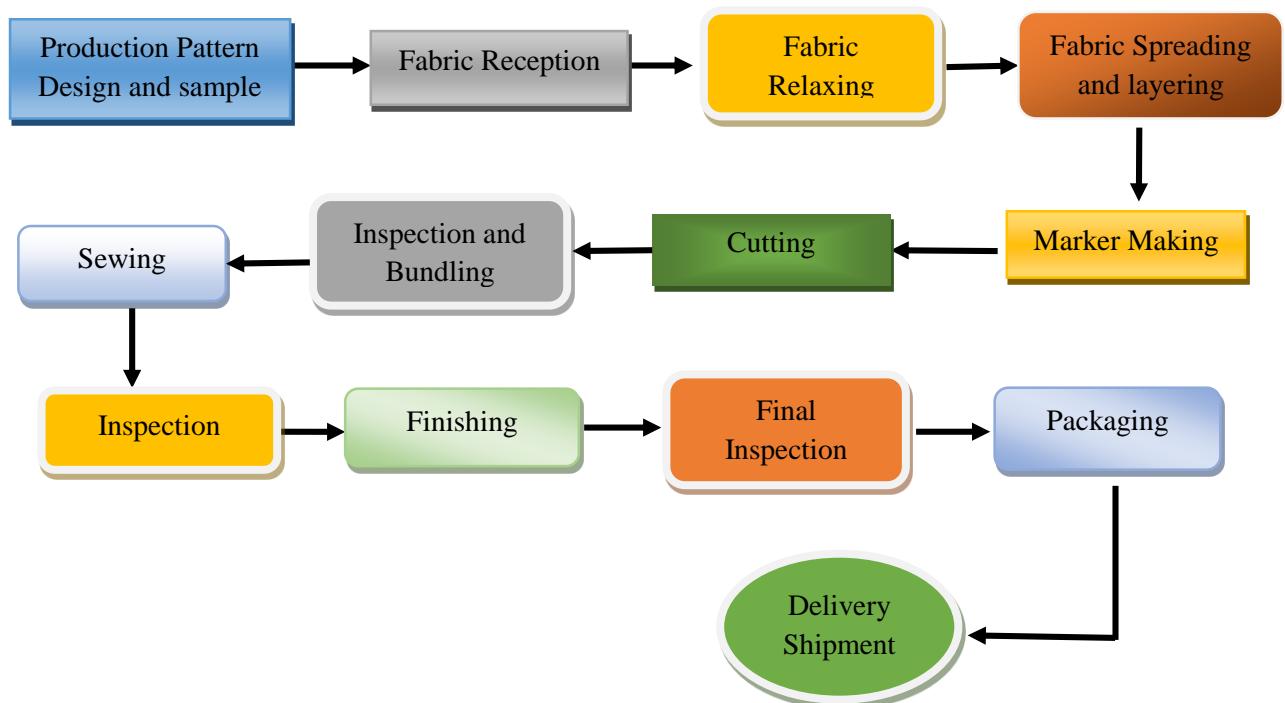


Figure 4.3- Process flow chart

Sewing in-charge checks that the product conforms to requirements and discusses with sewing manager and planning personnel for further enquiries. In case of defects, sewing in-charge shows operators the correct method of operation. End line Quality checkers conduct 100% inspection of garments for variable and attribute quality. Variable defect is measurable defect such as size chart whereas attribute defects comprise 25 various types of defects emanating from the sewing floor. Any defective garments are sent back to the operator for rework or fixing. Garments that are assumed to be good quality would pass to finishing section where label printing or embroidery, ironing, folding and packaging is done before final inspection. Garments that have sewing defects return back to the sewing line. Defect free garments go through the packaging process and cartoning based on their color and size mixes. For export garments, buyer quality personnel conducts quality inspection based on the acceptable quality level from a sample of boxes before delivery to the customer. Any defectives above the tolerance limit may result in either 100% inspection or delay of orders before defect reworks.

4.5 Measure

4.5.1 Defects per hundred units (DHU)

Quality has a huge impact on productivity of the company. As a result, profitability of the company is directly affected by the rate of reworks. In this section the impacts of defects on the productivity and profitability of the company were analyzed by using key performance indicators in the garment industry such as DHU, efficiency, productivity and cost per SAM. Defect reworks have a huge effect on line efficiency and labor productivity. Reworks of defects in the sewing machine operations consumes twice the standard allowed minutes (SAM). This is due to the fact that machine rework requires works such as unraveling or opening a seam and fixing a defect. Therefore, man-hour spent on defective product rework is higher the man-hour spent for Right first time (RFT) products produced. In the following table DHU for all of the five product varieties is discussed.

Table 4.3: Average Factory DHU

S. N ₀	Style	Total pieces checked	Total Defects	Total Pass	DHU	Total Defective
1	Polo shirt MLG025MM (Rib Fabric)	31,515	10,156	21,369	31.3	10,146
2	Polo shirt M846 (Self-Fabric)	13,602	3,892	9,710	30.3	3,892
3	Crew Neck (M1979M1)	43,103	5,843	37,260	14.5	5,843
4	Sleeveless Crewneck (M11957R1)	19,722	2,245	17,513	11.7	2,209
5	V-Neck (M11959M1)	20,369	2,093	18,276	10.63	2,093
Total		128,311	24,229	103,970	19.7	24,183

4.5.2 Efficiency

One of the most widely used key performance indicator (KPI) by garment manufactures is efficiency. It is primarily a measure of the effectiveness of the management or supervisors and as such is best applied to sections or departments of a factories and not the individual operator. Efficiency is calculated by minutes produced over minutes attended and expressed as percentage. Efficiency can either be calculated for single line or the factory as a whole. Factory efficiency can be calculated once line efficiency of different lines is identified.

$$\text{Efficiency of a line} = \left(\frac{\text{Produced minutes or Earned Minutes}}{\text{Available minutes or Attended minutes}} \right) * 100\%$$

Produced minutes or Earned minutes = output * Standard Allowed Minute (SAM)

Available minutes or Attended minutes = N₀ of operators * 480 Minute

$$\text{Hence, Efficiency of a line} = \left(\frac{\text{output} * \text{SAM}}{\text{N}_0 \text{ of operator} * 480} \right) * 100\%$$

For example efficiency of the crewneck t-shirt line can be calculated as follows

$$\text{Efficiency} = \left(\frac{690 \text{ pcs} * 11.27 \text{ min}}{24 * 480 \text{ min}} \right) * 100\% = \left(\frac{7,776.3}{11,520} \right) * 100\% = \mathbf{67.5\%}$$

In the following table average efficiency of the company along with efficiency of individual lines is discussed as follows.

Table 4.4: Calculation of efficiency for all product lines

Style	SAM	Total manpower	target per day at 100%	Average daily production	Efficiency
Sleeveless Crewneck (M11957R1)	11.12	24	1,036	699	67.5
V-Neck (M11959M1)	11.73	27	1,105	762	69.0
Crewneck – M11979	11.27	24	1,022	690	67.5
Polo with Rib fabric (MLG025MM)	24.88	50	965	325	33.7
Polo shirt M846 (Self-Fabric)	29.34	57	933	373	40.0
Average	17.668	36.4	1,012	570	55.54

4.5.3 Labor Productivity

Labor Productivity measures the relationship between units of labor (input) and units of production (output). Labor productivity can be calculated as follows:

$$\text{Labor Productivity} = \text{units of Output} / \text{units of Labor}$$

In this formula the Units of outputs are some measurable quantities of production, and the Units of Labor are man-powers used during the creation of the productive output. In the following table labor productivity for different styles is provided.

Table 4.5: Labor productivity for all styles

S. NO	Style	Machine	Man-power	daily output	Labor Productivity (pc/man/day)	machine Productivity (pc/mac/day)
1	Sleeveless Crewneck (M11957R1)	22	24	699	29	32
2	V-Neck (M11959M1)	24	27	762	28	32
3	Crewneck -M11979	22	24	690	29	31
4	Polo shirt with Rib fabric (MLG025MM)	37	50	325	7	9
5	Polo shirt- M846 (Self-Fabric)	43	57	373	7	9
	Average	30	36	570	20	22

Since Labor productivity varies from product to product as shown in the above table, we need to use best practice for measuring labor productivity which is by converting it in to shirt equivalent and t-shirt equivalent. In-order to convert it to a shirt equivalent and a t-shirt equivalent, we use a SAM value of 21 minutes for the shirt while the t-shirt has a SAM value of 8 minutes

a) Shirt equivalent

First Calculate Total produced minutes

$$\begin{aligned} &\rightarrow \text{Sleeveless produced minute} + \text{V-neck Produced minutes} + \text{crewneck produced minute} \\ &\quad + \text{polo rib fabric produced minute} + \text{polo self-fabric Produced minutes} \\ &= (699 \times 11.12) + (762 \times 11.73) + (690 \times 11.27) + (325 \times 24.88) + (373 \times 29.34) = 7,773 + \\ &8,938 + 7,776 + 8,086 + 10,944 = 43,517 \text{ minutes} \end{aligned}$$

Shirt equivalent Output = Total produced minutes / SAM of shirt

$$= 43,517 / 21 = 2,072 \text{ shirts}$$

Shirt Equivalent labor productivity

$$\begin{aligned} &\rightarrow \text{Shirt equivalent Output} / \text{Total manpower} \\ &= 2,072 / (4+27+24+50+57) \\ &= 2,072 / 182 = 11.38 \sim \mathbf{12 \text{ Shirts}} \end{aligned}$$

b) T-Shirt Equivalent

T-Shirt equivalent Output= Total produced minutes / SAM of T- shirt

$$= 43,517 / 8 = 5,440 \text{ T- shirts}$$

T-Shirt Equivalent labor productivity

$$\begin{aligned} &\rightarrow \text{T-Shirt equivalent Output} / \text{Total manpower} \\ &= 5,440 / (4+27+24+50+57) \\ &= 5,440 / 182 = 29.89 \sim \mathbf{30 \text{ T-Shirts}} \end{aligned}$$

4.5.4 Machine productivity

Calculating machine productivity is one way of measuring line productivity or factory's productivity. If labor productivity of a sewing line is measured, it is also interesting to calculate machine productivity. The calculations for machine productivity is similar to labor productivity and the values of machine productivity is shown in table 4.5 above. Similarly the shirt and t-shirt equivalent calculations for machine productivity is presented below.

Machine productivity = Number of total garments produced / Total stitching machines used

a) Shirt equivalent

1st: Calculate Total produced minutes

$$\begin{aligned} &\rightarrow \text{Sleeveless produced minute} + \text{V-neck Produced minutes} + \text{crewneck produced minute} \\ &\quad + \text{polo rib fabric produced minute} + \text{polo self-fabric Produced minutes} \\ &= (699 \times 11.12) + (762 \times 11.73) + (690 \times 11.27) + (325 \times 24.88) + (373 \times 29.34) = 7,773 + \\ &8,938 + 7,776 + 8,086 + 10,944 \\ &= 43,517 \text{ minutes} \end{aligned}$$

Shirt equivalent Output = Total produced minutes / SAM of shirt

$$= 43,517 / 21 = 2,072 \text{ shirts}$$

Shirt Equivalent labor productivity

$$\begin{aligned} &\rightarrow \text{Shirt equivalent Output} / \text{Total manpower} \\ &= 2,072 / (22+24+22+37+43) \\ &= 2,072 / 148 = \mathbf{14 \text{ Shirts}} \end{aligned}$$

b) T-Shirt Equivalent

T-Shirt equivalent Output = Total produced minutes / SAM of T- shirt

$$= 43,517 / 8 = 5,440 \text{ T- shirts}$$

T-Shirt Equivalent labor productivity

$$\begin{aligned} &\rightarrow \text{T-Shirt equivalent Output} / \text{Total manpower} \\ &= 5,440 / (22+24+22+37+43) \\ &= 5,440 / 148 = 36.75 \sim \mathbf{37 \text{ T-Shirts}} \end{aligned}$$

4.5.5 Cost per SAM or Cost per Garment

Cost per SAM or cost per garment is one of mostly used KPI'S in the garment industry. It is used by garment manufacturers in order to price apparel products or to fix service charges for outsourced works. The formula used to calculate the cost per SAM is Garment SAM multiplied by cost factor. Cost factor is a minute labor cost of the factory at factory average efficiency. Cost per SAM is fixed for a specific style.

The formula used to calculate cost per SAM is as follows:

$$\text{Cost per SAM or cost per garment} = \text{Garment SAM} \times \text{Cost factor}$$

$$\text{where, Cost Factor} = \text{Average Direct labor wage per day} / (\text{shift minute} * \text{Efficiency})$$

Average direct labor cost per day = 99.792 Birr/day/operator

Working minutes per day = 480 Minutes

$$\text{Cost Factor} = \left(\frac{99.792 \frac{\text{Br}}{\text{day}}}{480 * \text{Eff}} \right) = 0.2079/0.675 \rightarrow 0.308$$

Cost per SAM for crewneck = 11.27 min * 0.308 Br = 3.47 Br/Garment

Similarly cost per SAM for all styles is given in the following table

Table 4:6 Cost per SAM for all styles

Style	SAM	Efficiency	Cost factor	Cost per SAM (Birr)
Sleeveless Crewneck (M11957R1)	11.12	67.5	0.31	3.42
V-Neck (M11959M1)	11.73	69.0	0.30	3.53
Crewneck (M11979)	11.27	67.5	0.31	3.47
Polo with Rib fabric (MLG025MM)	24.88	33.7	0.62	15.35
Polo shirt M846	29.34	40.0	0.52	15.25
Average	17.668	55.54	0.41	8.21

4.5.6 Economic impact of defects

Sewing reworks result in an internal failure cost for the company. The sewing reworks consume more time than the standard allowed time due to duplication of works. Hence rework time is considered twice the normal pitch time. When Rework increases, productivity decreases there by decreasing profit margin of the company. In order to numerically analyze the impact of defects on financial stability and profitability of the company, it is important to have two important parameters. These are actual production capacity and attainable production capacity.

The economic impact of quality on the financial stability of the company is discussed in the following section by taking in to consideration the capacity of the company.

Total manpower of the sewing department is 375 people. By excluding middle management such as line supervisors, quality personnel and other management staff which totals 39 personnel, the total operators in sewing section is 336 personnel.

Daily available capacity = total manpower * absenteeism, where daily absenteeism = 10%

Daily available capacity = 336 * 0.9 → 302 personnel

Hence available capacity per day = 302*480 → 144,960 minute per day

Average SAM of five products = 17.7 minute

$$\text{Available capacity in terms of garments} = \frac{144,960 \text{ minute}}{17.7 \text{ minute}} = 8,190 \text{ pc/day}$$

The available capacity of the company is 8,190 pcs per day however, the actual capacity of the company depends on the efficiency level. Currently the average efficiency of five products is 55.54% on average

$$\text{Hence actual capacity per day} = \frac{8,190 \text{ pc}}{0.5554} = 4,549 \text{ pc/day}$$

Actual capacity per month = $4,549 \frac{\text{pc}}{\text{day}} * 26 \text{ day} = 118,274 \frac{\text{pc}}{\text{month}}$, since, 26 working days per month

Actual capacity per year = $4,549 \frac{\text{pc}}{\text{day}} * 288 \text{ day} = 1,310,112 \text{ pc/year}$, since 288 working days per year

Therefore, Cost per SAM at factory capacity is calculated as follows:

The cost per SAM per day is →

$$4,549 \frac{\text{pc}}{\text{day}} * 8.21 \frac{\text{Birr}}{\text{pc}} = 37,348 \text{ Birr/day}$$

The cost per SAM per Month is →

$$118,274 \frac{\text{pc}}{\text{month}} * 8.21 \frac{\text{Birr}}{\text{pc}} = 971,030 \text{ Birr/month}$$

the cost per SAM per year is →

$$1,310,112 \frac{\text{pc}}{\text{year}} * 8.21 \frac{\text{Birr}}{\text{pc}} = 10,750,02 \text{ Birr/year}$$

4.5.7 Identification of Sigma level

Sigma level is identified through data obtained from total production and total defectives. In order to calculate sigma level, it is important to identify defects per opportunities (DPO) and defects per million opportunities (DPMO). Defects per opportunities calculated by using the total number of defects and total defect opportunities also known as critical to quality parameters, which is 25. Hence, currently the process has a capability of around 1.3075 and a sigma level of around 3.93 as shown in the following table.

$$\text{DPO} = \frac{\text{total number of defects in a sample}}{\text{sample size} * \text{number of defect opportunities per unit}}$$

$$\text{DPO} = \frac{24,229}{128,311 * 25} = 0.00755$$

$$\text{DPMO} = \frac{\text{total number of defects in a sample}}{\text{sample size} * \text{number of defect opportunities per unit}} * 1000,000$$

$$\text{DPMO} = \frac{24,229}{128,311 * 25} * 1000,000 = 7,553$$

Process capability

Process capability addresses to the consistency and ability of the process. It implies what the process is capable to do. It is frequently convenient to have a simple, quantitative way to express process capability. One way to do so is by using the upper specification limit (USL) and lower specification limits (LSL).

The formula of Cp is:
$$C_p = \frac{USL-LSL}{6\sigma}$$

Where,

USL: Upper specification limit

LSL: Lower specification limit

σ : Standard deviation

In the event that $C_p < 1$, it implies that procedure mean μ is outside of indicated range and creates a high level of imperfections however, in the event that the procedure is focused all things considered $C_{pk} = C_p$. if $C_p > 1$ at that point procedure meets specifications. Likewise, if the procedure is under control calculating the process capability index is not necessary.

Table 4.7: Sigma level and process capability

S.NO	Measurement Parameter	Original Value
1	Total pieces checked	128,311
2	Total defects	24,229
3	DPO	0.00755
4	DPMO	7,553
5	Sigma Level	3.93
6	Process capability (C_p)	1.3075

4.6 Analyze

4.6.1 Control Charts

At this stage the researcher walks through process in order to observe the process and talk to concerned people. At this stage analysis of data through control charts and Pareto analysis is carried out to understand major defects. Also at this stage all data regarding the root causes are identified through brainstorming discussions with quality personnel and line supervisors.

Control charts are an effective tool to analyze process stability and characteristics of variations. There are two types of variation caused in a manufacturing process these are common causes of variation sometimes referred to as chance causes are Random causes that cannot be identified. Common causes of variations are unavoidable and their existence Causes slight differences in process variables like diameter, weight, service time, temperature, etc. common causes are Inherent to the process or random and are not controllable as a result if only common causes are present in the process, the process is considered to be stable or in control.

Assignable causes of variation on the other hand are causes that can be identified and eliminated. Typical causes of assignable variations are poor employee training, worn tool, machine needing repair, etc. Assignable causes are also referred to as special cause of variation that arise due to outside influences. If special causes of variation are present, the process is considered to be out of control. The main uses of control chart is to separate common and special causes of variation, to determine whether a process is in a state of statistical control or out-of-control, to estimate the process parameters (mean, variation) and to assess the performance of a process or Process capability. Furthermore, control charts help to monitor output, and it is a proven technique for defect prevention and improving productivity by providing diagnostic information for making necessary process adjustments.

Table 4.8: Different types of control charts and their application

S.N0	Type of data	Type of Sample	Appropriate chart
1	Defective	Constant	NP-chart (number of defective)
2	Defective	Variable	P-chart (proportion of defective)
3	Defects	Constant	C-Chart
4	Defects	Variable	U-chart

A control chart consists of a central line, an upper control limit and a lower control limit and the Characteristic values plotted on the chart which represent the state of a process. If all the values are plotted within the control limits without any particular tendency, the process is regarded as being in the controlled state, otherwise it is out of control.

A control chart can either be variable control chart which measured on a continuous scale such as length, weight, volume, pressure and temperature or an attribute control chart which summarizes the output of a process, or operation over time such as conformance and nonconformance.

Attribute data have only two values such as good/bad, conforming/non-conforming, or acceptable/not acceptable. In the following table below the criteria for choosing the appropriate control chart is shown.

Based on the above table, the benefits of using U-chart is as follows:

- The U- Chart is used when it is not possible to have an inspection unit of a fixed size, rather the number of nonconformities is per inspection unit.
- The U-chart measures the number of defects per product.
- It is similar to the C-chart. However, the number of defects are expressed per a unit basis.

Therefore, based on the above criteria the appropriate chart is U-chart

There are 5 steps to conduct a U-Chart analysis, these are:

Step 1:

Find the number of nonconformities-c (i) and the number of inspection units-n (i), in each sample i

Step 2:

$$\text{Compute } U(i) = C(i) / N(i) \rightarrow \bar{u} = \frac{\sum c}{\sum n}$$

Where U (i) = defects per unit

C = number of defects discovered in a lot

N = the number of inspection units

Step 3: Determine the centerline of the u chart:

$$\bar{U} = \frac{\text{total non - conformancin k sub - group}}{\text{total number of inspection units}}$$

$$\bar{U} = \frac{c(1) + c(2) + \dots + c(k)}{n(1) + n(2) + \dots + n(k)}$$

Step 4: The u chart has individual control limits for each subgroup i.

$$UCL = \bar{U} + 3\sqrt{\frac{\bar{U}}{n(i)}} \qquad LCL = \bar{U} - 3\sqrt{\frac{\bar{U}}{n(i)}}$$

Step 5: Plot the centerline, CL, the individual LCL and UCL, the process measurements, u (i), and interpret the control chart.

In the following figures below the U-chart is used to analyze the data points for all five product styles presented as follows:

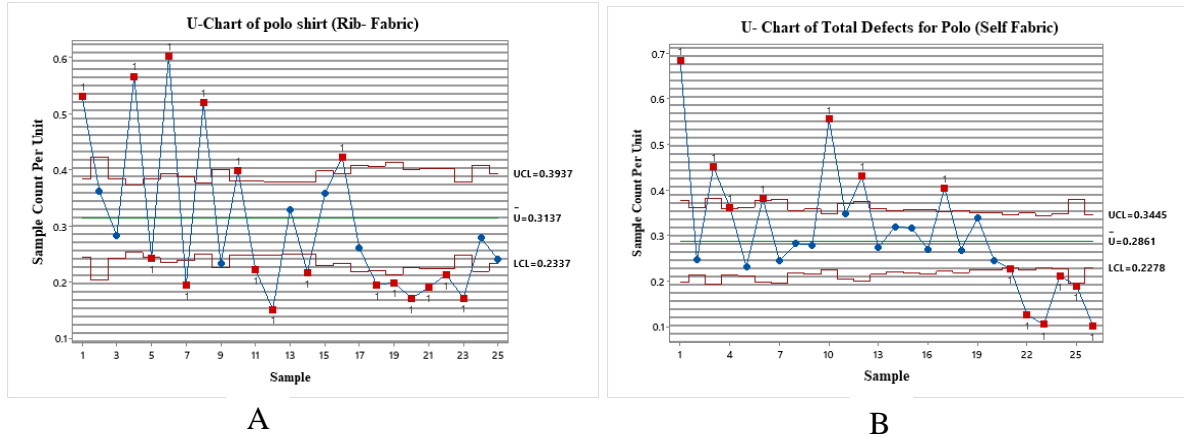


Figure 4.4- U-chart for A) style MLG025MM and B) style M846

Safa Tuna (2018) suggested a set of decision rules for detecting nonrandom patterns on control charts. Specifically, it suggests concluding that the process is out of control if

1. One-point plots outside the three-sigma control limits
2. Two out of three consecutive points plot beyond the two-sigma warning limits
3. Four out of five consecutive points plot at a distance of one-sigma or beyond from the center line
4. Eight consecutive points plot on one side of the center line

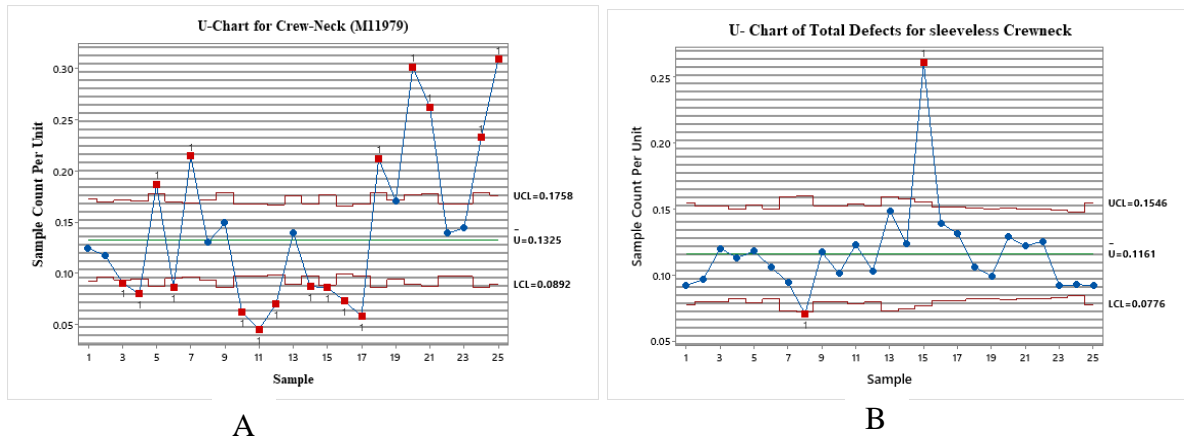


Figure 4.5- U-chart for A) Crewneck M11979M1 B) style M11957R1

From the above control charts, the production process for all five styles is considered to be out of control. It is easy to understand that production process for the two categories of polo have significant variations from the mean whereas the t-shirt categories have minor disturbances and mostly close to the mean values.

The reasons for existence of assignable causes for polo categories and t-shirt categories is observed from the shop floor and the major causes are summarized and presented in section 4.6.4.

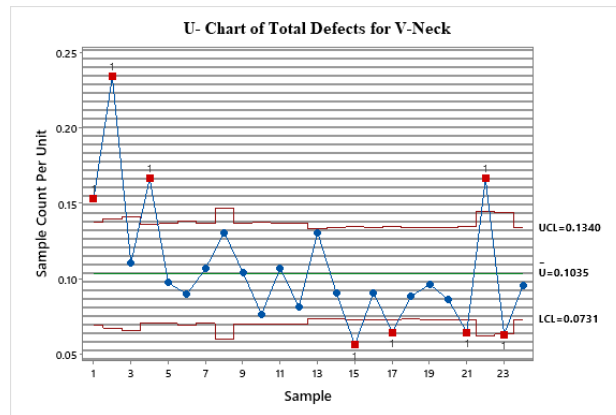
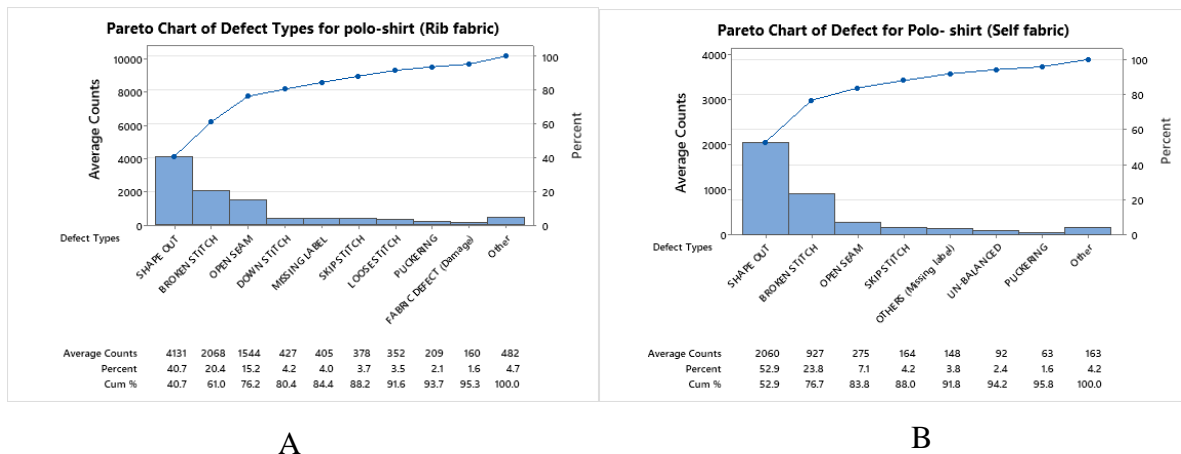


Figure 4.6- U-chart for style M11959M1

4.6.2 Pareto Analysis of major defects by defect types

Pareto chart is a special type of bar chart where the plotted values are arranged from largest to smallest. A Pareto chart is used to highlight the most frequently occurring defects. Based on secondary data from quality check sheet, sewing defect data is analyzed using Minitab Software which is available for free. Defect analysis of all five styles is presented in Appendix 4. Pareto analysis of major defects for all styles is graphically provided in the following sections as follows:

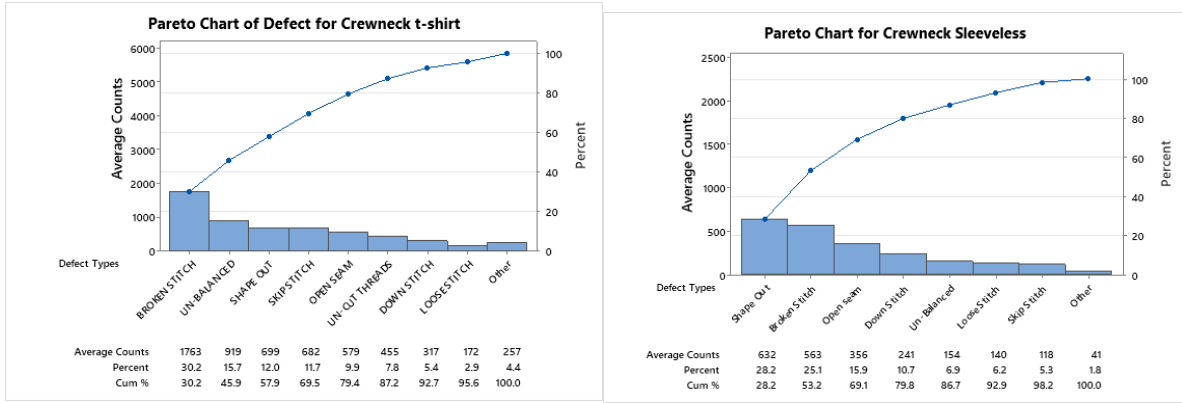


A

B

Figure 4.7- Pareto chart for defects by defect type for A) Polo rib fabric B) polo self-fabric

The aim of Pareto chart is to analyze the major defects, identify their root causes and develop appropriate solutions. This helps to identify common defects in all the styles and helps to know the average number of defect occurrence. The polo categories mainly comprise four defect types including shape out, broken stitch, open seam and down-stitch.



A

B

Figure 4.8- Pareto chart for defects A) for Crewneck t-shirt B) sleeveless crewneck t-shirt

Whereas Pareto analysis of defects in the t-shirt categories mainly comprise six types including shape out, broken stitch, open seam, unbalanced seam, down stitch and skip stitches. Unbalanced seams are irregularities in seam making where the symmetry or straightness is not maintained. Similarly, shape out seam is a seam where the shape of the seam results in deformities or non-conformance to requirements.

Pareto analysis for M11957R1 shows that shape out, broken-stitch, open-seam and down stitch are the most frequent defect types that contributed to 79.8. % of all defects as shown in figure 4.8 above. Similarly, Pareto analysis for defect types of style M11959M1 shows that broken-stitch, shape out and unbalanced seam are the most frequent defect types that contributed to 86.9 % of all defects as shown in the following figure below.

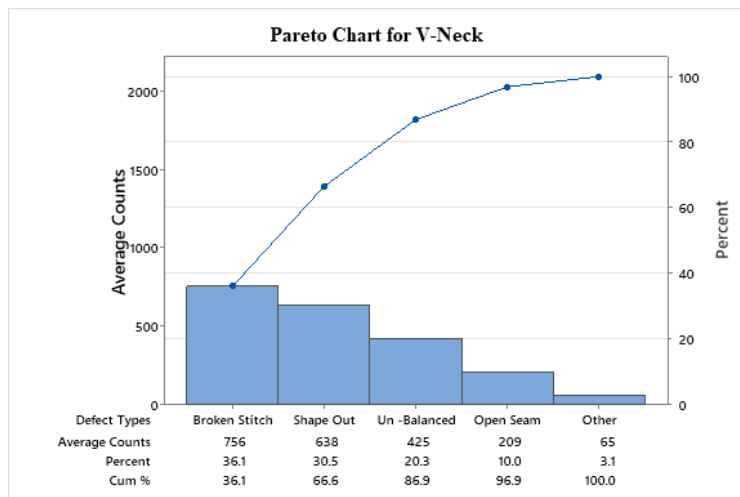


Figure 4.9- Pareto chart for defects for V-neck

Based on the table below, in the polo category the largest defect type is shape out (46.8%) on average while broken stitch is the second largest defect type (22.1%) on average. Where as in the t-shirt category, broken stitch is the largest defect category contributing to 30.5% on average while shape out is the second largest defect contributing to 23.6% on average. Pareto analysis of defect rates for the rest of products are discussed in the following table as follows.

Table 4.9: Analysis of major defects based on Pareto chart

N₀	Styles	Major defects	Share (%)	Cumulative (%)
1	Polo-Shirt (rib fabric)	Shape out	40.7	80.4
		Broken stitch	20.4	
		Open seam	15.2	
		Down stitch	4.2	
2	Polo-Shirt (self- fabric)	Shape out	52.9	83.8
		Broken stitch	23.8	
		Open seam	7.1	
3	Crewneck	Broken stitch	30.2	79.4
		Un-balanced	15.7	
		Shape out	12.0	
		Skip stitch	11.7	
		Open seam	9.9	
4	Sleeveless crewneck	Shape out	28.2	79.8
		Broken stitch	25.1	
		Open seam	15.9	
		Down stitch	10.7	
5	V-neck	Broken stitch	36.1	86.9
		Shape out	30.5	
		Un-balanced	20.3	

After identifying common defects in all styles, pie chart analysis is carried out to understand the aggregate results of each defect. Accordingly shape out has a highest percentage of occurrence or highest rework while broken stitch is the second largest defect leading to rework whereas open seam, unbalanced seam, down-stitch and skip stich are presented as shown in the graph below. The aggregate value of defects identified in the above table is calculated from 100% is presented in figure 4.10 below.

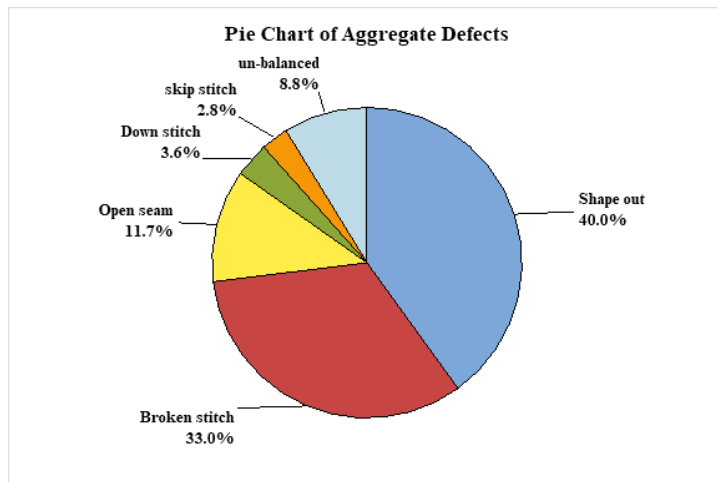


Figure 4.10 – Cumulative results of major defects

The above pie chart gives an aggregate percentage value for each of the five styles under investigation. The result from cumulative percentage of defects gives an insight to major defects.

4.6.3 Pareto Analysis of defects by operation types

Defect analysis by operation breakdown has many advantages and has hardly been studied in previous literatures. Classification of defects by operation breakdowns helps to identify whether the operation is machine or manual. If the operation is manual, it helps to identify what type of operation is responsible. If the operation involves machine, then identifying which type of machine is responsible for higher defects and investigating the machine separately is of paramount importance given that machine technologies in the garment industries varies considerably. Therefore, in the following figure, Pareto chart of frequent failures by category of operation is provided.

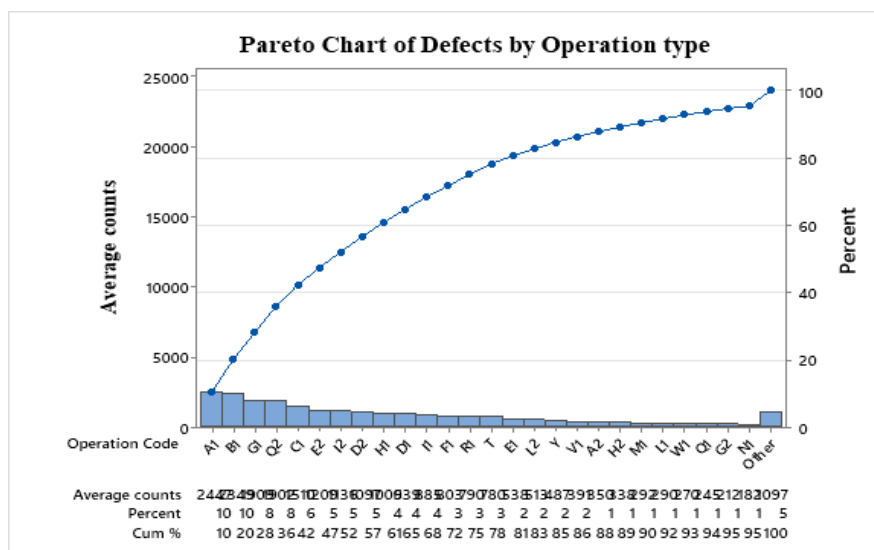


Figure 4.11 – Cumulative results of major defects by operation

Similarly Analyzing defects by operation types also helps to identify critical operation with respect to quality, areas of the garment that are identified through visual inspections and most importantly to identify the machine related with the operation. Defects by operation types for all styles is presented in Appendix 5. In the following table below critical operations or sources of defects that contributed to 80% of all defects are analyzed in the following table as follows.

Table 4.10: Cumulative results of major defects by operation types

	Operations	Defect Code	Defects	Percent %	Machine type	Stitch area
1	Collar top stich	A1	2,447	10	Cover stitch	Front & back
2	Placket top stitch	B1	2,349	10	Cover stitch	Left & right
3	Bottom hemming	G1	1,909	8	Cover stitch	Front & back
4	Sleeve hemming	Q2	1,902	8	Cover stitch	Sleeve
5	Collar attach on body	C1	1,510	6	Single Needle	Front & back
6	Front Neck Top Stitch	E2	1,209	5	Single Needle	Front
7	Sleeve top stitch	I2	1,136	5	Single Needle	Left & right
8	Back Neck Top stich	D2	1,097	5	Single Needle	Back
9	Shoulder top stich	H1	1,006	4	Single Needle	Left & right
10	Collar stand top stich	D1	939	4	Single Needle	Front & back
11	Side Seam	I1	885	4	Over lock	Left & right
12	Button place marking	F1	803	3	Manual	Front
13	Label attach	R1	790	3	Single needle	Back
14	Trimming (T)	T	780	3	Manual	-
15	Placket hemming	E1	538	2	Over lock	Front
	Total		19,300	80%		

Through Pareto analysis of defects by operations, the following important findings are obtained

- 1) Out of the 80% defects Cover stitch machine constitutes about $(8,607/19300) * 0.8 = 36\%$
- 2) Single needle machine constitutes about $(7,687/19300) * 0.8 = 39.8 = 32\%$ of defects
- 3) Manual work such as trimming and marking constitutes about $(1,583/19300) * 0.8 = 6.5\%$
- 4) Over lock machine constitutes about $(1,341/19300) * 0.8 = 7.37 = 5.5\%$ of defects

4.6.4 Root cause analysis

A root cause analysis also called an Ishikawa Diagram is a simple but effective tool that is used to identify different root causes of a problem. A Cause & Effect diagram is used to find the root causes of some identified problems or Effects. The root cause analysis of major defects identified in Appendix 6, shows that the major causes can be categorized under man, material, machine and methods. In the following section root cause analysis through cause-and-effect diagram also known as fishbone diagram is discussed.

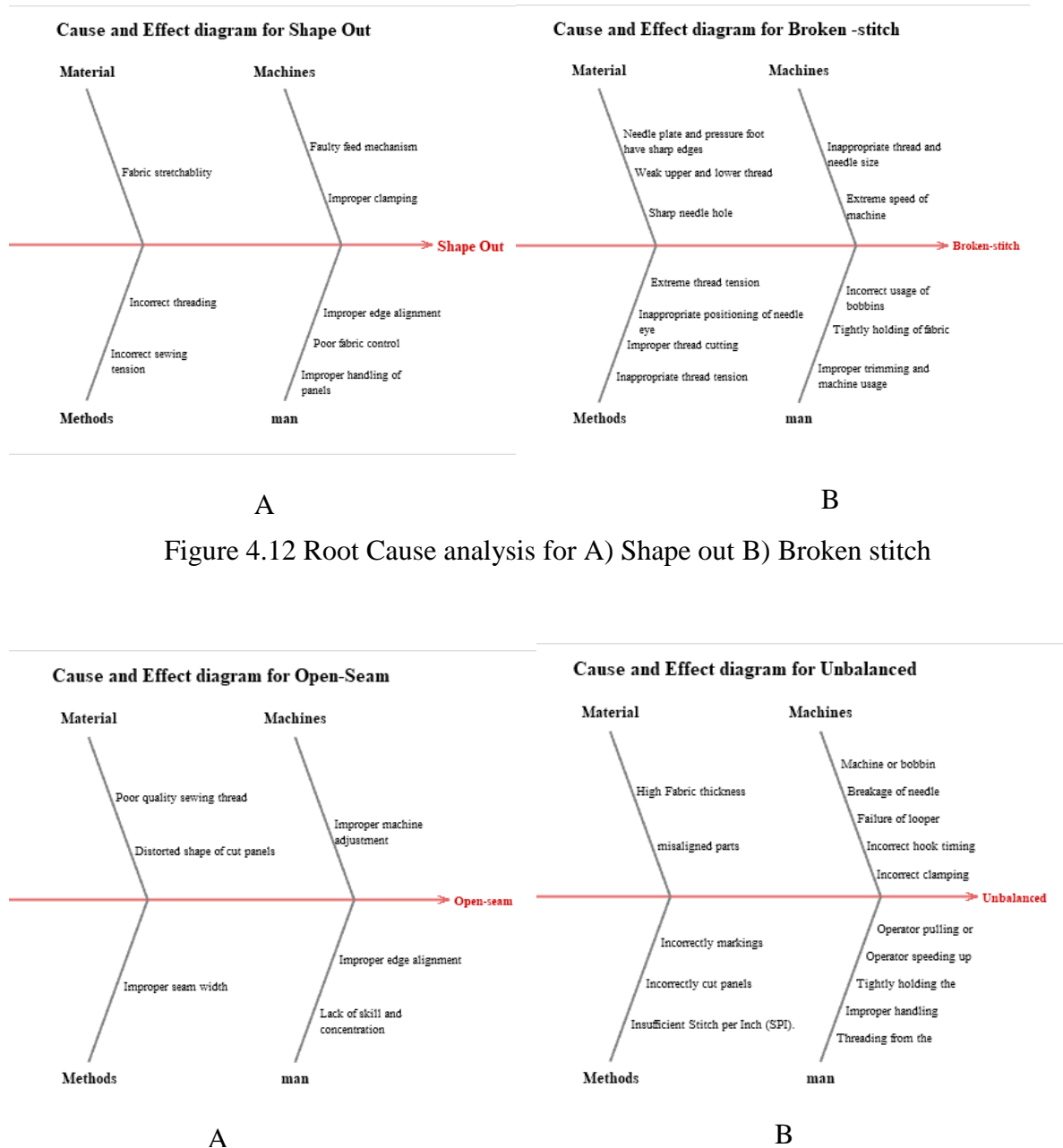


Figure 4.12 Root Cause analysis for A) Shape out B) Broken stitch

Figure 4.13 Root Cause analysis for A) Open Seam B) unbalanced seam

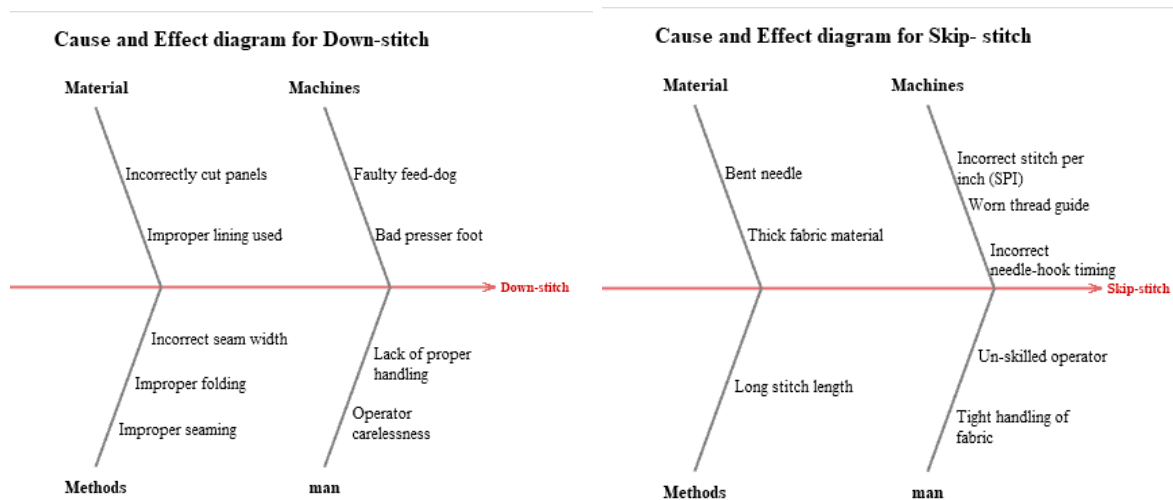


Figure 4.14 Root Cause analysis for A) Down-stitch B) Skip-stitch

Based on the root cause analysis the major causes are related with stitching and seam process. Stitching is the process of sewing by inserting a threaded needle through the fabric. Some of stitching defects identified are broken stitch, down stitch and skip stitches. Material and methods factors have also contribute to these defects. On the other hand there seaming defects which include shape outs, open seam, and unbalanced seam. A seam defect occurs when stitching is acceptable but the alignment is defective.

4.7 Improve

Failure mode and effect analysis

During the improvement stage, certain tools are used to mitigate quality problems or to enhance quality of the process. At this stage failure mode and effect analysis is used to prioritize mitigation strategies for failures with highest risk priority number (RPN). Failure mode and effect analysis is a risk identification and prioritization tool that is overlooked in the garment industry. The development of FMEA follows from findings of the root cause analysis and tries to prioritize failures and to develop improvement solutions.

The main purpose of failure mode and effect analysis is to identify and resolve products and processes that lead to accidents and incidence of failure. Failures can be machine failures or non-conformance of customer requirements. Failure in this case can be defects or causes of defects. The FMEA preparation and application takes in to consideration the causes of defects or modes of failures for common causes of defects based on the questionnaire and takes five point rating scale as presented in Appendix 2, Risk Priority Number (RPN) is obtained from the technical team.

In the following table below, the risk priority number of failures or defects is identified through severity (S), Occurrence (O) and Detection (D) as discussed in the following table.

Table 4.11: Results of Failure Mode and effect analysis

Function of failure	Potential failure mode	Potential Causes of failure	Potential effect of failure	S	O	D	RPN = S*O*D
Machine	Due to maintenance	Frequent machine breakdowns such as needle breakage	broken stitch / skip stitch Open seam/ shape out	2.5	2.6	1.5	10
	Parts problem	Worn out feed dog, bad presser foot, Sharp needle hole, damaged needle plate, worn thread path and eyelets	skip stitch /Down stich/ shape out/ unbalanced	2.5	2.5	1.4	9
	Machine Adjustment problem	Incorrect machine adjustment such hook-needle timing and feed mechanism	Skip stitch/ Shape out/ unbalanced/ open seam	2.3	2.3	1.3	7
Manpower	Due to poor training, skill and experience	Lack of skill and experience	Open seam/ down stitch/ skip stitch	2.6	2.6	1.5	10
		Lack of good handing or tight holding of fabric	Down-stitch/ unbalanced/ shape out/ skip stitch	2.7	2.5	1.3	9
		High Speeding up of the machine	Unbalanced	2.5	2.4	1.3	8
	Concentration	Lack of concentration	Open seam/ Unbalanced	3.1	2.7	1.2	10
	carelessness	Carelessness operator	Down stitch/ Unbalanced	3.0	2.5	1.4	10
Method	Set up Adjustment	Improper thread tension	Shape out/ broken stitch/ skip stitch	2.2	2.2	1.3	6
	Work-aids	Improper folders, attachments and guides, loops and needles	Down stitch/ skip stitch	2.6	1.8	1.4	7
	Workmanship	Improper edge alignment of cut panels	Open seam/ shape out	2.5	2.4	1.3	8
		Incorrect threading	Unbalanced/ skip stich	1.9	2.1	1.4	6
		Incorrect mark places	Unbalanced	3.0	2.6	1.5	12
Incorrect seam width (SPI)		Open seam/ down stitch/ skip stich/ unbalanced	2.9	2.7	1.3	10	

		Incorrect needle position	Broken stitch	2.1	1.9	1.2	5
		Improper thread cutting/trimming	Broken stitch	2.9	2.7	1.5	12
	Ergonomics	Poor sitting/working posture	Shape out/ open seam/ unbalanced /down stitch	2.2	2.1	1.2	6
Material	Raw Material and inputs	Poor quality thread	open seam/ broken stitch/ skip stitch	1.9	1.6	1.2	4
		Improper linings used	Down stitch	2.2	1.6	1.2	4
		Improper needle/Bent needle/dull needle	Broken stitch/ skip stitch	1.9	1.8	1.2	4
	Cutting defects	Defective cut panels	Down stich/ open seam/ unbalanced	3.0	2.5	1.6	12
		Distorted shape of cut parts	Down stich/ open seam/ unbalanced	2.8	2.2	1.5	9
	Characteristics of fabric	Difficult/stretchable fabric	Shape out	3.1	2.5	1.4	11

After conducting failure mode and effect analysis by using the prepared questionnaire for the technical team comprising sewing and quality personnel, the next step is prioritizing failures with the highest risk priority number from the list of failure discussed in the previous table. Based on the RPN, mitigation solutions are suggested in order to reduce the number of sewing defects and to bring the process under statistical stability. In the following table below failure modes with highest risk priority numbers (RPN) is presented as follows:

Table 4.12: Failure mode and effect analysis summary

Function of failure	Potential failure mode	Potential Causes of failure	Potential effect of failure	Calculated RPN
Machine	Due to maintenance	Frequent machine breakdowns such as needle breakage	broken stitch / skip stitch Open seam/ shape out	10
Manpower	Due to poor training, skill and experience	Lack of skill and experience	Open seam/ down stitch/ skip stitch	10
	Concentration	Lack of concentration	Open seam/ Unbalanced	10
	carelessness	Carelessness operator	Down stitch/ Unbalanced	10
Methods	Workmanship	Incorrect mark places	Unbalanced	12
		Incorrect seam width (SPI)	Open seam/ down stitch/ skip stitch/ unbalanced	10
		Improper thread cutting/trimming	Broken stitch	12
Material	Cutting defects	Defective cut panels	Down stitch/ open seam/unbalanced	12
	Characteristics of fabric	Difficult/stretchable fabric	Shape out	11

Problems related with the manpower can be solved through skill up-gradation training and placement of experienced operators on critical machine operations. Material problems such as color variations can be solved by effective material inspection at the store and cutting section. The cutting section should not pass defective cut panels to the sewing room. Optimum machine adjustment is important for making good quality garments. The machine adjustment should be done by an experienced technician with the help of sewing supervisor. Proper sewing techniques/methods should be employed which can be done by an industrial engineer specializing in the garment sector.

After selecting failures with highest RPN, proposing mitigation solution for the identified failures is developed by discussion with respective technical team is presented in the following table.

Table 4.13: Proposed solution based on the results of FMEA

Failures	Causes of Failures	Function	Proposed Solution
broken stitch / skip stitch Open seam/ shape out	Frequent machine breakdowns such as needle breakage	Machine	<ul style="list-style-type: none"> • Frequent Machine cleaning, preventive maintenance by mechanics, autonomous maintenance by operators
Open seam/ down stitch/ skip stitch	Lack of skill and experience	Manpower	<ul style="list-style-type: none"> • Skilled workers and Specialization training. • The use of deskilling devices such as folders, attachments and guides
Open seam/ Unbalanced	Lack of concentration		<ul style="list-style-type: none"> • Proper work motivation and incentive packages.
Down stitch/ Unbalanced	Carelessness operator		<ul style="list-style-type: none"> • Good relationship between operators and supervisors. • Supervisor skill up gradation
Unbalanced	Incorrect mark places	Method/ Workmanship	<ul style="list-style-type: none"> • Application of right templates for marking
Open seam/ down stitch/ skip stitch/ unbalanced	Incorrect seam width (SPI)		<ul style="list-style-type: none"> • Skill up gradation of operators
Broken stitch	Improper thread cutting/trimming		<ul style="list-style-type: none"> • Use of automatic machines and operator carefulness for manual thread trimming
Down stich/ open seam/ unbalanced	Defective cut panels	Material	<ul style="list-style-type: none"> • Placement of procedures to accept quality cut panels. • Quality control to detect and segregate defective cut panels
Shape out	Difficult/stretchable fabric		<ul style="list-style-type: none"> • Proper machine and thread Tension adjustment depending on the characteristics of the fabric

4.8 Summary of key findings

Based on the analysis conducted in previous sections, a higher out of control situation has been observed from the control chart for the polo categories where as a moderate level of out of control situation has been observed for the t-shirt categories. This indicates that the process for all five products is an out of control process. There is high amount of defects for polo which is 30.8 % DHU on average and for t-shirt which is 12.27%. Based on Pareto analysis of defects, the major defects which contribute to 80% of the problem are identified as six which include shape out 32.82%, broken stitch 27.1%, open seam 9.6%, unbalanced seam 7.22%, down stitch 2.97% and Skip stich a 2.29 % totally contributing to 82 % of all defects.

Furthermore Pareto analysis of defects by their operations identified operation conducted on cover machine contributed to 36%, while operations on single needle machines contributed to 32% whereas overlock machine and manual operation such as marking and trimming contributed to 5.5 and 6.5% respectively. The root causes of major defects are identified through discussion with the respective personnel of production and maintenance section. Shop floor observations are also conducted to verify the causes of major defects. The root causes of major defects summarized through the fishbone diagram categorizes the main sources in to machine, manpower, method and material.

Similarly the failure mode and effect analysis conducted by comprising a group of 17 personnel from the sewing and quality department is discussed and the results are presented. The impact of quality problems in the sewing section is analyzing using key performance indicators of the garment industry. The key performance indicators discussed are DHU, efficiency, productivity and cost per SAM or cost per garment. Analysis of key performance indicators strongly highlighted the impact of quality on the performance of the company. Furthermore, analysis of defect rework on the financial stability of the company is also thoroughly discussed. Defective products have high cost of productions than those of right first products due to high consumption of labor and material cost. As a results sewing defects have a big impact on the efficiency, productivity and profitably of the company.

CHAPTER –FIVE

5. Sewing process quality enhancement model

5.1 Model description

5.1.1 Preparation

The combination of DMAIC methodology of six sigma and FMEA is an innovative way of improving quality of sewing process as discussed in figure 5.1. The quality enhancement model is developed that envisages the formation of a cross functional quality team under the leadership of top management and the involvement of quality personnel, line supervisors and machine technicians. The team is responsible for monitoring, evaluating and improving quality of the sewing process through various regular meetings and the applications of quality enhancement tools as discussed in figure 5.1.

5.1.2 Define

At this stage, the Six Sigma team defines a project charter and the business processes to be undertaken during the Six Sigma implementation. The define phase should include case study selection, objective formulation, identification of suppliers, input, process, output and customers as well detail process flow chart of the sewing process under study. The define stage measures the size of the problem in terms of qualitative description. At this stage the relevance of the problem to the company is well investigated. The define stage makes sure that the project or case study selected have a significant importance to the organization.

5.1.3 Measure

The measure phase involves six sigma team to systematically collect, analyze and interpret available data that aids in further understanding of the problem using various metrics. The major parameters should be included in the measure stage are key performance indicators. It is also important to measure defects per million opportunities (DPMO), sigma level and process capability (Cp) at this stage.

5.1.4 Analyze

The analyze phase includes a series of methods that leads to the identification of the root causes of a problem. At this stage various root cause analysis tools can be used such as why-why analysis, and cause and effect analysis. Control charts of variable and attribute quality measurement can also be performed at this stage. Since control charts clearly show statistical stability of a manufacturing process including the textile and garment sector, its application has been widely effective.

Pareto analysis of defects helps to identify major causes that contribute to 80% of the effects. The most common root cause analysis tool is the cause-and-effect analysis also known as fishbone diagram through brainstorming and discussions. The fishbone diagram classifies potential root causes according to the four categories of machine manpower, method and material.

5.1.5 Improve

After identifying the problem with the Fishbone Diagram, then looking for improvement priorities with FMEA analysis through RPN calculations. FMEA method when effectively implemented can mitigate the risk, avoids or minimizes the failure and/or mistakes and prevents from total process breakdown or failure (Kifta, 2018). A questionnaire is used for analysis of causes of major defects. Finally prioritization of failure modes and mitigation solutions is provided in section 4.7.

5.1.6 Control

Since six sigma is a continuous improvement initiative, the key parameters that are measured before implementation of the project should be re-evaluated to make sure previous issues have been addressed and also to identify new problems that came along the implementation. During the control phase the quality indicators along with sigma level and DPMO are reevaluated in order to sustain improvements.

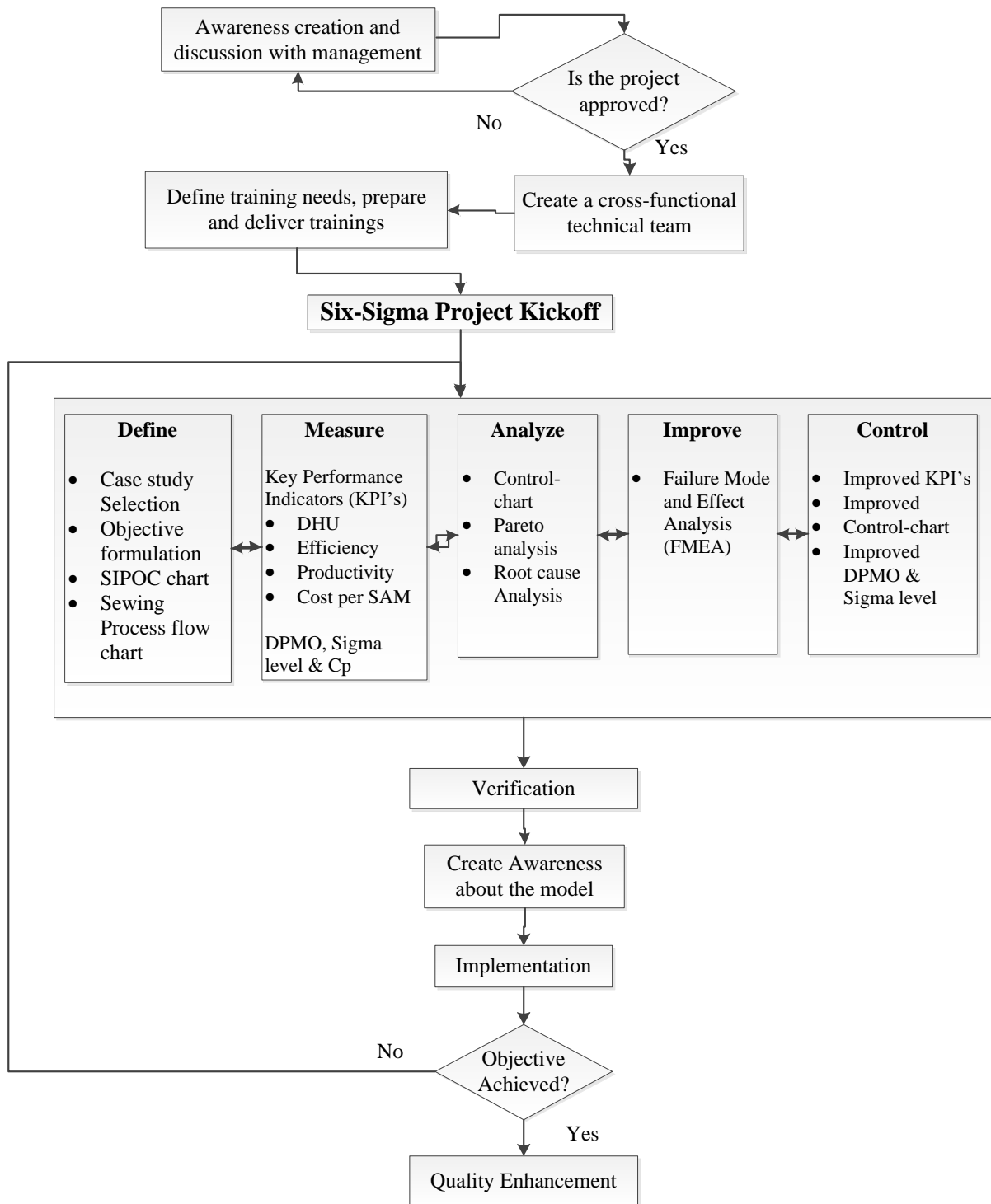


Figure 5.1- Proposed sewing process quality enhancement model

5.2 Model verification

5.2.1 Revised Control Charts

Based on the control charts presented at section 4.6.1, all process for five products exhibits an out-of-control situation as a result they process is statistically not stable. Hence at this stage data is filtered for assignable causes of variations by identifying outliers from the control chart and removing assignable variations. The revised data is again analyzed using control chart in order to identify process stability as discussed below.

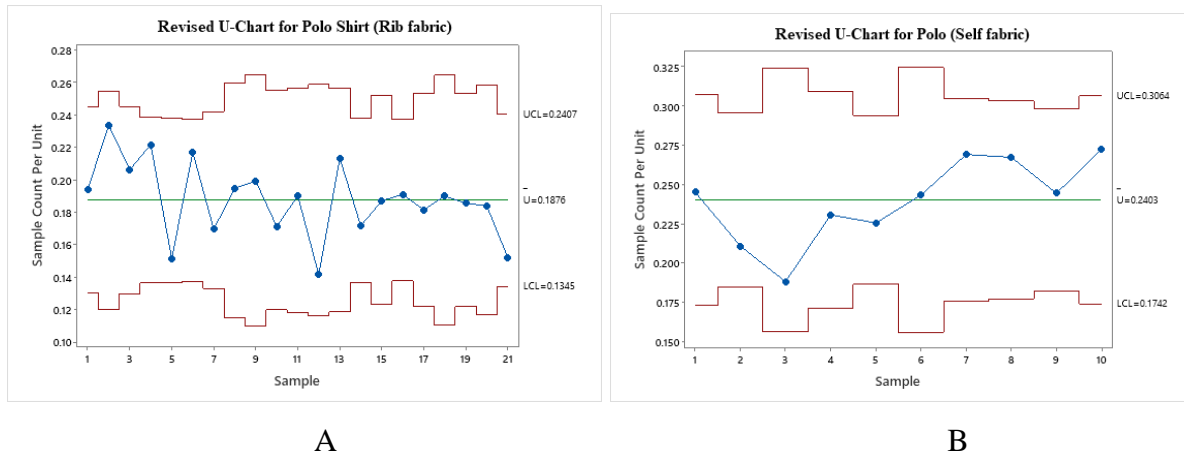


Figure 5.2- Revised control charts for A) polo shirt rib fabric B) Polo-shirt with self-fabric

Based on the revised control chart all the processes are identified as statistically stable process. From the control chart below, it is easily understandable that data points for all process are within their control limits.

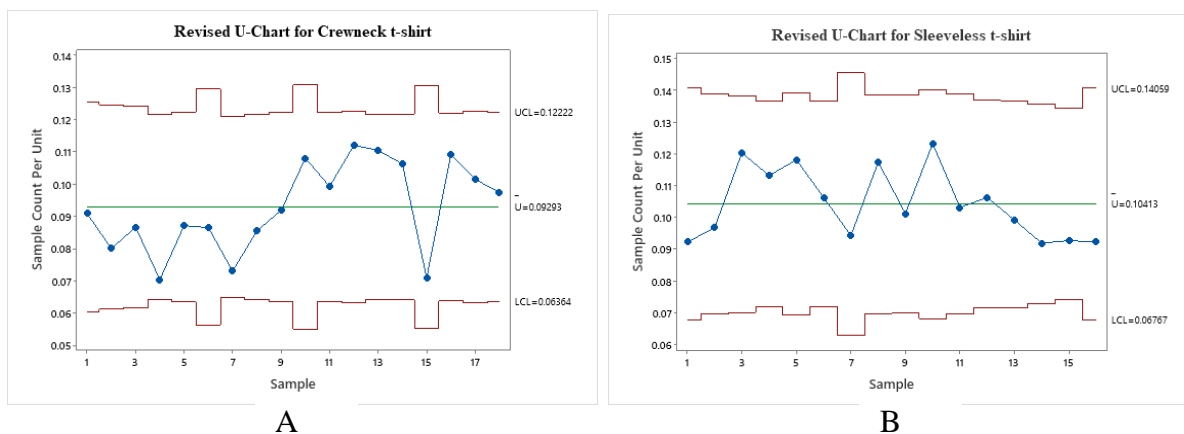


Figure 5.3- Revised control chart for A) Crewneck t-shirt B) sleeveless t-shirt

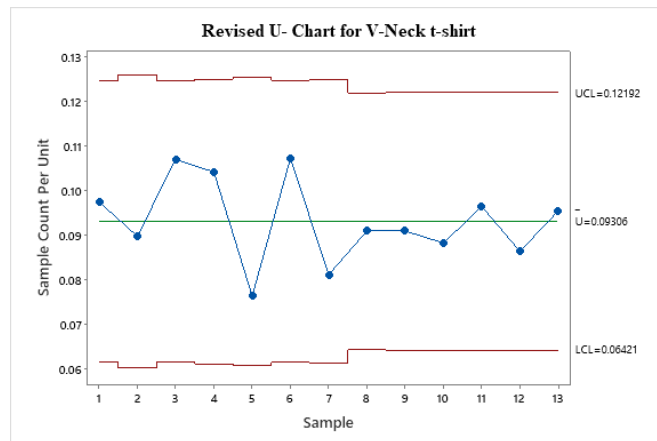


Figure 5.4- Revised control chart for V-Neck t-shirt

5.2.2 Revised Key Performance Indicators

Since, quality is an ongoing and a continuous process, it must be integrated with the overall business objective of the company. In order to improve the quality of garment production process in general and of sewing department in particular, key performance indicators of a sewing process must be measured for the top management to see the impact of improvements. As discussed in the model, the measurement phase is mainly concerned with measuring the level of quality problems specifically through analysis of quantitative data. Average defects per hundred units (DHU) is conducted separately for all styles under study and for the company as a whole. Defects per million opportunities (DPMO), sigma level and process capability index is analyzed to better understand the extent of the problem. In the following table below DHU is analyzed after improving the process through the exclusion of assignable causes of variations.

Table 5.1: DHU after improvement

S. No	Style	Total pieces checked	Total Defects	Total Pass	Improved DHU	Original DHU	Improve ment
1	Polo shirt MLG02MM (Rib Fabric)	9,702	1,820	7,882	18.8	31.3	12.5
2	Polo shirt M846 (Self-Fabric)	5,193	1,248	3,945	24.0	30.3	6.3
3	Crew Neck (M1979M1)	16,184	1,504	14,680	9.3	14.5	5.2
4	Sleeveless (M11957R1)	12,993	1,353	11,640	10.4	11.7	1.3
5	V-Neck (M11959M1)	11,809	1,099	10,710	9.31	10.63	1.3
Total		56,627	7,024	48,857	14.4	19.7	5.3

Improvement in efficiency is discussed in the following table. From the table below it can be understood that the biggest improvement is achieved for crew neck t-shirt whereas small improvements are achieved for polo shirt with self-fabric and sleeveless t-shirt. A total of 5.6 % improvement in the efficiency of the sewing lines is achieved on average as discussed below.

Table 5.2: Efficiency after improvement

Product/Style	SAM	Total manpower	Target per day at 100%	Average daily production	Improved Efficiency (100%)	Initial Efficiency (100%)	Improvement (100%)
Polo with Rib fabric (MLG025MM)	24.88	50	965	375	38.9	33.7	5.2
Polo shirt with self fab M846	29.34	57	933	394	42.3	40.0	2.3
Crewneck T-shirt M11979	11.27	24	1,022	815	79.7	67.5	12.2
Sleeveless Crewneck M11957R1	11.12	24	1,036	727	70.2	67.5	2.7
V-Neck M11959M1	11.73	27	1,105	823	74.5	69.0	5.5
Average				626.8	61.1	55.54	5.6

In the following table productivity of the company in terms of labor and machine is presented against the initial productivity discussed in section 4.5. The biggest improvement is achieved for the crewneck sewing line whereas other lines also achieved improvement in productivity while the polo shirt with self-fabric do not have improvement and remained at the value of 7 t-shirts per day per labor as discussed in the following table.

Table 5.3: Labor and machine productivity after improvements

S. NO	Style	Machine	Man-power	daily output	Labor Productivity (pc/man/day)	Machine Productivity (pc/mac/day)
1	Sleeveless (M11957R1)	22	24	727	30	33
2	V-Neck (M11959M1)	24	27	823	30	34
3	Crewneck -M11979	22	24	815	34	37
4	Polo shirt with Rib fabric (MLG025MM)	37	50	375	8	10
5	Polo shirt- M846 (Self-Fabric)	43	57	394	7	9
Average productivity to be					22	25
Average productivity as is					20	22
Average productivity improvement					2	3

Cost per SAM or cost per garment is also one of the key performance indicators in the garment sector. Cost per SAM varies depending on the output of products and the efficiency of the workforce. Cost per SAM is also used by merchandising department and top management to make price estimations for garment service works. Without reduced cost per SAM, it is impossible to remain profitable and competitive in the sector.

From the table below, it is understood that cost per SAM for polo shirt with rib fabric and self-fabric are significantly reduced. All the t-shirt categories also achieved a reduction in their respective cost per SAM estimate.

$$\text{Cost Factor} = \left(\frac{99.792 \text{ Br/day}}{480 * \text{Eff}} \right) = 0.2079 / 0.797 \rightarrow 0.26$$

$$\text{Cost per SAM for crewneck} = 11.27 \text{ min} * 0.26 \text{ Br} = 2.94 \text{ Br/Garment}$$

Similarly the revised cost per SAM for all styles is given in the following table

Table 5.4: Cost per SAM estimates after improvement.

Style	SAM	Efficiency	Cost factor	Improved Cost per SAM (Birr)	Initial Cost per SAM (Birr)	Improvement (Birr)
Sleeveless (M11957R1)	11.12	70.2	0.30	3.29	3.42	0.13
V-Neck (M11959M1)	11.73	74.5	0.28	3.27	3.53	0.26
Crewneck – M11979	11.27	79.7	0.26	2.94	3.47	0.53
Polo with Rib (MLG025MM)	24.88	38.9	0.53	13.30	15.35	2.05
Polo shirt M846	29.34	42.3	0.49	14.42	15.25	0.83
Average				8.206	7.445	0.76

Since the company has a daily, monthly and yearly production capacity of 4,549 pc, 118,274 pc and 1,310,112 pc respectively as discussed in section 4.5, the projected average cost per SAM improvement by 0.76 Birr. This results in a quality cost saving of 3,457 Birr per day, 89,888 birr per month and 995,685.12 birr per year. In the following figure improvements in cost per SAM is discussed using bar chart as follows

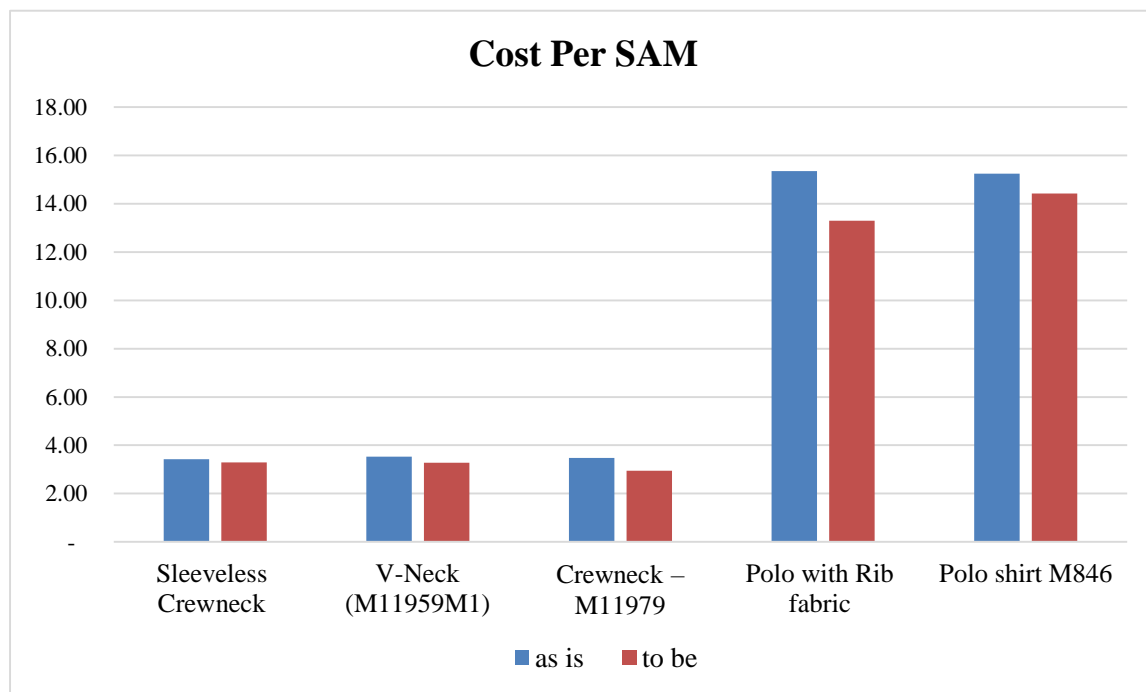


Figure 5.5- Improvements of Cost per SAM

5.2.3 Revised Sigma level and process capability

Sigma level is identified through revised data. The revised sigma level and process capability has shown improvements. The process has a capability of around 1.3598 and a sigma level of around 4.08. In the following table sigma level of the sewing process before and after improvement is presented.

Table 5.5: Sigma level and process capability after improvement

S.NO	Measurement Parameter	Improved Value	Original Value
1	Total pieces checked	56,627	128,311
2	Total defects	7,005	24,229
3	DPO	0.004948	0.00755
4	DPMO	4,948	7,553
5	Sigma Level	4.08	3.93
6	Process capability (C_p)	1.3598	1.3075
	Improvement of sigma level	0.15	
	Improvement of Process capability (C_p)	0.0523	

From the above table DPMO is improved from 7,553 to 4,948. Similarly, the sigma level is improved from the existing 3.93 to 4.08 by 0.15 whereas the process capability has improved from the existing 1.3075 to 1.3598 by 0.053.

5.3 Control phase

The Control phase controls the improved process or product performance to ensure the targets are met. Once the solution has resulted in improvements, the improvements must be standardized and sustained over time. In the control phase the overall implementation of the sewing process quality enhancement is re-evaluated against defects per hundred units, sigma level and DPMO. The control phase should make sure that there are no assignable causes of variation and that the process is within a statistical control. At this stage the continuous process of achieving business excellence through the application of six sigma is evaluated continuously to make sure that mistakes, hindrances and communication gaps are corrected along the way. Hence, the main task of this stage is to analyze achieved results during implementation continuous process and modify and/or set new targets based on the results achieved.

5.4 Model Validation

Model validation is conducted for the purpose of demonstrating that the developed model can bring expected results in the actual process. The model validation is conducted by taking expert opinions from within the company. A total of 3 experts are selected for the purpose of validating the model through detail presentation of the research findings and discussions of the proposed model. In the following table below background of experts whose opinion is considered is provided.

Table 5.6: Background of Experts

S.N0	Position of Expert	Educational Background	Area of specialization	Years of experience
1	Operational director	Diploma in Garment production	Garment production	13
2	Production manager	Diploma in Garment production	Garment production	18
3	Planning head	BSc in Industrial Engineering	Garment Industrial Engineering	8

The model validation conducted separately with three experts from the company include operational director, planning head, and production manager. Based on discussion with operational director and planning head, the model is considered reliable and includes some key performance indicators of the sector that is important to verify and predict the quality status and its impact on company performance. All major issue addressed by FMEA are validated. Furthermore the FMEA analysis is essential quality enhancement tool from the company side given that all information is gathered adequately and precisely. There is lack of adequate knowledge to understand sigma level and process capability discussed in the measure phase of the model. Regarding the quality enhancement model in enhancing quality of the sewing process to the target results obtained as discussed in model verification, the experts agreed with certainty. Hence the quality enhancement framework is applicable to improve the quality of the garment sewing process.

Based on discussion with production manager all the points raised by failure mode and effect analysis are validated. Regarding the effectiveness of the model in bringing the expected quality improvement indicated by key performance indicators, the expert is optimistic about the results.

The expert agreed that application of the model in the sewing process can even lead to better results. Therefore, the developed model is valid for the company based on the opinion of experts from the case company.

5.5 Summary of the chapter

The chapter discusses in detail about the development of a continuous quality enhancement model that utilizes various quality enhancement tools with a six sigma continuous improvement framework. Statistical process control tools such as control charts, Pareto charts, root cause analysis or fishbone diagram, process analysis tools such as supplier, input, process, output and customer chart (SIPOC), process flow diagram tools have been effectively utilized. Furthermore key performance indicators of the garment industry such defect per hundred units, efficiency, productivity and cost per SAM have also been used. Similarly measurement of sigma value and process capability has also been conducted. Based on the inputs available, the process of conducting six sigma project has been presented with simplicity. Based on the data available from the company, improvement are made conceptually, while practical implementation of the developed model is also expected to yield better results. To conduct enhancement of quality based on the developed model, the company is capable of taking the initiative provided that all data pertaining to various phases are available. The developed model provides the right tools and procedures for the company to improve quality of the sewing process. Six sigma framework are applied in different manufacturing and service industries, however, the development of six sigma framework specifically for the garment sewing process have a significant impact on companies they adopt more six sigma projects to enhance their quality and to become profitable and competitive in the global market. Therefore, the developed model significantly improves the perception of industries leaders and management on the effective utilization quality enhancement models such as this.

CHAPTER – SIX

6. Conclusion and Recommendation

6.1 Conclusion

The causes of poor quality in the garment industry can be from fabric, cutting process, sewing and finishing sections. However, defects in the sewing section are one of the major contributors to garment defects. Reducing defect is very important for ensuring the quality of products hence, improving quality of the sewing process is mandatory to sustain in this global competitive market. Causes of defects in sewing section are mainly due to Poor quality of raw material coming from cutting section, inadequate training of workers in the company, poor maintenance of machinery and improper work methods.

Based on the aggregate results, the most frequent occurrences of sewing defect are shape out (32.82%), broken stitch (27.1%), open- seam (9.6%), and unbalanced seam (7.22%), down stitch (2.97%) and skip stitch (2.29%). These defects were the major causes of high rate of reworks in the enterprise leading to (82%) of defects. By conducting Pareto analysis of sewing defects based on the type of operations, the study identified that cover stitch machines contributed to 36% of defects while the single needle lock stitch machine contributed to 32% of defects. Similarly manual operation and over lock machine contributed to 6.5 and 5.5% of all defects respectively.

From the U-chart, it can be understood that the process has encountered an out-of-control situation for all styles. The causes of this situations has been traced back and its root cause are identified as machine failures and operator issues (non- detection of defects). Generally the root cause analysis has shed some light on major factors that contribute to the creation of sewing defects. In order to address those issues a technical quality control team must be established and receive trainings on ways of quality improvement techniques.

The deployment of failure mode effect analysis tool is effective to prioritize implementation of corrective actions. Through Application of six sigma and FMEA approach, the study showed a decrease of DHU by an average of 5.3% from the existing 19.7% to 14.4% whereas as improved the average efficiency by 5.6 from the existing 55.54% to 61.14%. Sigma level is also improved by 0.15% from the existing 3.93 to 4.08 whereas, process capability is improved by 0.053% from the existing 1.3075 to 1.3598.

Absence of proper factory quality standard in the enterprise also creates poor understanding of quality. Specific critical operations were more prone to defects than others. Putting skilled and experienced operators in these critical operations also improves quality. The study also identified Lack of skill up gradation training in the enterprise, machine failure and adjustment issue, manual work such as trimming and marking, lack of awareness about quality issues of the company by the middle management, absence of inline quality checkers and standard operating procedures to control quality of incoming cut panels have contributed to low quality performance in the case company. Absence of inline quality control or roving quality leads to late identification of defects. Hence the company should focus on areas of quality failures identified by FMEA, in order to enhance the quality of the sewing process and thus become cost effective, profitable and competitive in the global market.

Therefore, if the company gives due attention and takes the initiative to implement the model based on the findings of this study, key performance indicators of the company can be enhanced.

6.2 Recommendation

To become competitive in today's market, it is essential for the company to offer consistent quality product to their customers. It is better to emphasize on quality improvement as quality improvement leads to productivity improvement and competitive advantage. Initiatives such as quality control teams and projects produce better quality results. Continuous quality enhancement models such as this can keep the enterprise at the competitive edge both in the export market.

Keeping in mind the objectives, this study has developed a continuous quality enhancement model using six sigma methodology comprising selected statistical process control tools such as control charts, Pareto chart and root cause analysis to identify major defect for all styles that contribute 82 % of the defects. The enterprise can apply the proposed solutions that is developed from failure mode and effect analysis to eliminate and/or reduce the frequency of those defects.

The company should have enough maintenance personnel to address frequent machine problems. Cleaning of machine parts by operators will become helpful since most cotton products have high dust amount accumulated in the hook and loop of the machine. Continuous training of operators should be conducted as there is turnover of employees. The company should also provide adequate training for quality personnel about apparel quality particularly defect classifications (taxonomy) in the garment industry and preparation of control charts and Pareto tools. Furthermore computer aided deployment of control charts and Pareto analysis training should be delivered to quality manager. Finally, the company is recommended to deploy in- line quality personnel that should control quality of the sewing process after providing adequate training.

6.3 Future Research Area

Future research should focus to address other sections of the garment industry such as incoming fabric quality, cutting room quality and finishing quality so as to develop an integrated model for continuous quality improvement in the garment industry. Future study should also address the effect of incentive schemes on operator performance and line efficiency in the Ethiopian garment industries.

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Appendices

Appendix 1: DHU of the Products under the study

Defects for Crew Neck t-shirt

Style: Crew Neck M1979M1						
S. N ^o	Date	Total pieces checked	Total Defects	Total pass	DHU	line
1	1/7/2014	731	91	640	12.4	1
2	2/7/2014	895	105	790	11.7	3
3	2/7/2014	792	72	720	9	1
4	7/7/2014	837	67	770	8	1
5	8/7/2014	590	110	480	18.6	8
6	8/7/2014	854	74	780	8.6	1
7	12/9/2014	916	196	21.3	21.3	6
8	13/9/2014	799	104	695	13	3
9	25/9/2014	564	84	480	14.8	4
10	25/9/2014	981	61	920	6.2	6
11	26/9/2014	985	45	940	4.5	4
12	26/9/2014	1022	72	950	7	6
13	27/9/2014	639	89	550	13.9	4
14	27/9/2014	964	84	880	8.7	6
15	29/9/2014	624	54	570	8.6	4
16	30/09/2014	1068	78	990	7.3	4
17	30/09/2014	977	57	920	5.8	6
18	13/06/2015	558	118	440	21.1	4
19	14/06/2015	802	137	665	17	6
20	14/06/2015	629	189	440	30	4
21	14/06/2015	596	156	440	26.1	4
22	14/06/2015	964	134	830	13.9	3
23	15/06/2015	958	138	820	14.4	6
24	15/06/2015	573	133	440	23.2	4
25	15/06/2015	636	196	440	30.8	4
26	15/06/2015	988	108	880	10.9	3
27	16/06/2015	938	128	810	13.6	6
28	16/06/2015	577	137	440	23.7	4
29	16/06/2015	619	179	440	28.9	4
30	16/06/2015	1017	87	930	8.5	3
31	17/06/2015	831	141	690	16.4	6
32	17/06/2015	613	173	440	28.2	4
33	17/06/2015	581	141	440	24.2	4

34	17/06/2015	969	89	880	9.1	3
35	18/06/2015	490	70	420	14.2	6
36	18/06/2015	583	63	520	10.8	3
37	20/06/2015	977	97	880	9.9	6
38	20/06/2015	552	112	440	20.2	4
39	20/06/2015	525	85	440	16.1	4
40	20/06/2015	1004	124	880	12.3	3
41	29/06/2015	548	108	440	19.7	4
42	29/06/2015	915	105	810	11.4	6
43	21/06/2015	946	106	840	11.2	6
44	21/06/2015	1036	176	860	16.9	3
45	21/06/2015	1023	113	910	11	6
46	22/06/2015	521	81	440	15.5	4
47	24/06/2015	998	118	880	11.8	6
48	24/06/2015	1007	107	900	10.6	3
49	25/06/2015	383	83	300	21.6	4
50	25/06/2015	592	42	550	7	3
51	27/06/2015	1007	127	880	12.6	3
52	28/06/2015	988	108	880	10.9	3
53	28/06/2015	946	96	850	10.1	6
54	29/06/2015	975	95	880	9.7	3
		43,103	5,843	35,561	14.5	

Defects for Polo-shirt with Rib fabric

Style: Polo shirt MLG02MM (Rib Fabric)						
S. N ^o	Date	Total pieces checked	Total Defects	Total pass	DHU	line
1	25/08/14	576	306	270	53.1	5
2	25/08/14	235	85	150	36.1	4
3	26/08/14	910	700	210	76.9	5
4	26/08/14	565	160	405	28.3	4
5	28/08/14	774	439	335	56.7	5
6	28/08/14	581	141	440	24.2	4
7	29/08/14	453	273	180	60.2	5
8	29/08/14	515	100	415	19.4	4
9	4/9/2014	688	358	330	52	5
10	4/9/2014	372	87	285	23.3	4
11	5/9/2014	504	104	400	20.6	4
12	5/9/2014	641	256	385	39.9	5
13	6/9/2014	649	144	505	21.2	4
14	8/9/2014	660	100	560	15.1	4
15	9/9/2014	686	226	460	32.9	4
16	10/9/2014	677	147	530	21.7	4
17	12/9/2014	397	142	255	35.7	5
18	12/9/2014	442	187	255	42.3	4
19	13/9/2014	311	81	240	26	4
20	13/9/2014	566	96	470	16.9	1
21	15/9/2014	323	63	260	19.5	4
22	15/9/2014	281	56	225	19.9	1
23	16/9/2014	424	119	305	28	4
24	16/9/2014	368	63	305	17.1	4
25	17/9/2014	352	67	285	19	4
26	17/9/2014	332	47	285	14.1	4
27	18/9/2014	356	76	280	21.3	4
28	19/9/2014	658	113	545	17.1	4
29	22/9/2014	319	89	230	27.8	4
30	23/9/2014	406	76	330	18.7	4
31	23/9/2014	441	106	335	24	4
32	25/04/15	113	33	80	29.2	1
33	26/04/15	453	133	320	29.3	1
34	27/04/15	74	14	60	18.9	4
35	27/04/15	267	117	150	43.8	1
36	1/5/2015	451	171	280	37.9	1

37	2/5/2015	408	168	240	41.1	1
38	5/5/2015	529	171	358	32.3	1
39	6/5/2015	265	167	98	63	1
40	9/5/2015	385	241	144	62.5	1
41	20/05/15	290	130	160	44.8	1
42	22/05/15	505	195	310	38.6	1
43	23/05/15	471	198	273	42	1
44	24/05/15	297	142	155	47.8	1
45	3/6/2015	427	197	230	46.1	1
46	4/6/2015	266	146	120	54.8	1
47	7/6/2015	586	286	300	48.8	1
48	8/6/2015	556	196	360	35.2	1
49	9/6/2015	616	236	380	38.3	1
50	10/6/2015	329	144	185	43.7	2
51	10/6/2015	546	241	305	44.1	1
52	11/6/2015	294	125	169	42.5	2
53	11/6/2015	520	140	380	26.9	1
54	13/06/15	257	107	150	41.6	2
55	13/06/15	680	130	550	19.1	1
56	14/06/15	610	160	450	26.2	1
57	15/06/15	604	154	450	25.4	2
58	15/06/15	391	71	320	18.1	1
59	16/06/15	475	95	380	20	2
60	16/06/15	284	54	230	19	2
61	16/06/15	393	73	320	18.5	1
62	17/06/15	386	121	265	31.3	2
63	17/06/15	352	87	265	24.7	2
64	17/06/15	363	43	320	11.8	1
65	18/06/15	326	74	252	22.6	2
66	18/06/15	349	96	253	27.5	2
67	18/06/15	357	37	320	10.3	1
68	19/06/15	343	68	275	19.8	2
69	19/06/15	337	62	275	18.3	2
70	19/06/15	300	35	265	11.6	1
71	20/06/15	598	91	507	15.2	2
		31,515	10,156	21,369	31.3	

Defects for Polo shirt with self-fabric

Style: Polo Shirt MR846 (Self Fabric)						
S. N^o	Date	Total pieces checked	Total Defects	Total pass	DHU	line
1	2/6/2014	316	216	100	68.3	4
2	2/6/2014	477	117	360	24.5	5
3	3/6/2014	291	131	160	45	4
4	3/6/2014	485	175	310	36	5
5	4/6/2014	455	105	350	23	5
6	5/6/2014	323	123	200	38	4
7	5/6/2014	304	74	230	24.3	5
8	7/6/2014	543	153	390	28.1	5
9	8/6/2014	506	141	365	27.8	4
10	8/6/2014	685	380	305	55.4	5
11	9/6/2014	375	130	245	34.6	4
12	9/6/2014	333	143	190	42.9	5
13	10/6/2014	495	135	360	27.2	4
14	10/6/2014	580	185	395	31.8	5
15	11/6/2014	526	166	360	31.5	5
16	12/6/2014	520	140	380	26.9	4
17	12/6/2014	596	241	355	40.4	5
18	14/6/2014	546	146	400	26.7	5
19	23/6/2014	650	220	430	33.8	4
20	23/6/2014	642	157	485	24.4	5
21	24/6/2014	749	169	580	22.5	4
22	24/6/2014	663	83	580	12.5	5
23	25/6/2014	781	81	700	10.3	4
24	25/6/2014	697	147	550	21	5
25	26/6/2014	308	58	250	18.8	5
26	30/6/2014	756	76	680	10.5	5
		13,602	3,892	9,710	30.3	

Defect for sleeveless crewneck t-shirt

Style: Sleeveless Crew Neck t-shirt M11957R1						
S. N^o	Date	Total pieces checked	Total Defects	Total pass	DHU	Line
1	2/6/2014	705	65	640	9.2	1
2	2/6/2014	786	76	710	9.7	3
3	3/6/2014	807	97	710	12.0	1
4	3/6/2014	902	102	800	11.3	3
5	4/6/2014	771	91	680	11.8	1
6	4/6/2014	895	95	800	10.6	3
7	5/6/2014	552	52	500	9.4	1
8	5/6/2014	538	38	500	7.1	3
9	7/6/2014	793	93	700	11.7	1
10	7/6/2014	801	81	720	10.1	3
11	8/6/2014	723	89	634	12.3	1
12	8/6/2014	786	81	705	10.3	3
13	9/6/2014	558	83	475	14.9	1
14	9/6/2014	599	74	525	12.4	3
15	10/6/2014	686	135	587	19.7	1
16	10/6/2014	832	116	720	13.9	3
17	11/6/2014	829	109	720	13.1	3
18	12/6/2014	885	94	795	10.6	1
19	12/6/2014	888	88	800	9.9	3
20	14/6/2014	861	111	750	12.9	1
21	14/6/2014	911	111	800	12.2	3
22	23/9/2014	915	115	800	12.6	1
23	24/6/2014	958	88	870	9.2	1
24	24/6/2014	1036	96	940	9.3	3
25	26/6/2014	705	65	640	9.2	1
		19,722	2,245	17,513	11.42	

Defect for V-Neck t-shirt

Style: V- Neck M11959M1						
S. N^o	Date	Total pieces checked	Total Defects	Total pass	DHU	Line
1	15/9/2014	803	123	680	15.3	3
2	16/9/2014	712	167	545	23.5	3
3	16/9/2014	652	72	580	11.0	2
4	17/9/2014	858	143	715	16.7	3
5	17/9/2014	842	82	760	9.7	2
6	18/9/2014	780	70	710	9.0	3
7	18/9/2014	851	91	760	10.7	2
8	19/9/2014	489	64	425	13.1	3
9	19/9/2014	826	86	740	10.4	2
10	22/9/2014	812	62	750	7.6	3
11	23/9/2014	840	90	750	10.7	3
12	23/9/2014	838	68	760	8.1	2
13	24/9/2014	1047	121	926	11.6	3
14	24/9/2014	1012	92	920	9.1	2
15	25/9/2014	964	54	910	5.6	3
16	25/9/2014	1001	91	910	9.1	2
17	26/9/2014	962	62	900	6.4	3
18	26/9/2014	1009	89	920	8.8	2
19	27/9/2014	996	96	900	9.6	3
20	27/9/2014	996	86	910	8.6	2
21	29/9/2014	962	62	900	6.4	3
22	29/9/2014	540	90	450	16.7	2
23	30/9/2014	571	36	535	6.3	3
24	30/9/2014	1006	96	910	9.5	2
		20,369	2,093	18,276	10.56	

Appendix 2: FMEA (Failure Mode and Effect Analysis)



Masters of Science in Industrial Engineering (MSc)

እኔ ሙስጠፋ ሙሐመድ የመጨረሻ አመት የማስተርስ ተማሪ ሲሆን በአሁኑ ሰዓት “Enhancing Quality of a Garment Sewing Process: A case of Eltex Textile and Garment Factory” ወይም “የጋርመንት የስፊት ሂደትን ጥራት ማሻሻል: የኤልቴክስ ጨርቃጨርቅ ፋብሪካ ማሳያ ጥናት በሚል ርዕስ የመመረቂያ ጥናታዊ ጽሁፍ እየሰራሁ እገኛለሁ ፤ ስለሆነም የእናንተ ግብዓት የጥናቱን አላማ ለማሳካት እጅግ በጣም አስፈላጊ ሆኖ በመገኘቱ፤ ይህን መጠይቅ በፍቃደኝነት፤ በግልጽነትና፤ በእውነተኛነት እንድትሞሉልኝ በትህትና እየጠየቅኩኝ፤ ከዚህ የሚገኘው መረጃ ለትምህርት አላማ እና ለእውቀት ሽግግር ብቻ እንደሚውል ከወዲሁ እገልጻለሁ፤

ከልብ አመሰግናለሁ!!

Target Group: Line Supervisors and Quality Personnel

1. አጠቃላይ መረጃ:

I) የስራ ድርሻ: መስመር ተቆጣጣሪ/ Supervisor ኪሊት/ Quality

II) ዕድሜ
ከ20 በታች 21-25 26-35 36-45 ከ46 በላይ

III) የትምህርት ደረጃ
1-8 9-10 11-12 TVET ድግሪ

IV) አጠቃላይ የስራ ልምድ
0 – 1ዓመት 1-2ዓመት 3-5ዓመት 6-10 ዓመት ከ11ዓመት በላይ

2. የብልሽት መንስኤ እና ተጽዕኖ ትንተና (1-5)

ደረጃ	ገለጻ
1	በጣም ዝቅተኛ/ ምንም
2	ዝቅተኛ/ አናሳ
3	መካከለኛ/ ጉልህ
4	ከፍተኛ/ ዋነኛ
5	በጣም ከፍተኛ/ አስከፊ

የብልሽት ክፍሎች	ብልሽት ሊፈጠር የሚችልበት ሁኔታዎች	ብልሽት የሚፈጠርበት መንስኤዎች	ብልሽት የሚያስከትለው ተጽዕኖዎች/ Defect	የከባድነት ደረጃ	የመከሰት እድል	ለመለየት አዳጋችነት
ማሽን	በማሽን ምክንያት	ተደጋጋሚ የማሽን መበላሸት፤ ለምሳሌ የመርፌ መሰበር	1. የተበጠሰ ስፊት 2. የተዘለለ ስፊት 3. ክፍተት ያለበት 4. ቅርጹን የቀየረ			
	በማሽን ክፍሎች ምክንያት	ያረጀ ጥርስ፣ያረጀ መርገጫ፣ የተቸፈቸፈ የመርፌ ሳህን፣ ያረጀ የክር ማሳለፊያ	1. እኩል ያልሆነ 2. የተዘለለ ስፊት 3. ቅርጹን የቀየረ 4. ከጨርቅ ውጭ የተሰፋ			
	በማሽን አጀስትመንት ምክንያት	የተሳሳተ የማሽን አጀስትመንት፣ ለምሳሌ የተሳሳተ የላይኛው እና የታችኛው መርፌ የጊዜ አጠባበቅ (timing)	1. የተዘለለ ስፊት 2. ቅርጹን የቀየረ 3. እኩል ያልሆነ 4. ክፍተት ያለበት			
ሰራተኛ	የስልጠና ጉድለት፤ የችሎታ እና ልምድ ምክንያት	የችሎታ እና ልምድ ማነስ	1. ክፍተት ያለበት 2. ከጨርቅ ውጭ የተሰፋ 3. የተዘለለ ስፊት			
		የአያያዝ ችሎታ ማነስ/ ጥብቅ አድርጎ ጨርቅ መያዝ	1. ከጨርቅ ውጭ የተሰፋ 2. እኩል ያልሆነ 3. ቅርጹን የቀየረ 4. የተዘለለ ስፊት			
		በከፍተኛ ፍጥነት ማሽን መስራት	1. እኩል ያልሆነ			
	የአትኩሮት ምክንያት	የትኩረት ማነስ	1. ክፍተት ያለበት 2. እኩል ያልሆነ			
	የግድየለሽነት ምክንያት	ግድየለሽ መሆን	1. ከጨርቅ ውጭ የተሰፋ 2. እኩል ያልሆነ			
የአሰራር - ዘዴ	በቅድመ-ዝግጅት ምክንያት	ልክ ያልሆነ የክር አወጣጠር (tension)	1. ቅርጹን የቀየረ 2. የተበጠሰ ስፊት 3. የተዘለለ ስፊት			
	በሰራ - መርጃዎች ምክንያት	ልክ ያልሆነ ፎልደር (ማጠፊያ)፣ አታችመንት፤ ጋይድ፤ የላይኛው መርፌ እና የታችኛው መርፌ (Loop)	1. ከጨርቅ ውጭ የተሰፋ 2. የተዘለለ ስፊት			
		ልክ ያልሆነ የጠርዝ አያያዝ	1. ክፍተት ያለበት 2. ቅርጹን የቀየረ			

	በስራ አሰራር ምክንያት	የተሳሳተ የክር አገባብ	1. እኩል ያልሆነ 2. የተዘለለ ስፊት			
		የተሳሳተ ምልክት አደራረግ	1. እኩል ያልሆነ			
		የተሳሳተ የስፊት ስፋት (ዊድዝ: width)	1. ክፍተት ያለበት 2. ከጨርቅ ውጭ የተሰፋ 3. የተዘለለ ስፊት 4. እኩል ያልሆነ			
		የተሳሳተ የመርፌ አይን አቀማመጥ	1. የተበጠሰ ስፊት			
		ልክ ያልሆነ አቀነጫጫብ እና የማሽን አጠቃቀም	1. የተበጠሰ ስፊት			
		ምቹ ያልሆነ/ መጥፎ አቀማመጥ	1. ቅርጹን የቀየረ 2. ክፈተት ያለበት 3. ከጨርቅ ውጭ የተሰፋ 4. እኩል ያልሆነ			
የግብዓት	በጥሬ -እቃ ግብዓት ምክንያት	ዝቅተኛ የክር ጥራት	1. ክፍተት ያለበት 2. የተበጠሰ ስፊት 3. የተዘለለ ስፊት			
		ልክ ያልሆነ ማድረቂያ እና ገበር	1. ከጨርቅ ውጭ የተሰፋ			
		ልክ ያልሆነ መርፌ/ የታጠፈ መርፌ/ የተጣመመ መርፌ	1. የተበጠሰ ስፊት 2. የተዘለለ ስፊት			
	በቆረጣ-ስህተት ምክንያት	ብልሽት ያለበት የተቆረጠ ጨርቅ	1. ከጨርቅ ውጭ የተሰፋ 2. ክፍተት ያለበት 3. እኩል ያልሆነ			
		የተዛባ ቅርጽ የያዘ የተቆረጠ ጨርቅ	1. ከጨርቅ ውጭ የተሰፋ 2. ክፍተት ያለበት 3. እኩል ያልሆነ			
	በጨርቅ ባህሪ	አስቸጋሪ ጨርቅ/ የሚለጠጥ ጨርቅ	1. ቅርጹን የቀየረ			

Appendix 3: Review of Literatures on Six sigma and FMEA

S/N ₀	Author and Date	Title	Objectives	Methodology/Tools	Results/Findings
1	Khorshidi et al., 2013	Implementation of SPC with FMEA in less-developed industries with a case study in car battery manufactory plant	To improve quality using the integration of FMEA and SPC in a car battery industry in a less-developed industry	cause-and-effect diagram, FMEA method, Pareto chart, check sheet, and control charts have been used to implement SPC	The study presented an algorithm for implementation of SPC in a car battery manufacturing company using FMEA method
2	Chuenyindee and Prasetyo, 2020	Roller Chains Quality Enhancement using Six Sigma and Failure Mode and Effects Analysis (FMEA)	To enhance the quality of roller chains manufacturing process by utilizing Six-Sigma methodology and Failure Mode and Effects Analysis	Six sigma and FMEA methods. The tools used are pareto chart, fishbone diagram, X&R control charts, design of experiments (DoE), T-Test, regression analysis using Minitab software	The study indicated production capability could be increased from 0.50, which was lower than the standard, to 2.28 (78.10% improvement), and could also reduce the defects from 158,629.86 PPM to 3.64 PPM
3	Hibarkah Kurnia et al., 2021	Quality Improvement with the DMAIC Approach Using the Implementation of Benchmarking and KPI Methods	To determine the leading causes of dominant defects, increase the sigma level, and propose improvements to be included in the KPI method so that the relevant department can control it using the DMAIC approach	The methods are a combination of Six sigma and FMEA; the tools include cost of quality (CoQ), sigma level, Pareto diagram, fishbone analysis, RPN, DoE, and Analysis of Variance	This study found that the dominant factor causing the socks defect was inappropriate linking needle at 504 RPN, the yarn hardness was varied at 441 RPN, and the thread clumps cutter was 384 RPN, the sock that went straight into the plate was 294 RPN. Proposed improvement solutions

4	Hartono et.al, 2021	Improving Quality on Tire Curing Process by Using Six Sigma and (FMEA) Method - A Case Study in Tire Manufacturer	The objective is to reduce defects in the tire curing process of Truck Bus Bias Tire Manufacturing	Uses six sigma and FMEA method. tools used are sigma level, pareto, Fishbone analysis and RPN	Based on the RPN value, It proposes to measure the service life of spare parts, such as seals, packing and lubricating oil so that part replacement can be done before the damage occurs
5	Ibad Primahesa and Yustina Ngatilah 2022	Quality Analysis Of Bakery Products Using The Six Sigma Method And Failure Mode And Effect Analysis (FMEA) Case Study On Cv. Xyz 2022	The objective is to analyze quality of bakery products using six sigma and FMEA	Uses the DMAIC methodology of six sigma and uses FMEA tool in the improve stage	The study Identified three products with high defect issues and also used 3 critical to quality (CTQ) attributes which are also defect categories. Using fishbone analysis and FMEA. It provided improvement areas using risk priority number (RPN).
6	EL-Hadidy and EL-Sisy, 2023	Defects analysis in the apparel industry	The objective of the study is to reduce the total defect % to the minimum level and thereby improving quality and reducing waste	The tools include Process Flowchart, Pareto Chart, fishbone diagram, Factorial design, and sigma level	The study demonstrated that a manufacturing unit's sigma level improved from 0.9 to 2.4, prompting a stronger focus on improving production quality
7	Indrawati and Shabrina, 2023	Integration of Six Sigma, FMEA and TRIZ to Improve Product Quality: Upright Piano Case Application	The research focuses on quality improvement of upright piano using the Six sigma, FMEA and TRIZ (Theory and Innovative Problem Solving) method	The methods include Six sigma, FMEA and TRIZ. The tools deployed are COQ (critical to quality), DPMO, sigma level, P-control chart, pareto diagrams and RPN	Based on the research the average value of DPMO for 9 months is 2,547 with a sigma value of 4.3 The value of the highest Risk Priority Number (RPN) is 192 is the improper handling of the operator. Solution provided are new design of cabinet shelf and the standard operational procedure

Appendix 4: Defects by Defect category

Defect code	Defect Types	Polo shirt MLG025MM (Rib Fabric)	Polo shirt M846 (Self- Fabric)	Crew Neck (M1979M1)	Sleeveless Crewneck (M11957R1)	V-Neck (M11959M1)
A	SKIP STITCH	378	164	682	118	7
B	BROKEN STITCH	2,068	927	1763	563	756
C	LOOSE STITCH	352	14	172	140	0
D	DOWN STITCH	427	61	317	241	0
E	UN-BALANCED	48	92	919	154	425
F	PLEATS	101	28	98	0	11
G	GATHERING	44	0	0	18	0
I	SHAPE OUT	4,131	2060	699	632	638
J	JOINTS UNEVEN	71	0	0	23	0
K	TICKET STICKER	10	0	0	0	0
M	MEASUREMENT	22	0	0	0	0
N	NEEDLE HOLE	30	0	45	0	47
O	OPEN SEAM	1,544	275	579	356	209
P	PUCKERING	209	63	0	0	0
Q	WRONG LABEL	0	0	35	0	0
T	UN-CUT THREADS	112	0	455	0	0
V	INCORRECT SPI	6	0	0	0	0
W	PARTS COLOR CHANGE	32	42	12	0	0
X	WRONG THREAD	6	0	0	0	0
Y	FABRIC DEFECT	160	18	56	0	0
Z	OTHERS (Missing label)	405	148	11	0	0
	Total	10,156	3,892	5,843	2,245	2,093

Appendix 5:- Defects by Operation Type

Operation Type	Code	Average counts
Collar top stich	A1	2447
Placket top stitch	B1	2349
Collar attach on body	C1	1510
Collar stand top stich	D1	939
Placket hemming	E1	538
Button place marking	F1	803
Bottom hemming	G1	1909
Shoulder top stich	H1	1006
Side seam	I1	885
Collar stand binding	J1	114
Cuff attach	K1	90
Yoke attach	L1	290
Fabric damage (Y)	Y	487
Sleeve attach	M1	292
Placket attach	N1	182
Trimming (T)	T	780
Collar & stand folding	O1	55
Yoke folding	P1	76
Collar and stand attach	Q1	245
Label attach	R1	790
Button holing	S1	68
Yoke place marking	U1	18
Button attach	V1	391
Shoulder attach	W1	270
Placket folding	X1	43
Cuff tack	Z1	49
Placket tack	A2	165
Logo attach	A2	185
Cuff preparation	B2	118
Collar preparation	C2	5
Back Neck Top stich	D2	1097
Front Neck Top Stitch	E2	1209
Rib Tack	F2	51

Neck Binding	G2	212
Side Top stitch	H2	338
Sleeve top stitch	I2	1136
Arm Hole Tack	J2	69
Rib Round stitch	K2	114
Rib attach on body	L2	513
Rib checking	M2	72
Sleeve centering	N2	56
Side vent hemming	O2	68
Collar attach	P2	31
Sleeve hemming	Q2	1902
Other		262
Total		24,229

Appendix 6:- Root Cause Analysis

Shape out			
Machine	Man	Material	Method
<ul style="list-style-type: none"> ✓ Faulty feed mechanism ✓ Improper clamping 	<ul style="list-style-type: none"> ✓ Improper handling of panels ✓ Improper handling ✓ Poor fabric control ✓ Improper edge alignment 	<ul style="list-style-type: none"> ✓ Fabric Stretchability 	<ul style="list-style-type: none"> ✓ Incorrect sewing tension ✓ Incorrect threading

Broken stitch			
Machine	Man	Material	Method
<ul style="list-style-type: none"> ✓ Inappropriate thread and needle size ✓ high speed of machine 	<ul style="list-style-type: none"> ✓ Improper trimming and machine usage ✓ Tightly holding of fabric ✓ Incorrect usage of bobbins 	<ul style="list-style-type: none"> ✓ Needle plate, pressure foot, needle holes may have sharp edges ✓ Weak upper and lower thread ✓ Sharp needle hole 	<ul style="list-style-type: none"> ✓ Inappropriate thread tension ✓ Improper thread cutting ✓ Inappropriate positioning of needle eye. ✓ Extreme thread tension

Open Seam			
Machine	Man	Material	Method
<ul style="list-style-type: none"> ✓ Improper machine adjustment 	<ul style="list-style-type: none"> ✓ Lack of skill and concentration ✓ Improper edge alignment 	<ul style="list-style-type: none"> ✓ Poor quality sewing thread ✓ Distorted shape of cut panels 	<ul style="list-style-type: none"> ✓ Improper seam width

Un-balanced seam			
Machine	Man	Material	Method
<ul style="list-style-type: none"> ✓ Machine or bobbin tension is too high. ✓ Breakage of needle ✓ Failure of looper ✓ Incorrect hook timing ✓ Incorrect clamping 	<ul style="list-style-type: none"> ✓ Threading from the wrong side ✓ Improper handling ✓ Tightly holding the fabric ✓ Operator speeding up machine too rapidly ✓ Operator holding back or pulling fabric against correct machine feed 	<ul style="list-style-type: none"> ✓ High Fabric thickness ✓ misaligned parts 	<ul style="list-style-type: none"> ✓ Insufficient Stitch per Inch (SPI). ✓ Incorrect cuts ✓ Incorrect marking

Down -stitch			
Machine	Man	Material	Method
<ul style="list-style-type: none"> ✓ Faulty feed-dog ✓ Bad presser foot 	<ul style="list-style-type: none"> ✓ Operator carelessness ✓ Lack of proper handling 	<ul style="list-style-type: none"> ✓ Incorrectly cut panels ✓ Improper lining used 	<ul style="list-style-type: none"> ✓ Improper seaming ✓ Improper folding ✓ Incorrect seam width

Skip -stitch			
Machine	Man	Material	Method
<ul style="list-style-type: none"> ✓ Incorrect stitch per inch (SPI) ✓ Worn out thread guide ✓ Incorrect needle-hook timing 	<ul style="list-style-type: none"> ✓ Tightly handling of fabric ✓ Unskilled worker 	<ul style="list-style-type: none"> ✓ Bent needle ✓ Thick fabric material 	<ul style="list-style-type: none"> ✓ Long stitch length

Appendix 7: Interview Questions



Masters of Science in Industrial Engineering (MSc)

Interview Questions for top management

Dear Respondent, The purpose of this interview is to collect data on the factors affecting sewing quality of Eltex Textile and Garment PLC, Bishoftu plant. So, you are kindly requested to answer correctly and honestly. Please answer the questions freely as **every information provided will be treated confidentially**.

For any enquiry, please contact:

Researcher: Mustefa Mohammed +251-91638-8287

Advisor: - Dr. Kassu Jilcha (PhD) +251-911-94 80 14

Co-adviser:- Ms. Mehret Getachew (PhD candidate) +251-943-65 10 37

Part I

Name: _____ Gender _____ Position _____

Educational Level _____ Experience _____

Part II

1. What are the main products of the company?
2. How do you define the quality level of products in the company?
3. What are the major problems responsible for poor quality in the company?
4. What are the major quality problem in the sewing section?
5. What are the major process to ensure quality in your company?
6. What activities are undertaken to produce quality product in the sewing department?
7. What do you think should be done to improve quality level in general and specific to sewing?
8. What are the major products that have significant quality issues?
9. How do you control and manage the defect level in the sewing section?

Appendix 8: Company Quality Check-sheet

Factory Name		ELTEX TEXTILE AND GARMENT FACTORY								Buyer	Date	
Line #		21								Style #	30/09/14	
OPERATION TYPES		M11779M1								AGS	022 24648	
Defect code		1-hour 02-03,	2-hour 03-04,	3-hour 04-05,	4-hour 05-06,	5-hour 07-08,	6-hour 08-09,	7-hour 09-10,	8-hour 10-11,	Name	Remarks	
Attack on body	I	111	1	1							5	
seam topstitch	O	111	1	1		1	1	1	111		13	
seam topstitch	I	1			11			11			5	
seam hemming	A	1	1	11	1	1	11	1			9	
bottom hemming	A	1		1	11						4	
neck topstitch	O	1		1							2	
side seam shoulder	A		111	1		1					8	
side seam waist	A		111	1	1	1					5	
front neck topstitch	I			1							1	
bottom hemming	I			1	1	1		1			4	
damage	V					1		111	1		5	
trimming	T					11			11		4	
neck binding	P					1					1	
side seam & label cuff	F					1	11				3	
shoulder topstitch	B					11	1	111	11		9	
Total p/100 checked		130	131	130	127	162	126	131	131		1068	
Total Defects		10	11	10	7	12	6	11	11		78	
Total Pass		120	120	120	120	150	120	120	120		990	
DH/100		7.6%	8.3%	7.6%	5.5%	7.4%	4.7%	8.3%	8.3%		7.3%	
Sign QA												
Sign Sup												
A-SKIP STITCH	F+RMS 067	F-PLEATS	F2.M6 A.GG	K-TICKETING STICKER	A-CHC	P-FUCKERING	F+RMS 068	U-UNEVEN STITCH/NO PAINT				
B-BROKEN STITCH	F+RMS 067	G-CATHERING	H-UP F+RMS 068	L-INSECURE/NO BARTACK	F+RMS 068	Q-WRONG LABEL	F+RMS 068	V-SPI INCORRECT AND PAINT				
C-LOOSE STITCH	067 CAS	H-STAINS	M-6.92/P.017	M-MEASUREMENT DEFECT	F+RMS 068	R-RAW EDGES	A-000.01	X-WRONG THREAD / AND 0.11, 11C				
D-DOWN STITCH	067 CAS	I-SHAPE OUT	P-0.7 F+RMS	N-NEEDLE HOLE	A-000.01 P.068	S-PLEATS	H-UP F+RMS 068	W-PARTS COLOR CHANGE AND 0.11, 11C				
E-UNBALANCED	067 CAS	J-JOINTS UNEVEN	067 CAS	O-OPEN SEAM	H-UP F+RMS	T-UNCUT THREADS	F+RMS 068	Y-FABRIC DEFECTS, F+RMS, F+RMS				
								Z-OTHER DEFECTS				
Sign QA Sup				Sign PM				Sign GM				

Appendix 9: Plant, Products and foreign buyers of the company



A

B

C

A) knitting machine at akaki plant B) Garment factory at Debrezeit plant C) Shop in Addis



Some products of the company



Some of International buying houses