Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical & Industrial Engineering

Reducing reject and reworks in garment industries by using an improved failure modes and effects analysis (FMEA): a case study in Lucy garment industry.

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: Alemayehu Tsegaye

Advisor: Ermias Tesfaye (PhD)

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By

Alemayehu Tsegaye

Approved by the Board of Examiners:

Dr. Ermias Tesfaye Advisor Name	For Signature	6, Dec, 2023 Date
Dr. Mengist Hailemariam Internal Examiner	Signature	6 Dec 2023 Date
Dr. Ing. Amare Matebu External Examiner	Signature	06, Dec, 2023 Date
Dr. Araya Abera School Dean	Signature	06/12/23 Date
Dr. Sosina Mengistu Associate Director for PG Program	Signature	06/12/23 Date

Declaration

I hereby declare that the work which is being presented in this thesis entitled Reducing reject and reworks in garment industries by using an improved failure modes and effects analysis (FMEA): a case study in Lucy garment industry 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.

Signature ______________ ______________________

Alemayehu Tsegaye Date

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

Advisor's signature_______________ ______________________

Advisor's name Dr. Ermias Tesfaye Date

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List of Abbreviations

ETB---Ethiopian Birr

FMEA--Failure Modes and Effects Analysis

DFMEA--- Design Failure Mode and Effect Analysis

PFMEA--- Process Failure Mode and Effect Analysis

RPN--Risk Priority Number

SFMEA--- Service Failure Modes and Effects Analysis

SIPOC---Suppliers, Inputs, Process, Outputs, and Customers

UCL-- Upper Control Limit

LCL--- Lower Control Limit

PDCA--Plan-Do-Check-Action cycle

Abstract

The garment industry faces significant challenges in reducing reject and rework rates, which adversely impact productivity, costs, and customer satisfaction. This thesis proposes an approach to improve the existing Failure Mode and Effect Analysis (FMEA) methodologies, aiming to address these critical issues more effectively.

The problem statement highlights the limitations of current FMEA practices in tackling reject and rework issues comprehensively. Traditional FMEA techniques often fail to account for the dynamic nature of garment production and the complex interplay of various factors contributing to failures. Consequently, conventional FMEA methodologies fall short in providing comprehensive and accurate risk assessments and mitigation strategies for reducing reject and rework rates.

This research aims to bridge these gaps by developing an improved FMEA framework specifically tailored for the garment industry. It has integrated identification of potential failure modes, assessed their impacts, and prioritized them based on criticality. Furthermore, the framework has incorporated real-time monitoring and feedback mechanisms to enable proactive identification of failure modes during the production process.

The proposed research employed a mixed-methods approach, combining quantitative data analysis and qualitative expert interviews to validate the effectiveness of the enhanced FMEA framework. Additionally, case studies will be conducted within garment manufacturing companies to evaluate the framework's practical implementation and assess its impact on reject and rework reduction.

The anticipated outcomes of this research include a refined FMEA methodology that addresses the limitations of existing approaches, leading to enhanced accuracy in identifying potential failure modes, evaluating their severities, and developing effective mitigation strategies. The proposed framework has the potential to significantly reduce reject and rework rates in the garment industry, thereby improving productivity, reducing costs, and enhancing customer satisfaction.

Overall, this thesis presents a new and inclusive approach for minimizing reject and rework rates in the garment industry through an improved FMEA methodology. It offers valuable insights and actionable recommendations for industry practitioners, researchers, and decision-makers to optimize production processes and achieve higher operational efficiency.

Keywords: FMEA, apparel industry, quality, reject and rework

Chapter One:

1. Background and Justification

1.1. Introduction

The global rule that makes a firm to be competitive and sustainable is the ever-changing customer expectations; the ability of an organization to adapt to the demands imposed by a changing environment. Exceeding customer expectations through better quality, cheap price, faster delivery time, and being more agile is the only guarantee to survive and sustain within the market (John M.Nicholas, 2005). Making the customers buy one's product the first time is easy. But making the customers come to themselves, again and again, is a difficult task. Therefore, the question of quality products comes here. The customer uses the product gives a grade and makes the decision to come again or not.

Incorporating the customer's voice as an ingredient for designing the product has become an important factor in attracting and retaining customers and an essential aspect in most business strategy models. It is one of the most significant factors in the success of companies and an important source of competitive advantage. It is a strategic weapon, a fundamental basis in competitive strategies, and a major focus of interest in marketing activities (KHALIFA, 2004). It has been recognized that value delivered to customers leads to customer loyalty and that loyalty and profits are strongly linked to value created for customers. Customers are loyal to a company if the company offers them superior value compared to its competitors.

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As the global economic condition changes fast, generally in an industry more focus is given to profit margin, customer demand for high-quality products, and improved productivity. A manufacturing company that possesses many complexities can be highly challenged when maintaining production goals and standards in conjunction with a major organizational change. Garment manufacturing is a complex industry for many reasons.

By reacting faster in minimization of reworks to make a product as consistent with patron call for predicted first-class, the business enterprise can make investments with much less cash and greater value savings. (Khan, 2013).

As (Meekhof & Bailey, 2017) Failure Modes and Effects Analysis (FMEA) is a proactive assessment tool created for quality assurance in manufacturing industries. The purpose of the Failure Modes and Effects analysis is to identify steps in the process that result in record errors and to prioritize the need to improve those steps. FMEA is a preventative risk management tool used to anticipate and detect process or design failures and their causes, and to identify ways to resolve issues related to those failures before they reach the customer. FMEA results can be used to prioritize efforts for process improvements and to reduce failures and associated risks. Through FMEA, users can anticipate and prevent problems, reduce costs, shorten product development or production times, and achieve safe and reliable products and processes. Simply put, FMEA answers questions such as: what can go wrong? How likely is an error to occur? and if an error does occur, what are the consequences of that error?

To be effective in defects and rejection reduction, it is essential to establish and maintain clear, complete, and current written records of inspection and test procedures for each operation. These records should identify the criteria for acceptance/rejection. In the Apparel Manufacturing Industry, the main raw material is fabric; others are different types of trimming and accessories. Operational wastages in the Apparel manufacturing process are top surface rework, printed label rework, sewing defects, pinhole rework, fabric defects, improper fly shape, and other reworks(M. M. Islam et al., 2013).

For any garment industry, production and quality management or waste reductions have a major impingement on the overall factory economy. In the garment industry, maximum quality constraints arise in the sewing department. The minimization of reworks in the sewing department of any apparel industry for quality improvement plays a significant role in the overall factory economy(Nitesh Kumar Sahoo, 2020a).

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In the garment industry, ensuring high product quality is of utmost importance to manufacturers. Reject and rework rates pose significant challenges, leading to decreased customer satisfaction, increased costs, and compromised operational efficiency. To address these issues, a key approach utilized in the industry is Failure Mode and Effect Analysis (FMEA). However, existing FMEA methodologies have limitations in effectively tackling the unique challenges faced in garment production. Therefore, the objective of this study was to develop an improved FMEA approach specifically tailored to the garment industry, to reduce rejection and rework rates, enhance product quality, and optimize manufacturing processes. By implementing this improved FMEA, manufacturers can strive to meet industry standards and customer expectations while maximizing profitability and competitiveness.

The main reason to choose FMEA rather than another tool is that its proactiveness. There are also proactive tools like six sigma. But it is vast and it does not fit specifically with the objective of this thesis. Six Sigma emphasizes the importance of addressing the root causes of defects and failure. FMEA enables six sigma project teams to take this philosophy one step further by assigning each potential cause a risk priority number so that the most likely causes of failure that have the greatest impact on the customer can be identified easily and addressed first.

1.2. Problem Statement

The demand for higher value at a lower price is increasing and to survive, apparel manufacturers need to improve their operations by producing the right-first-time quality and waste reduction. It is important to identify, quantify, and eliminate sources of variation in an operational process, optimize the operation variables, and improve and sustain process performance with well-executed control plans (Khan, 2013). It is important to focus on reducing scrap, rework, re-inspection, and rejections that lead to nonconforming products. Because they are the source of internal failure cost that covers 81% of the quality cost (Demissie et al., 2017).

In the garment industry, reject and rework rates pose significant challenges to manufacturers, resulting in decreased product quality and increased costs. Existing Failure Mode and Effect Analysis (FMEA) methodologies have limitations in effectively addressing these issues in the unique context of garment production. Therefore, the problem addressed in this study was the need to develop an improved FMEA approach specifically tailored to the garment industry, to reduce rejection and rework rates and improve overall product quality.

A shirt is the main product in the Lucy garment industry. The company spent a huge amount of money to buy the latest types of machinery and to train its employees to incur higher quality and customer satisfaction. Even though professional and experienced personnel train the workers, their efficiency is still only 58%. The quality assessment process is not clearly defined and besides the availability of inline quality checkers, defective items are frequently detected at the end of production by the end-line quality control team. The root causes of these defective final products are not known and they are not recorded for future information. These challenges make the company unable to establish permanent solutions and vibrant quality improvement.

The rework rate in 2022 G.C. is about 10%. This percentage as per the standard rework rate, of 2.5% is about four times big. On average daily out of the company is 1400pcs. Annually it is 1,092,000pcs. Out of this output, about 109200pcs are defective. Additionally, the annual rejection rate is about 4.5% and it counts about 49,140pcs. It takes 45 minutes to produce a single shirt and on average rework time is 1.2 minutes. Then, 1310400 minutes per year were lost due to rework. This indicates that they lose time to produce 29120pcs. The company gains 70-birr profit from a single shirt. Therefore, the company loses 2,038,400birr per annum due to rework. On the other hand, the rejection rate is 4.5%, which is about 49,140 PCs per annum. When it is converted into money, it is about 3,439,800birr per year if the rejection rate is reduced to zero percent. Therefore, the company loses a total of **5,478,200 birr** per year due to rejection and rework *(Tarekegn T. 2014 June 30, yearly quality audit)*. The higher rate of rework and rejection in the industry leads to bottleneck processes, reduces production efficiency, longer throughput time, higher waste, operator fatigue and dissatisfaction, longer delivery time, and totally, leads factories to be exposed to higher loss of quality, productivity, and profitability.

Therefore, by identifying the root causes of rework and rejection, and assigning possible remedies to those root causes before they occur, this research aims to minimize the rate of rework and rejections; thus, it will improve delivery time, production efficiency, productivity, and profitability, and minimize the cost of poor quality.

Research questions

This thesis shall answer the following questions:

- What are the major defects and causes of defects in the Apparel Industry?
- Does FMEA improve reworks and rejects in the company?
- What type of actions and strategies shall be adopted to improve rejection and rework in the company?

1.3. Objective

1.3.1. General Objective

The main objective of the research was to develop an improved Failure Mode and Effect Analysis (FMEA) approach that could be applied specifically in the garment industry to reduce reject and rework.

1.3.2. Specific Objective

- To identify the major defects and causes of defects in the Apparel Industry.
- To evaluate the performance of FMEA in reducing reworks and rejects in the company.
- To enumerate actions and strategies that shall be adopted to reduce rejection and rework in the company.

1.4. Scope of the research

The research entails Reducing rejections and reworks in garment industries by using the Failure Modes and Effects Analysis (FMEA) tool case study in the Lucy garment industry. The research mostly focuses on identifying the existing challenges of rework and rejections in the Lucy garment manufacturing industry sewing room, specifically on shirt products. This is because the most defective items are generated in the sewing room and the shirt is the main product, it does not include the problems of all product types and other departments.

1.5. Limitation

Secondary data like records are very important for this study. These data are not found easily and as much as the required quantity and quality. Interviews are necessary for the investigation. However, the willingness of the company's organization to give a response to the questions raised by the researcher is very limited.

1.6. Significance of the research

1.6.1. Benefits

By using the FMEA process which is a proactive method, the research identifies and contextualizes the failure, providing insight into the scope of its effects, providing information necessary for early identification of the future, and forming a method for evaluating changes and the urgency of action. It reduces problems caused by rework and rejection in garment industries including longer throughput time, higher wastages, operator fatigue and disappointment, longer delivery time, loss of productivity, and profitability. Thus, it maintains quality, improves efficiency, manufacturing performance, productivity, the profitability of the industries, and improves customer satisfaction.

1.6.2. Beneficiaries

The researcher itself gains knowledge and experience from the study, because of the above-listed benefits it saves companies from the cost of poor quality and improves productivity and profitability, for customers of the company; it will improve their satisfaction through quality improvements and short delivery time.

Chapter Two:

2. A Literature Review

2.1. Introduction

This part of the study analyzed different literature from different theoretical points of view. The study analyzed the literature from a quality, productivity as well and process enhancement ability point of view. The study defined key quality terms and critically analyzed shortcomings of the conventional FMEA from the apparel industry point of view.

For tackling the raised research question this part of the study tried to look at prior works in the area to answer the objective of the study. Accordingly, quality-related terminologies and concepts have been carefully collected to pinpoint the research to the rooted base. For doing so different databases, key terms, and search engines are utilized for the fate of getting peer-reviewed high-quality research outcomes. A systematic literature-type approach was chosen for conducting this part of the work. Scopus, science direct, Google Scholar, and many more database sources were addressed for the work.

Keywords like: - reject and rework, quality tools, FMEA framework, apparel industry, garment industry, and sewing defects have been used as key terms for database search.

Accordingly, a total of 1800 prior works were identified. Later additional records were added and it reached 1904 articles. After the first screen with the criteria of duplication and irrelevancy to the study objective, were reduced to 850 screened in prior studies. After the title and abstract review, almost half were deducted 630 were screened 247 went for a detailed full article review and 58 were included in the final analysis of the study.

A systemic approach of a literature review methodology is generally adopted with many iterative incidences. Different databases and search engines like Google scholar, Scopus, and AAU-subscribed free journals were critically analyzed as a source of articles. Peer-reviewed journal articles are given priority. The following graph shows the summary of the literature methodology.

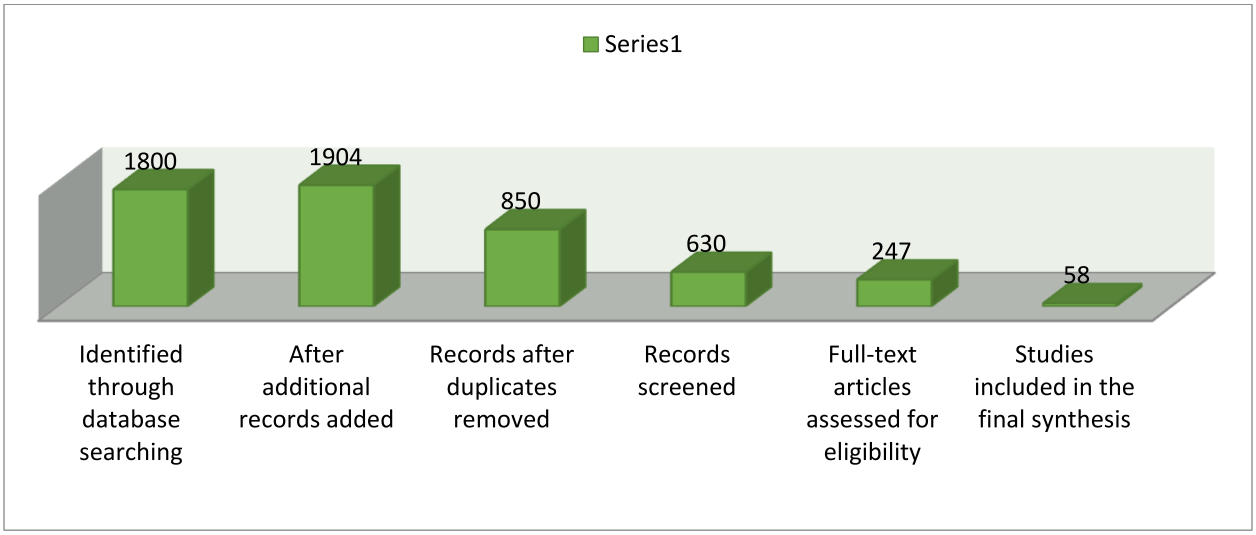


Figure 1 Literature Review Method

2.2. Quality definition

Product quality is an illustration of a customer's experience with a product evaluated against their expectations during the buying process life cycle (Mika Valtasaari, 2000). Quality products begin with product specifications based on what customers say they want and need. Capturing the essence of what customers want "the voice of customers "and translating it into a design faithful to those wants is the first step in producing a quality product. But the design must account for many things besides what the customer wants; it must consider the realities of the manufacturing process; the skills, equipment, technology, and resource capabilities of the manufacturer; the availability of purchased materials and parts; and the development and manufacturing costs of the product. All of this is the realm of quality of design. To develop a high-quality, low-cost product, and do it in less time than the competition requires early, simultaneous attention to a plethora of issues affecting people in engineering, marketing, sales, finance, manufacturing, customer service, and purchasing, as well as suppliers and the customers themselves. Early and continued involvement of all these parties is necessary for designing a product that meets both the requirements of the customer and the capabilities of the producer (John M.Nicholas, 2005).

Table 2-1 Quality Definitions

	Quality gurus	Definition
1.	FEIGENBAUM	• Quality is total composite product (goods and services) characteristics, through which the product in use will meet the needs and expectations of the customers. • The concept of quality must start with the identification of

		customer quality requirements and must end only when the finished product is placed into the hands of the customer who remains satisfied through various stages of the relationship with the seller
2.	American Society of Quality Control (ASQC)	• Quality is the totality of features and characteristics of a product (goods and services) that bears on its ability to satisfy given needs”
3.	ISO 9000:2000	• Quality is the degree to which a set of inherent characteristics fulfills requirements.
4.	Joseph M. Juran	• Quality is fitness for use or purpose
5.	Philips B Crosby	• Quality is Conformance to requirements
6.	W. Edwards Deming	• A predictable degree of uniformity and dependability at low cost and suited to the market
7.	Bill Conway	• Development, manufacture, administration, and distribution of consistently low-cost products and services that customers need and want.

Therefore, quality is defined as

Quality is defined by many authors or Guru but the basic definition that seems very compatible with today’s scenario is the definition by Joseph Juran. He articulates quality is just fitness for use. That means the customers must tell what they want. They are to pay to buy the product. Therefore, today many authors are accepting the meaning of quality from Joseph Juran’s definition.

Table 2-2 Quality Tools

	Quality tools	Description
1.	Inspection system Up to 1930	• The quantity of material to be inspected is quite small. • Either the producer did the inspection or the receiver • Inspection is fine if your production volume is quite small. • The problem is a matter of mass production. • 100% inspection methods are essential for controlling mistakes in medical equipment manufacturing and the like. • For other manufacturing processes if 100% inspection is made two things will happen: - the first one is the cost of manufacturing will be high and the second one is when an inspection is made on every product the quality of that will be degraded.
2.	SPC 1940	• If mass production is the issue, people realize that they must worry about the process too. • Process control by observing the output is stated by Walter Shewhart • If I observe the output, and I collect some data from there and depending on what I want to adjust, if I can utilize that data to come back and control these factors or we controlling the process and there, by I will be controlling the output.
3.	DOE 1975	• Not necessarily all the factors are to be controlled. • How to select the best factor that most affects the output.

4.	Taguchi 1980	• 2/3rd of the quality problem comes from design errors. • The design of the product and the design of the process are the main issues. • Which of the design factors both in process design and product design could affect the output? He utilized DOE in a very clever way to answer this question. • Robust design is a very special design that holds down to the performance even, if the environment becomes hostile. It was also first introduced by Taguchi.
5.	Quality management system 1980-1990	• Of course, you will have all these techniques, but we all know you can put things together; you can put people machines materials all those things together, but unless we have a proper management system think the study will port very well. • So, their people again, shifted their gears and they figured out appropriate quality management systems. • One of the quality management systems that are, pretty common most of you heard of is called TQM total quality management.
6.	Six sigma 1995	• Six Sigma is a business improvement approach • Seeks to find and eliminate causes of defects and errors in manufacturing and service processes. • Focuses on the outputs that are critical to the customers and a clearer financial return to the organization • Aims at producing no more than 3,4 ppm defects

		• Pioneered by Motorola in the mid-1980s • Popularized by the success of General Electric

2.3. Causes of Rejection and Rework in the apparel industry

The world's consumption of clothing is still rising, and many fashion labels are coming under fire for creating low-quality clothes with short lifespans that raise the already unmanageable amounts of post-consumer trash. Although acknowledged, garment failure due to poor technical durability has not received much attention from academic researchers. Cooper & Claxton (2022) found that color fading and pilling are the most frequent reasons for garment failure. Other factors included logo failure, discoloration, fabric collapse, inadvertent damage, loss of dimensional stability, and seam gaps. Increased garment durability can be attained by adhering to technical best practice recommendations, but it also demands efficient process management during the product development and manufacturing phases. Technical solutions must be implemented, which calls for adequate testing, enhanced technical expertise, and collaboration to advance better design principles, and new business models(Cooper & Claxton, 2022).

Furthermore, there can be many reasons behind the problems that cause rejection and rework in the apparel industry. Understanding the cause of these problems and a solution for each case would result in better performance. Most causes of rejection and rework in the apparel industry can be tackled by avoiding errors during the handling of materials/machines and by following the right working methods. The most common defects in the apparel industry can be stated as follows: - Skipped stitches, Seam pucker, and Brocken stitch, Fabric defects, unbalanced stitches, stains, and many more(ADhir Chandra Paul, Md. Atikul Islam, 2018; Bharath S, Arvind V, 2017; Khan, 2013; Nitesh Kumar Sahoo, 2020b; Shimelis Tamene Gobena, 2020).

Process flaws include those that result in process variance, faulty products, and gaps in meeting client requirements. It should be recognized that these issues before attempting to fix them. Man, Method, Material, and Machine are the areas where mostly classified categories can result in rejection and rework. The following list of causes of rejection and rework is adapted from literature(FIRAOL, 2021; Hanbay et al., 2016; Tekletsadik, 2023; Upasham, 2016).

Table 2-3 Causes of Rejection and Rework in the apparel industry

Causes of Rejection and Rework in the apparel industry	Man	Machine	Material	Process
1. Firm fabric holding	XX			
2. Low raw materials quality			XX	XX
3. Needle tension is too tight		XX		
4. The needle or bobbin is not threaded properly	XX			
5. The needle is too heavy for the thread				XX
6. The stitches are too coarse for the fabric being sewn				XX
7. Wrong fabric cut	XX			
8. Faulty feed dog	XX			
9. The fabric holding too tight	XX			
10. Incorrect needle eye position	XX			
11. Wrong needle size				XX
12. Increase in speed	XX			
13. Looper-to-needle timing			XX	
14. The thread is too fine or too heavy for the needle		XX		XX
15. Needle long-time usage				XX
16. Quality of the thread and type of the thread		XX		XX
17. Improper needle size and thread				XX
18. Both threads are pulled back under the	XX		XX	

presser foot				
19. Improper stitch	XX			
20. Inadequate thread strength for seam		XX		XX
21. Not following the machine guide	XX			XX
22. Bobbin doesn’t rotate properly			XX	
23. Lint has collected in the bobbin holder			XX	
24. The needle hook is slightly bends			XX	XX
25. Improper trimming	XX			
26. The carelessness of operators and quality inspectors	XX			XX
27. Worker engagement and attention	XX			
28. Wrong presser foot pressure		XX		XX
29. Incorrect clamping		XX		
30. Uncontrolled speed	XX	XX		
31. Wrong stitching techniques				XX
32. Big fabric thickness			XX	

Source: adapted from (FIRAOL, 2021)

2.4. Cost of rejection and rework in the apparel industry

In the current manufacturing phenomenon, the majority of businesses must compete against aggressive domestic and foreign rivals for customers' business in terms of quality, on-time delivery, and pricing(Chan et al., 2003). Customers often bargain for price reductions once a year and demand quality and full delivery on schedule. As a result, companies' top priority now is to save expenses while raising overall quality. In reality, the best strategy to manage product costs, quality, and delivery times is to decrease the inventory level(Chan et al., 2003).

2.5. Quality tools for reducing rejection and rework in the apparel industry

As per (Beyene, 2017) discussions different quality tools such as checklists, Pareto analyses, cause-effect diagrams, and control charts can be utilized for quality control purposes in the apparel industry. Checklists are used to estimate the frequency of sewing errors in the sewing department's activities. The Pareto analysis is used to look at the operations with the highest rates of sewing defects as well as how these procedures affect the defect rate. For the operation with the highest rate of stitching defects, the causes of the faults are examined using a cause-and-effect diagram. A p-control chart is used to statistically determine whether or not the sewing department's failure rate is under control(Beyene, 2017). Well defined statistical quality control system can help in eliminating hundred percent inspection by sampling-based inspection(Beyene, 2017; Khan, Mazedul, 2013; Tekletsadik, 2023).

Furthermore, in apparel industries and any other manufacturing industry, 7 QC (Quality Control) tools are very helpful in resolving quality-related issues. These are the tools for resolving quality problems that are based on numerical values. A group of data analysis tools known as 7 QC tools is used in the garment industry to help efforts to continuously improve quality. The following figure illustrates the 7QC tools: -

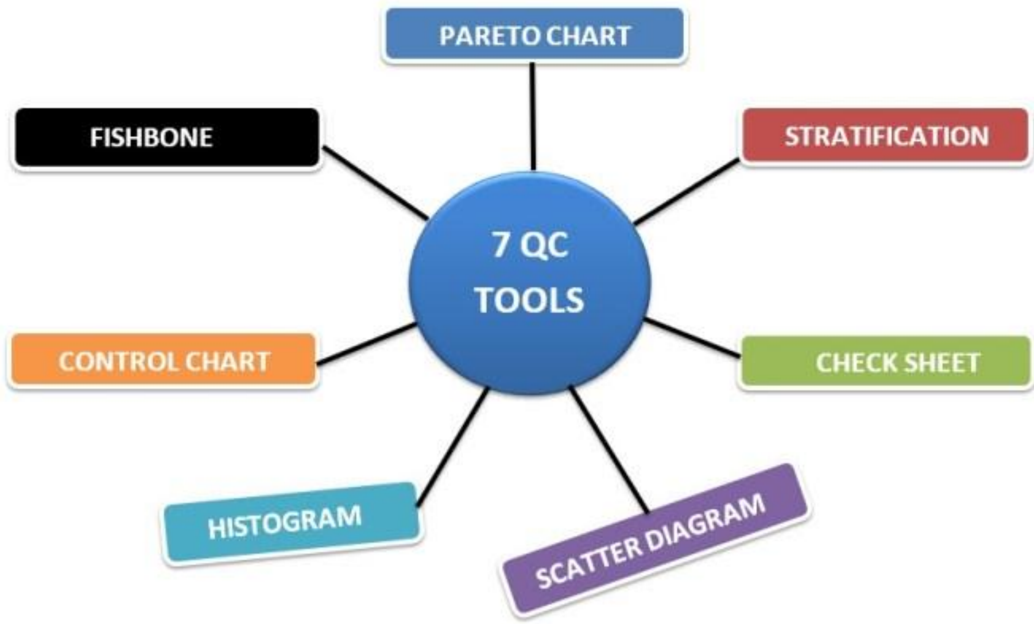


Figure 2 seven quality tools

Source: taken from https://i0.wp.com/ordnur.com/wp-content/uploads/2018/03/7-QC-Tools-in-Apparel-Industry.jpg.

2.6. The general methodology followed to minimize reworks and rework in the apparel industry

The work of Khan, and Mazedul, (2013) proposed a generalized methodology for minimizing rework in the apparel industry. As per their recommendation, their thirteen-step general methodology can lead the industry to gain higher productivity and profitability with improved quality products by minimizing rework activities. It also minimizes cost and improves internal throughput time(Khan, Mazedul, 2013).

1. *"Review of the existing quality system in the company*
2. *Identification of defects in the various departments by collecting data from old records*
3. *Analysis of data collected to identify majorly occurring defects*
4. *Categorization of defects*
5. *Development of a model Quality Inspection System*
6. *Implementation of check sheets to capture defects in different departments*
7. *Training on concepts of quality, the importance of maintaining correct data, and usage of the collected data to analyze and solve quality issues through the tools of quality*
8. *Introduction of Inline Inspection on Sewing floor through a pilot run in one line*
9. *Training on the Sewing floor to QC's, supervisors, and checkers on filling in the format and on making Cause & Effect Diagrams*
10. *Analysis of defects occurring in the check sheets implemented in various departments and devising suggestions to improve upon them*
11. *Spreading of Inline inspection to other lines*

12. *Tracking improvements and comparing them with previous situations in different departments*
13. *Visual communication of performance.”*

The source is taken from (Khan, Mazedul, 2013)

Finally, they come up with a five-step model that eliminates rejection and rework. The first is Inline Inspection through the Defect Frequency Rating System. The second is Defect capturing at the End Line through check sheets. Third is the Analysis of defects. Fourth is Cause and effect Analysis of the highest occurring Defects. The Fifth is Effective Solutions Provided(Khan, Mazedul, 2013).

For reducing rejection and rework in the apparel industry statistical quality control(SQC) tools such as Pareto analysis, root cause diagram, and Ishikawa diagram are suggested(Tekletsadik, 2023). Tekletsadik, (2023) applied Pareto Analysis and Cause-and-effect diagrams for a detailed examination of rejection and rework in the apparel industry. They revealed from their Pareto-analysis six top defect types; cuff assembly seam slip out, sleeve hemming, button slip out, side seam puckering, button missed, and placket seam out as a major cause and reject and rework in the apparel industry(Tekletsadik, 2023).

The study by Nitesh Kumar Sahoo, (2020) also applied Pareto Analysis and Cause-Effect diagram. Their approach suggested that the first step is to review the existing production and quality inspection process. Data from the previous six months that are available in the company are used to gather information about the different sorts of problems. By gathering information with the aid of end-line checking formats and implementing in-line audit formats, it is possible to learn about the various defects of ongoing styles. These defects are discovered by checking the pieces, which enables the checker to assess the defective rates and DHU percentage(Nitesh Kumar Sahoo, 2020).

2.7. Concept of Failure Modes and Effect Analysis

Failure Modes and Effects Analysis (FMEA) is a systematic, proactive method for evaluating a process to identify where and how it might fail to assess the relative impact of different failures and to identify the parts of the process that are most in need of change. FMEA is an engineering technique used to identify, prioritize, and alleviate potential problems from the system, design, or process before the problems are actualized.

FMEA includes a review of the following:

Failure modes (What could go wrong?), Failure causes (Why would the failure happen?) Failure effects (What would be the consequences of each failure?)

Teams use FMEA to evaluate processes for possible failures and to prevent them by correcting the processes proactively rather than reacting to adverse events after failures have occurred. FMEA is particularly useful in evaluating a new process before implementation and in assessing the impact of a proposed change on an existing process.

It was begun in the 1940s by the U.S. military, failure modes and effects analysis (FMEA) is a systematic approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service. It is a common process analysis tool.

"Failure modes" means the ways, or modes, in which something might fail. Failures are any errors or defects, especially ones that affect the customer and can be potential or actual. "Effects analysis" refers to studying the consequences of those failures.

Failures are prioritized according to how serious their consequences are, how frequently they occur, and how easily they can be detected. The purpose of the FMEA is to take actions to eliminate or reduce failures, starting with the highest-priority ones.

Failure modes and effects analysis also document current knowledge and actions about the risks of failures, for use in continuous improvement. FMEA is used during design to prevent failures. Later it’s used for control, before and during the ongoing operation of the process. Ideally, FMEA begins during the earliest conceptual stages of design and continues throughout the life of the product or service(ASQ, 2012).

Failure Mode and Effect Analysis (FMEA) was first developed as a formal design methodology in the 1960s by the aerospace industry with its obvious reliability and safety requirements. The FMEA is used to analyze concepts in the early stages before hardware is defined (most often at system and subsystem). It focuses on potential failure modes associated with the proposed functions of a concept proposal. The cause-and-effect diagram is used to explore all the potential or real causes (or inputs) that result in a single effect (or output). Causes are arranged according to their level of importance, resulting in a depiction of relationships and a hierarchy of events. This can help us to search for root causes, identify areas where there may be problems, and compare the relative importance of different causes(Prajapati, 2012).

2.8. Classification of Failure Mode and Effect Analysis (FMEA)

Failure Mode and Effect Analysis (FMEA) according to (Theodoros & Ioannis, 2007)and (Ünal & Acar, 2016). can be broadly classified as system, design, process, and services. The system is composed of subsystems and subsystems in turn composed of elements.

1. System failure mode and effect analysis are all about finding potential defect types among the elements that build the system.
2. Design Failure Mode and Effect Analysis (DFMEA) deals with the possibility of failures of products with a consequent impact on safety and the environment. DFMEA entails building failure resistance into the system at the design stage. This involves considering

factors such as material properties, noise level, components and subcomponents interaction, geometry, etc.

3. Process Failure Mode and Effect Analysis (PFMEA) explores possible failure in processes with consequent effects on the reliability of the process, customer satisfaction level, and safety hazards. This requires considering factors such as manufacturing procedures, methods of process operation, human and environmental factors, the accuracy of measurements, conditions of equipment
4. Service FMEA: It is a method to analyze the service before it reaches the customer.

2.9. When to Perform Failure Mode and Effect Analysis (FMEA)

The FMEA document is an essential document throughout the design stage of a product and the operation of processes. It is very important to ensure that reliability is consistently evaluated and improved when performing FMEA. The following timings are especially important when performing FMEA.

- When a process, product, or service is being designed or redesigned, after quality function deployment.
- When an existing process, product, or service is being applied in a new way
- Before developing control plans for a new or modified process
- When improvement goals are planned for an existing process, product, or service
- When analyzing failures of an existing process, product, or service
- Periodically throughout the life of the process, product, or service
- When customer satisfaction is not fully met as indicated by their feedback.
- When new policies and regulations are instituted or existing regulations are modified by regulatory bodies.

A failure modes and effects analysis (FMEA) is "A systematic process for identifying potential design and process failures before they occur, with the intent to eliminate them or minimize the risk associated with them" FMEA procedures are based on standards in the reliability engineering industry, both military and commercial. It is a methodology in product development and operations management for analysis of potential failure modes within a system for classification by the severity and likelihood of the failures. A successful FMEA activity helps a team to identify potential failure modes, based on experience with similar products or processes. Failure modes are any errors or defects in a process, design, or item, especially those that affect the customer and can be potential or actual. Effects analysis refers to studying the consequences of those failures(Ambekar et al., 2013)

According to (Sharma & Srivastava, 2018) FMEA determines the risk priorities of failure modes through the risk priority number (RPN), which is the product of the occurrence (O), severity (S), and detection (D) of a failure.

(RPN = O * S * D)

2.10. Methods for studying the failure modes of the main theoretical models

The brain-storming method is frequently used to find the various failure modes of the system based on features when determining potential failure modes. Function-based failure modes include the following: (1) no action, early action, too large a value, unable to reach the desired value and stop; (2) failure modes based on machinery, such as wear, deformation, bending, overheating, loosening, bite, abnormal noise, and vibration; and (3) failure modes based on electrical (e.g., open circuit, short circuit, poor contact, dirt, broken line). Although brainstorming is the method used most frequently to discover failure modes, Bluvband et al. concluded that the expert group's brainstorming session was lacking and frequently resulted in the failure modes being missed.

Table 2-4 FMEA application areas so far

NO.	Modeling method	Application domain	The problem solved	References
1.	The function fault design Method (FFDM) is driven by the knowledge base	Bell 206 helicopter	Failure mode identification	(Stone et al., 2005)
2.	Fault tree analysis (FTA)	CNC machine tool	Key component failure mode Identification	(Zhang, Li, et al., 2019)
3.	FTA + evidence network	CNC machine tool	System failure	(Zhang, Zhang, et al., 2019)
4.	FTA + logical structure	Water tank water level control system	System failure and cause analysis	(Hurdle et al., 2007)
5.	Network model	Subway system	Component failure mode	(Deng et al., 2015)
6.	Directed graph + matrix method	Machine tool	Critical function module failure	(Venkata Rao & Gandhi, 2002)
7.	Directed graph + FTA	Aircraft fuel testing system	Failure mode and cause	(L.M. Bartlett, 2009)
8.	Fishbone diagrams + laws of	Mouse	Failure mode identification	(Hata, T., Kobayashi,

	evolution			N., Kimura, F., & Suzuki, 2000)
9.	Extending the Go model + Fault propagation algorithm	Robot mobile platform	Failure propagation	(Liu et al., 2019)
10.	cause-effect graphing + Initial hazard matrix	Salmon industrial processing	Critical failure control point	(Arvanitoyannis & Varzakas, 2008)
11.	Hazard and operability analysis	Product	Failure mode identification	(Eubanks, 2012)
12.	graph theory + FTA	Hydraulic power steering	Fault cause and mode	(James et al., 2018)
13.	Directed graph + information flow	Aircraft fuel rig system	Fault diagnosis and monitoring	(Kelly & Bartlett, 2007)
14.	Module-based fault propagation model	Air purifier	Failure propagation	(Noh et al., 2011)
15.	Functional fault identification and propagation (FFIP) analysis framework	Boiling water nuclear reactor	Failure propagation	(Sierla et al., 2012)
16.	Cause and effect propagation	Software verification	Failure modes and causes	(Tumer et al., 2003)

17.	Statistics + data mining		Fault identification	(Arunajadai SG, Uder SJ, 2004)
18.	Process constitutes elements	manufacturing process	Failure mode identification	(Zheng et al., 2018a)(Zheng et al., 2018b)

2.11. Conventional FMEA framework

In the conventional FMEA framework, there were limitations in the use of RPN to prioritize the risk of product failure(Fazli & Kazerooni, 2022). So far plenty of studies have been conducted to improve the performance of FMEA by modifying the RPN calculation to prioritize the risk of failure (Estorilio & Posso, 2010; Fazli & Kazerooni, 2021, 2022; Oldenhof et al., 2011; Subriadi & Najwa, 2020). The following figure (Subriadi & Najwa, 2020) illustrates the most commonly used traditional FMEA framework. This conventional FMEA framework is generic and needs to be improved for the intended objective(Subriadi & Najwa, 2020).

Table 2-5 Traditional FMEA framework

Sequence of actions	Steps of conventional FMEA framework
1.	Review in the process or the product
2.	Brainstorm potential failure modes
3.	List the potential effects of each failure mode
4.	Assign a severity ranking for each effect
5.	Assign an occurrence ranking for each failure model
6.	Assign a detection ranking for each failure mode
7.	Calculate for RPN
8.	Prioritize the failure modes for action
9.	Take action to eliminate or reduce the high-risk factors
10.	Calculate the resulting RPN as the failure modes are reduced

Subriadi & Najwa (2020) unearthed the performance of FMEA from their experiment as traditional FMEA produced inconsistent RPN values. Whereas,(Fazli & Kazerooni, 2021) proved that conventional FMEA frameworks were costly and needs to be adapted to the specific objective that were intended to do. Likewise, Fazli & Kazerooni (2022) also asserted that improving the generic FMEA framework would both reduce time and cost of operation. Therefore, there needs to be an improved FMEA framework to address this study's objective.

2.12. Literature Summary

Table 2-6 Literature Review Summary

Title	Author and Year	Contribution	Limitation
Efficiency Improvement by Reducing Rework	(Nitesh Kumar Sahoo, 2020b)	By using a Checklist, cause, and effect diagram, Pareto analysis, and traffic light systems: they reduced DHU from 7.28% to 3.83% and A total of 11.72% production efficiency yield and helped to produce 92 pieces of extra units	The tools and analysis method are conventional.
and Rejection on the Shop Floor	(Rahman et al., 2018)	They Implemented 5s and Plan Do Check and Act (PDCA) system and Plan- Do-Check and Action program was developed for the potential causes of the problems.	The change that the research brought was not indicated.
Minimization of Sewing Defects of an Apparel		Followed Inline inspection through defect frequency rating, end-line defect check sheet, cause, and effect analysis, and corrective actions and got DHU reduced from 16% to 8% and rework reduced	It is not a proactive technique

Industry in Bangladesh with 5S & PDCA	(Khan, 2013)	by 5%	
Minimization of Reworks in Quality and Productivity Improvement in The Apparel Industry	(Lemma, 2019)	A statistical control chart was mainly used as a tool to detect the problems and solutions were recommended.	It does not demonstrate the result that the research brought and quantify the outcomes
Minimize defects of products to improve quality by statistical quality control tools in garment	(Alam & Huda, 2018)	Using direct observation, defects were recorded, by cause-and-effect diagram root causes were identified, and the optimal solution was set. Accordingly, after finding different cases of the problems, a single potential cause was tested under variable conditions and the optimal solution was found.	There were many root causes found. Only one problem has been solved. So, it does not represent the whole.

Critical Analyses of Sewing Defects and Minimization of them	(Patil et al., 2017)	The causes of problems were identified, and through experimentation and testing problems were solved. Solutions include: machine-setting change and operator awareness about the properties of fabric. Due to this The rate of defective output was reduced from 8% to 4%	The actions taken to overcome the problems were just for the time being and are not continuous solutions.
Sewing Reworks in the Apparel Industries	(Bharath S, 2017)	Six sigma is used as a method to solve the problem. In doing so, SMV reduced from 7.312 to 6.571 minutes, and labor productivity increased from 29.56 to 35.55 and efficiency increased from 45.03 % to 48.66 % which increased the productivity of 31 pieces per day	The way the result is achieved was not clearly shown and discussed.
Minimization of		Implementation of six sigma. Therefore, a reduction in the overall	The root causes are not

Defects in Garment during Stitching	(Hayajneh & Bataineh, 2010)	quality level from 7.7 % to 2% has been achieved	survived in detail, the way the result is obtained was not clearly defined, and even it is corrective action.
Minimizing Reworks, Rejection Rate, and Time Waste in a Textile Industry Using Six sigma Tools	(Amrina & Lubis, 2017)	The lean manufacturing approach was applied as a method. Due to this, Suggestions are developed by identifying the root cause of defects, over production, and inventory using Cause and Effect Diagram. Failure Modes and Effect Analysis (FMEA) recognized the highest potential risk is the low quality of the material.	It has not been included how much the recommended solution is effective and the change that they brought.
Applying Six Sigma Methodology Based On	(Jaware et al., 2018)	The seven quality control tools have been applied. Therefore, Remedies for the root causes have been identified and action plans	DMAIC can be used in our day to day activities and it is oldest mechanism of analysis

"DMAIC" Tools to Reduce		were set. Then until the optimal thickness is obtained, modification was done. Finally, it was optimized. After action taken % rejection reduced to 0.65 % from an average of 16.66% before the project.	method
Production Defects in Textile Manufacturing	(Demissie et al., 2017)	An applicable quality improvement model to improve the overall performance of the Apparel sector. The quality improvement model for Ethiopian garment enterprises and the Quality improvement implementation model as a whole have been developed	The effectiveness of the model has not been indicated yet
Minimizing Waste Using Lean Manufacturing: A Case in Cement Production	(Pazireh et al., 2017)	. Failure mode and effect analysis through optimization technique was used to minimize the amount of flaw products and improve efficiency and productivity. In an attempt to optimize the inspection activities of the operator, to enhance the chance of finding the flawed product in each station, and eventually, to decrease the frequency of flaws in products, several inspectors are assigned to each workstation. Then the optimum total rejected	increasing the number of inline and end-line quality checkers may reduce the chance of flaw output products, but there may be many other solutions for this problem. So this paper does not consider

		products percentage is obtained.	other perspectives and shows the best solution through comparison.
	(M. M. Islam et al., 2013)	Flow charts have been used to describe every activity and workstation needed and to identify where the most challenges occur. A histogram was used to detect DHU in the sewing department concerning their percentage. A fishbone diagram was used to identify the root causes and the effects of the defects. Different solutions have been suggested for the most occurring causes and the best solutions have been selected implementation of the solution through experimentation. stitching D.H.U. reduced to 8% from 16% as earlier, uncut thread D.H.U. came down to approximately 10% from 22% earlier.	It was a reactive action which means the solutions were found after problems emerged
Reduction of machining	(Kolte & Chandurkar,	A check sheet was used to inspect defects. Root causes have been identified by a cause-and-effect diagram, line chart is used to	Evaluating Solutions for Effectiveness and Ease of

rejection of shift fork by using seven quality tools	2018)	Analyze DHU% before and after the trial. All the root causes have been categorized under machine, material, man, and method. Then the most common root causes are identified using Pareto analysis indicating that the most frequent causes of the defects are related to machine problems. Corrective actions are suggested and implemented through experimentation. After corrective experimental action has been taken, overall DHU is reduced to 15.33% from 16.66%. The performance of the stitching line of the apparel industry was improved by reducing 1.33% DHU.	Implementation was recommended for further study as uncovered portions in this paper. So it should be studied by other researchers.
Quality assessment and improvement for	(Silva de Santis & Pereira Marcicano, 2016)	FMEA tool supports the implementation of improvements and process monitoring, enabling corrective and preventive actions. A cause and effect diagram was applied to identify root causes and their effects. Meetings were conducted to check the progress and to enhance the improvement. 5 WIHs have been analyzed to assign proper personals, time, place, methods, and machines.	Since corrective actions have been taken after the problems already happened, it was reactive and it will be a solution after some costs have

		Finally, problem-controlling models have been developed. A checklist was developed to control the occurrence of the defects and a process flow chart was created to enhance the consistency of the uniform procedure. a possible effective and one action for control was prepared, corrective measures and improvements were attributed for each risk presented.	been encored. So, it is better to have a proactive way of problem-solving mechanism.
Ethiopian garment enterprises	(T. Islam et al., 2017)	Identifying and analyzing defects in sewing lines and implementing corrective actions. Data have been collected from QC personal and by direct observation and recording. Collected data were analyzed using Pareto to identify the major occurring defects and cause and effect diagram to identify the causes, and sub-causes and to identify that man, machine, material, or method is mostly causing the defects. Then corrective actions are suggested and implemented. Six sigma level was checked to fit the standard and the occurrence of defects per million opportunity using six sigma software.	Still, the limitation is being a reactive solution

		After the implementation of corrective actions, overall defective output was reduced to 4% from 11.29% and the sigma level lies at 2.88 which is acceptable	
Analyzing the enhancement of production efficiency	(Kapuria et al., 2017)	Continuous improvement in reducing the defects through the Kaizen (Continuous Improvement) system. After collecting data through direct observation and recorded documents, Pareto analysis was performed on the highest occurring defects, which are vital few where 80% of total defects occur. Root causes for the main defects were identified using a cause-effect diagram. To reduce the sewing defects the following kaizen steps were followed. **Brainstorming**, a Goal Set Up to reduce the percentage of sewing defects from the production line to improve productivity, defect, and output data were collected, plans for the corrective actions were set, things that should be done concerning implementation were set, *checking* through inspection,	It was reactive to the problems

		monitoring and measuring periodically. **Action**: if there is no change plans with more new ideas are set and the process is repeated. By implementing the Kaizen process, the factory increased the efficiency of the production line from 45% to 60%. It is economical for a factory. Sewing defects are minimized significantly.	
using FMEA through simulation-based optimization	(Dambhare et al., 2013)	DMAIC methodology of Six Sigma was undertaken to resolve the problem. **Define phase**; the machine was producing defective bore that was not within the designated tolerance limits and varied non-uniformly leading to rework which cost 49kW on the energy meter, USD 20000 per year in reworking the bores affected, 400 hours per month time for rework. **Measure Phase:** statistical software Minitab was used to analyze the Gage R&R ratio.	The process to solve the problem was good and curing. But it was reactive.

		Analyze Phase: fault tree analysis was used to analyze root causes. **Improvement Phase:** Actions to be taken were planned**.** **Control Phase:** the parameters that affected the output were proposed and actions that were proposed were implemented The rework decreased to 2.2%. Monthly man-hours for rework were reduced to 43 hours from 400 hours. Energy wasted in rework was saved. The most important factor was cost saving. The cost was reduced to USD 2000 annually saving USD 18000.	
technique: A case study in apparel manufacturing	(Senaviratna, 2013)	An experimental way of problem-solving mechanism was used. The process flow chart was to show the manufacturing procedure, Major types of defects were identified through the Pareto Chart, and Generalized Linear Modelling (GLIM 3.76’) was used to identify the most affecting causes that are leading the defects to occur. Then discussing with managers concerning personal remedial actions were proposed and implemented	It was a remedial action rather than a preventive.

		The percentage occurrence of the three defects was reduced to 5% from 25%	
Minimization of Defects in the Sewing Section of the Apparel Industry	(Dhanyashree & Nagesha, 2017)	The production and rejection data of the foundry and machine shop sections in the foundry unit is collected for six months. Prioritization, identifying root causes, and finding solutions for the prioritized problems. The implementation was done. The process flow chart is studied to understand the production process and to understand the prevailing production process. Pareto analysis is carried out to prioritize the various defects in the product. At the CNC finishing stage, there were many defect types, and corresponding to 50 rejected components were collected the occurrence, percentage, and cumulative have been investigated, and found that rejections are mainly due to the deviation in the critical dimensions. by using a Cause-and-Effect diagram causes	Since corrective actions have been taken to solve the problems, it is late, and after so much loss has been gained. So if it is preventive and proactive it will save the cost and customer.

		under the category of man, machine, method, and measurement were analyzed and Improvement actions were suggested and implemented to resolve the root causes identified. Through proper data collection systematic analysis and implementation of corrective actions, the following results have been achieved. Reduced rejection rate from 23.02% to 8.05% Reduced costs of poor quality from Rs. 6982 to Rs.1686 Reduced scrap and rework from 4.5% to 2.15% Reduced operator fatigue significantly.	
Performance Improvement in the Apparel Industry by reducing DHU%	(Dhileephen & Aravindan, 2020)	Various machining processes in the advance housing were identified, the defects and their reasons were noted, and the rejection rates due to each defect were studied. The highest percentage of rejections was detected. Component dimensions were checked that they were under intended limits. Solutions were	The result was not proofed or any kind of verification was not shown or quantified.

		suggested. A process flow chart was used to understand the sequential processes and the focusing area. The Pareto diagram was used to understand the percentage and the number of rejections of any defect and prioritization. Root causes of the defects were investigated using a fishbone diagram and the correlation of the root causes was survived by a scattered diagram and showed no relationship. Then why-why analysis was carried out to investigate further causes. Finally, solutions have been suggested for the main causes. As per the paper, the implementation of the given suggestions will reduce rejections of advanced housing, by controlling the occurrence of blow holes and rusting.	
Use of Quality Tools for	(Bharathi et al.,	The lean approach is employed to reduce variations and to reduce waste by annihilating the root causes for failures that occur during	The framework has been test implemented for

Problem Analysis (FMEA and Ishikawa Diagram) in a	2017)	the Submerged Arc Welding (SAW) process. The DMAIC approach is employed to reduce variations and minimize waste ***Project charter and flow*** chart have been used to create a clear understanding among the organization about the purpose, cost, risks, and total required process, The ***SIPOC diagram*** was used to have a clear idea of the processes involved, materials used, and agencies responsible and suppliers for each process in the **define phase**, critical defect is found using ***Pareto chart*** and ***Value***	analyzing variations and wastes generated in the SAW process. In the future, studies could be conducted on different welding processes.

2.13. Literature Gap

The literature gaps this study has unearthed is that there is no clear and universal approach to alleviate reject and rework in apparel industry. The conventional FMEA framework has irregularities in the development of process FMEAs that contributes to inconsistencies. Therefore, there is clear literature gap that there is no well-defined FMEA framework that can reduce reject and rework in apparel industry.

Chapter Three:

3. Methodology

The difficulty of accurately evaluating the risk factors O, S, and D has been widely debated, and the standard FMEA does not take into consideration the relative relevance of risk variables(Liu et al., 2012, 2013). Liu (2016) improved the FMEA framework for healthcare by introducing novel FMEA models based on uncertainty theories and multi-criteria decision-making (MCDM) methods.

3.1 Research design

The proposed research employed a mixed-methods approach, combining quantitative data analysis and qualitative expert interviews to validate the effectiveness of the enhanced FMEA framework.

The development of an improved FMEA framework for reducing reject and rework in the apparel industry has never been tried before. The ordinary traditional FMEA framework needs to be adapted to the nature of the apparel industry. This study adapted six phases of work for developing the improved FMEA framework.

3.2 Sampling system

Purposive sampling technique have been implemented to select the samples. The research aimed to choose selective operators based on skills, education level and working department. Only operators who can understand the questions raised from the researcher have been selected. Additionally, maintenance operator, line supervisors, production and quality managers, and few academicians whose research areas related to apparel quality have been selected purposefully.

3.3 Data collection

Primary data was collected by direct observation and interview. Secondary data was collected from different article and companies previously recorded data.

3.4 Data analysis

Data have been analyzed using pareto analysis, u chart analysis and failure made and effect analysis tools, and it was presented by tabulation and graphs.

3.5 Research frame work

The development of an improved FMEA framework for reducing reject and rework in the apparel industry has never been tried before. The ordinary traditional FMEA framework needs to be adapted to the nature of the apparel industry. This study adapted six phases of work for developing the improved FMEA framework

3.5.1 Phase one: - Problem identification Literature review, Define the research objective:

Conduct a comprehensive review of existing literature on FMEA and its application in the garment industry. Identify any previous studies or best practices related to reducing rejects and reworks.

The objective of the research, which is to reduce rejects and reworks in garment production have been Clearly stated.

This phase was carried out through workshops with subject experts from the Academy and industry, where the definition of the domain was the result of an agreement of these experts in terms of acceptance of the validity of the problem definition and the fact that the creation of the improved FMEA framework would be a promising means to solve this problem. The domain of the framework was established during this step.

3.6 Phase two: - Planning, data collection and analysis

The purpose of the FMEA framework, the construction techniques, and the project management structure were all defined during this phase. During this stage, the framework's potential connections to other FMEA frameworks, current standards and norms, the methods used and how they would affect the timing and logical order of the framework construction activities, the organization and coordination of construction activities, and an analysis of technologies to aid in the construction process were all examined. A basic planning of the framework was produced after this phase.

3.7 Phase three: - Construction

During this phase, a synthesis of the body of knowledge in the theoretical field was developed, a conceptual framework base was built, a detailed plan for the construction, including all its components and levels of granularity, was defined, and finally, the first iteration of the framework was built.

3.8 Phase four: - Validation

The goal of this phase was to make sure that the framework adhered to and was used appropriately for the domain to which it is oriented. This was done by adjusting and revisions based on interactions with the experts in the field. Fundamentally, the purpose of the validation was to make sure that developers and specialists agreed. Cycles of iterations were used for this, during which new structures, entities, and components were presented, discussed, and verified (or rejected). This reasoning suggested that the validation took place concurrently with and in addition to the construction.

3.9 Phase five: - Evaluation

This phase involved pilot testing and evaluation of the developed FMEA framework quality. The practical tests aimed to evaluate the degree of adherence to the problem, as well as its applicability by the users to which it is oriented. Lucy garment Plc. was selected for practical testing of the developed FMEA framework for reducing reject and rework in the apparel industry. The comparison of the traditional FMEA framework and the newly developed FMEA framework and the performance of the improved FMEA framework for reducing reject and rework in the apparel industry was evaluated.

3.10 Phase six: - Documentation

This phase covered the final recording of the framework for its practical use.

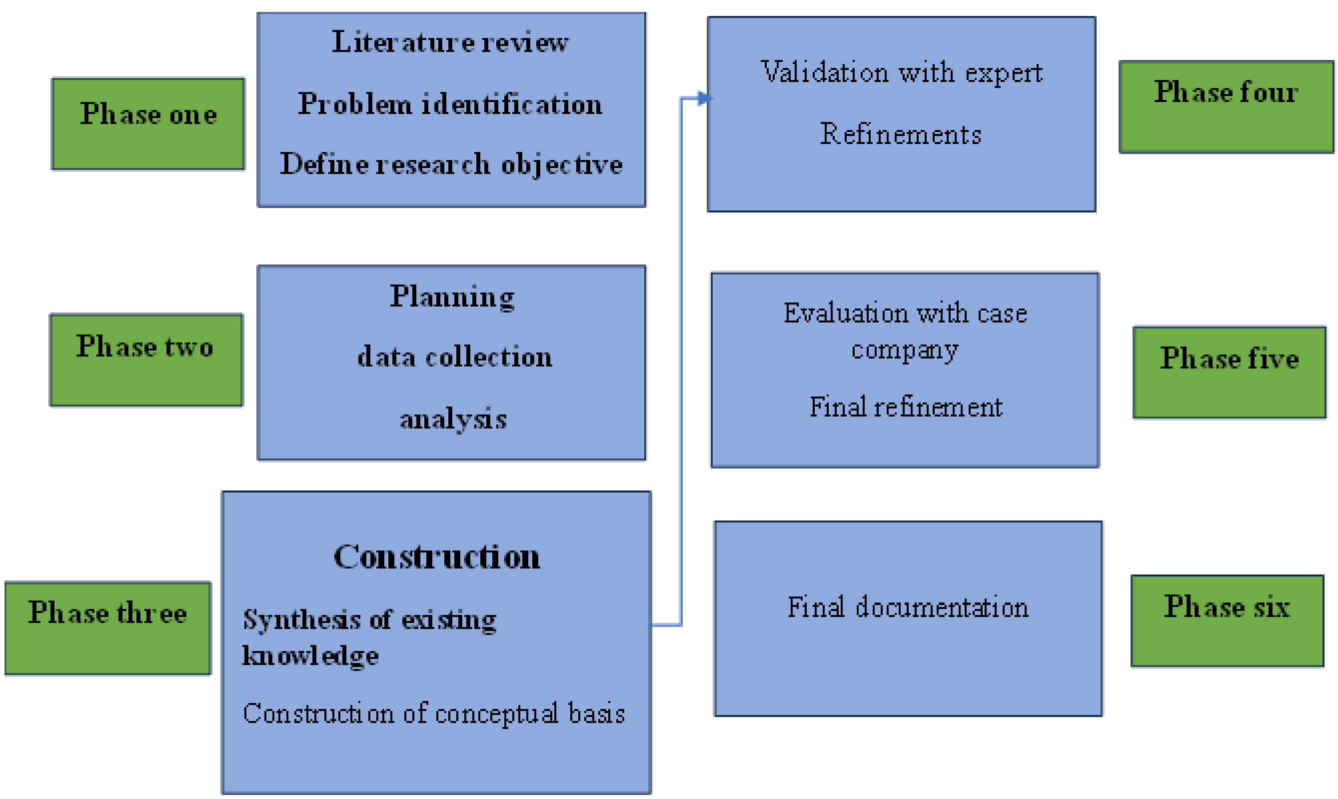


Figure 3Research framework

Chapter four

4 Reducing rejects and rework in the apparel industry through a customized FMEA

The Failure Mode and Effects Analysis (FMEA) is a valuable tool used in various industries for identifying potential failure modes and improving product quality. However, the unique characteristics of the apparel industry necessitate customization of the traditional FMEA framework. In this essay, here the reasons why customization is essential for the apparel industry and how it can enhance risk management and product quality has been explored. Customizing the FMEA framework for the apparel industry is essential to effectively address the unique challenges and requirements of this dynamic sector. By tailoring the methodology to accommodate the fast-paced nature, specific failure modes, regulatory compliance, design considerations, and customer feedback, organizations can enhance their risk management processes and improve product quality. The customization of FMEA ensures that the analysis is aligned with the industry's demands, ultimately leading to improved product performance, customer satisfaction, and brand reputation in the competitive apparel market. Embracing customization in FMEA allows apparel manufacturers to stay ahead of the curve, mitigate risks effectively, and deliver high-quality products that meet the ever-changing demands of consumers.

4.1 Expert interview response and analysis

This part of the study illustrates the analysis of interviews with experts in improving the FMEA framework for the apparel industry.

1. Use of FMEA in the Apparel Industry:
    - Most experts acknowledged that FMEA is not widely utilized in the apparel industry for reducing rejects and rework.
    - Some experts mentioned that FMEA is more commonly associated with other industries, such as automotive or manufacturing.

- A few experts highlighted the potential benefits of implementing FMEA in the apparel industry, such as improved process control and enhanced product quality.

2. Shortcomings of the FMEA Framework in the Apparel Industry:
    - The experts generally agreed that the traditional FMEA framework may not directly address the unique challenges and characteristics of the apparel industry.
    - Several experts mentioned that the calculation of Risk Priority Number (RPN) in FMEA may not accurately reflect the specific risks and impact in the apparel manufacturing process.
    - Assumptions made during the analysis were identified as potential sources of bias and flaws in the FMEA framework when applied to the apparel industry.
3. Benefits and Challenges of Implementing FMEA in the Apparel Industry:
    - Experts acknowledged that implementing FMEA in the apparel industry can bring potential benefits, including reduced rejects and rework, improved process efficiency, and enhanced customer satisfaction.
    - However, they also highlighted challenges such as resistance to change, lack of awareness and knowledge about FMEA, and the need for strong leadership support and organizational commitment.
4. Improvements Needed for FMEA in the Apparel Industry:
    - Experts emphasized the need for a detailed qualitative study to understand the specific needs and challenges of the apparel industry and to tailor the FMEA framework accordingly.
    - Suggestions were made to refine the RPN calculation method to better reflect the risks and impact in the apparel manufacturing process.
    - Experts also recommended incorporating industry-specific factors and variables into the FMEA analysis to improve its effectiveness.
5. These findings from the expert interviews provide valuable insights into the current state of FMEA implementation in the apparel industry, its shortcomings, and the potential benefits and challenges of using FMEA to reduce rejects and rework. These findings can guide further research and the development of an enhanced FMEA framework tailored specifically to the apparel industry.

Table 0-1 Summary of the interview with experts

Expert A	➢ Recognizes the importance of FMEA in industries like automotive and manufacturing but acknowledges its limited use in the apparel industry. ➢ Suggests that the dynamic nature of the industry, such as changing fashion trends and short product life cycles, makes it challenging to implement FMEA effectively. ➢ Recommends adapting FMEA to accommodate the unique characteristics of the apparel industry, such as incorporating design changes and material variability into the analysis.
Expert B	➢ Shares a similar view, stating that FMEA is not commonly practiced in the apparel industry. ➢ Highlights the need for a comprehensive understanding of failure modes and their impacts on product quality and customer satisfaction. ➢ Suggests that FMEA can be beneficial in identifying potential risks and implementing preventive measures, leading to improved product quality and reduced rejects.
Expert C	➢ Expresses skepticism about the applicability of FMEA in the apparel industry due to its fast-paced and fashion-driven nature. ➢ Recommends exploring other quality improvement tools and techniques that are better suited to the industry's specific challenges. ➢ Emphasizes the importance of a holistic approach to quality management, considering factors such as design, production processes, and supply chain management.
Expert D	➢ Acknowledges the limited use of FMEA in the apparel industry but believes it has untapped potential. ➢ Proposes adapting FMEA to focus on critical failure modes and high-impact areas, considering the industry's unique challenges. ➢ Suggests that FMEA can help in identifying process bottlenecks, improving material selection, and optimizing production methods to reduce rejects and rework.
Expert E	➢ Shares positive experiences of implementing FMEA in certain apparel manufacturing companies. ➢ Highlights the benefits of FMEA, such as improved process control, higher product quality, and reduced costs associated with defects. ➢ Recommends educating industry professionals about the value and application of FMEA to encourage its wider adoption in the apparel industry.
Expert F	➢ Expresses concerns about the practicality of FMEA in the apparel industry due to its subjective nature and the difficulty of quantifying risks. ➢ Suggests that a more qualitative approach, such as conducting a root cause analysis, may be more suitable for identifying and addressing failure modes in the industry. ➢ Recommends exploring other quality improvement frameworks that align better with the apparel industry's needs.

Expert G	➢ Advocates for the adoption of FMEA in the apparel industry, highlighting its potential to improve process efficiency and reduce defects. ➢ Emphasizes the importance of involving cross-functional teams, including designers, production managers, and quality control personnel, in the FMEA process. ➢ Recommends integrating FMEA with other quality improvement methodologies to create a comprehensive approach to reducing rejects and improving product quality.
Expert H	➢ Acknowledges the limited use of FMEA in the apparel industry but believes it can be a valuable tool for improving product quality and reducing rejects. ➢ Suggests that FMEA should be modified to include specific failure modes related to fabric quality, sewing techniques, and design changes in the apparel industry. ➢ Recommends conducting pilot studies to evaluate the effectiveness of FMEA in the industry before implementing it on a larger scale.
Expert I	➢ Expresses skepticism about the practicality of FMEA in the apparel industry due to its complex and subjective nature. ➢ Suggests that a more simplified and streamlined approach to risk assessment may be more suitable for the industry. ➢ Recommends exploring other quality improvement methods, such as statistical process control, to address rejects and rework in the apparel manufacturing process.
Expert J	➢ Shares positive experiences of using FMEA in the apparel industry, particularly in large-scale manufacturing companies. ➢ Highlights the benefits of FMEA, such as improved process control, enhanced product quality, and reduced defects. ➢ Emphasizes the need for proper training and education to ensure the successful implementation of FMEA in the apparel industry.
Expert K	➢ Expresses concerns about the lack of awareness and knowledge about FMEA in the apparel industry. ➢ Recommends conducting awareness campaigns and training programs to educate industry professionals about the benefits and application of FMEA. ➢ Suggests that industry associations and organizations can play a role in promoting the adoption of FMEA in the apparel industry.
Expert L	➢ Advocates for the adoption of FMEA in the apparel industry, highlighting its potential to identify and mitigate risks. ➢ Suggests that FMEA can be particularly beneficial in addressing challenges related to material variability, design changes, and production processes. ➢ Recommends customizing the FMEA framework to align with the specific needs and characteristics of the apparel industry.

4.1 Summary of Expert Response for the need for FMEA to be customized

The Failure Mode and Effects Analysis (FMEA) methodology has proven to be a valuable tool in various industries for identifying failure modes and improving product quality. However, the apparel industry presents its own set of unique challenges and requirements that necessitate customization of the traditional FMEA framework.

The apparel industry operates in a fast-paced and dynamic environment, characterized by ever-changing fashion trends, seasonal collections, and short product lifecycles. This dynamism requires organizations to make quick decisions and rapidly develop new products. Consequently, the traditional FMEA framework, which relies on a more structured and time-consuming approach, may not align well with the industry's need for agility. Customization of FMEA allows for the incorporation of streamlined processes that accommodate the industry's fast-paced nature while ensuring effective identification and mitigation of failure modes.

The apparel industry faces specific failure modes and risks that are distinct from other industries. These include fabric defects, sizing issues, color fading, stitching problems, and poor garment fit. These failure modes may not be adequately addressed by the traditional FMEA framework, which primarily focuses on technical failures. Customizing FMEA for the apparel industry involves the development of specific risk assessment criteria that encompass these industry-specific failure modes. This customization ensures that the analysis is comprehensive and tailored to the unique challenges faced by apparel manufacturers.

The apparel industry is subject to various regulatory and compliance requirements, including product safety, labeling standards, and environmental regulations. Customizing FMEA enables organizations to incorporate these requirements into the analysis, ensuring that potential failures related to compliance are identified and addressed proactively. Furthermore, the customization of FMEA allows for the inclusion of ethical considerations, such as fair-trade practices, labor rights, and environmental sustainability. By customizing the framework, organizations can align their risk assessment with industry-specific ethical guidelines, reinforcing their commitment to responsible and sustainable practices.

In the apparel industry, design and aesthetics play a crucial role in consumer satisfaction and brand reputation. Customizing FMEA involves incorporating design-related risks and aesthetic considerations into the analysis. This includes assessing the risk of design flaws, potential discrepancies between the intended design and the final product, and the impact of aesthetic failures on consumer perception. By considering these factors, organizations can identify potential failure modes that may affect the appeal and desirability of their products, ultimately enhancing the quality and marketability of their offerings.

The customization of FMEA for the apparel industry should also account for end-user and customer feedback. Fit, comfort, and style are critical factors in consumer decision-making. By integrating customer feedback into the risk assessment process, organizations can identify failure modes that directly impact customer satisfaction. This customization fosters a customer-centric approach to quality improvement, aligning product development with the preferences and expectations of the target market.

Customizing the FMEA framework for the apparel industry is essential to address the unique challenges and requirements of this dynamic sector. By tailoring the methodology to the industry's fast-paced nature, specific failure modes, regulatory compliance, design considerations, and customer feedback, organizations can enhance product quality and mitigate risks effectively. The customization of FMEA ensures that the analysis is aligned with the industry's demands, ultimately leading to improved product performance, customer satisfaction, and brand reputation in the competitive apparel market.

4.2 SWOT analysis of FMEA for the apparel industry:

The SWOT analysis of FMEA in the apparel industry reveals its strengths in risk mitigation, collaboration, compliance, and customer satisfaction. However, it also highlights weaknesses related to subjectivity and resource intensiveness. Leveraging opportunities such as integrating digital tools and customization for design and aesthetics can enhance the effectiveness of FMEA in the apparel industry. Overcoming threats like resistance to change and adapting to rapidly changing fashion trends is essential for successful implementation. By capitalizing on strengths, addressing weaknesses, seizing opportunities, and mitigating threats, the apparel industry can effectively customize and utilize FMEA to enhance product quality and customer satisfaction.

Table 0-2 Swot analysis of FMEA

Strengths: 1. Risk Mitigation: FMEA enables apparel manufacturers to identify and mitigate risks specific to the industry, such as fabric defects, sizing issues, color fading, and stitching problems. This helps in improving the overall quality of garments and reducing customer complaints. 2. Collaboration and Cross-Functional Integration: FMEA encourages collaboration among different departments involved in the apparel production process, including design, production, quality control, and supply chain. This cross-functional integration allows for a comprehensive analysis of failure modes and effective risk mitigation strategies. 3. Compliance with Regulations: FMEA can help apparel manufacturers ensure compliance with industry-specific regulations, such as product safety standards, labeling requirements, and environmental sustainability guidelines. By identifying potential failures related to compliance, organizations can take proactive measures to meet regulatory standards. 4. Customer Satisfaction: By addressing failure modes related to fit, comfort, and aesthetics through FMEA, apparel manufacturers can enhance customer satisfaction. This leads to increased brand loyalty and positive word-of-mouth, ultimately driving business growth.	**Opportunities:** 1. Integration with Digital Tools: The apparel industry can leverage digital tools and technologies to streamline the FMEA process. This includes using software for data collection, analysis, and visualization, enabling efficient risk assessment and decision-making. 2. Customization for Design and Aesthetics: FMEA can be customized to address the unique challenges of design and aesthetics in the apparel industry. This customization can help identify failure modes related to design flaws, inconsistencies between the intended design and final product, and aesthetic failures that may impact customer satisfaction.
Weaknesses: 1. Subjectivity in Risk Assessment: FMEA relies on the expertise and judgment of individuals conducting the analysis. This subjectivity may introduce biases and limitations, potentially impacting the accuracy and effectiveness of the analysis. Ensuring proper training and standardization of the FMEA process can help mitigate this weakness. 2. Resource and Time Intensiveness: Conducting a comprehensive FMEA analysis for the apparel industry, considering the variability of raw materials, production processes, and fashion trends, can be resource-intensive and time-consuming. Organizations with limited resources or tight deadlines may find it challenging to allocate sufficient time and personnel for FMEA.	**Threats:** 1. Resistance to Change: Implementing FMEA in the apparel industry may face resistance from employees who are accustomed to traditional quality control methods. Overcoming this resistance and ensuring buy-in from all stakeholders is crucial for the successful adoption and implementation of FMEA. 2. Rapidly Changing Fashion Trends: The fast-paced nature of the apparel industry, with frequent changes in fashion trends, can pose a challenge for FMEA. It requires organizations to continuously update their risk assessments to align with evolving design preferences and market demands.

4.3 Development of improved FMEA in the apparel industry

The goal of this part of the study is to propose a methodological approach for lunching FMEA-enhanced reducing rejects and rework in the apparel industry. The following list of activities illustrated in Figure 7 is developed for mitigating reject and rework in the apparel industry. The developed FMEA framework is generally divided into four stages with each of the four stages having sub-sections. The stages are described as follows: -

4.1.1 Stage one

Under this stage five core actions need to be well addressed. The first one is assessing system objects and identification. Following this clearly understanding and defining the business model has been done. Then, the next stage is to establish an FMEA team member. Finally, under this sub-section, the developed FEAM will develop an assessment model and will get training.

1. Identify context
2. Identify business process
3. Establish FMEA team
4. Determine the assessment method
5. Training/ procedure for understanding.

4.1.2 Stage two

In the second stage, two lists of operations have been addressed. First, the FMEA team needs to brainstorm to identify potential failure modes for rejection and rework in the apparel industry. Following this, the FMEA team lists potential failure modes.

1. Brainstorming potential failure mode

2. List potential failure modes

4.1.3 Stage three

Here under stage three of this new proposed FMEA framework for mitigating reject and rework in the apparel industry four list have been conducted.

Each of the listed failure modes needs to be assessed. Then risk priority number RPN) would be calculated based on the severity, detection, and occurrence score compiled by the FMEA team. Then defect prioritization could be done. Finally, under this stage; the number of defects that cause 80% rejects and rework could be determined and acted upon it.

1. Asses each failure modes
2. Calculate RPN
3. Defect prioritization
4. Determine the number of failures causes to be acted upon.

4.1.4 Stage four

Under the final stage of the proposed FMEA framework around four lists of operations need to be addressed. Detailed and factual root cause analysis needs to be done for the selected defects that cause reject and rework in the apparel industry. The mitigation strategy for the selected defects could be developed. Following this, remedy action could be carried out on the causes of the selected defects. Finally, RPN needs to be again calculated to compare the performance of the developed FMEA framework.

1. Develop root cause analysis (RCA) for the selected failure causes
2. Develop a mitigation strategy for the selected factors

3. Take action to eliminate or reduce the high-risk factors

4. Calculate the resulting RPN as the failure modes are reduced

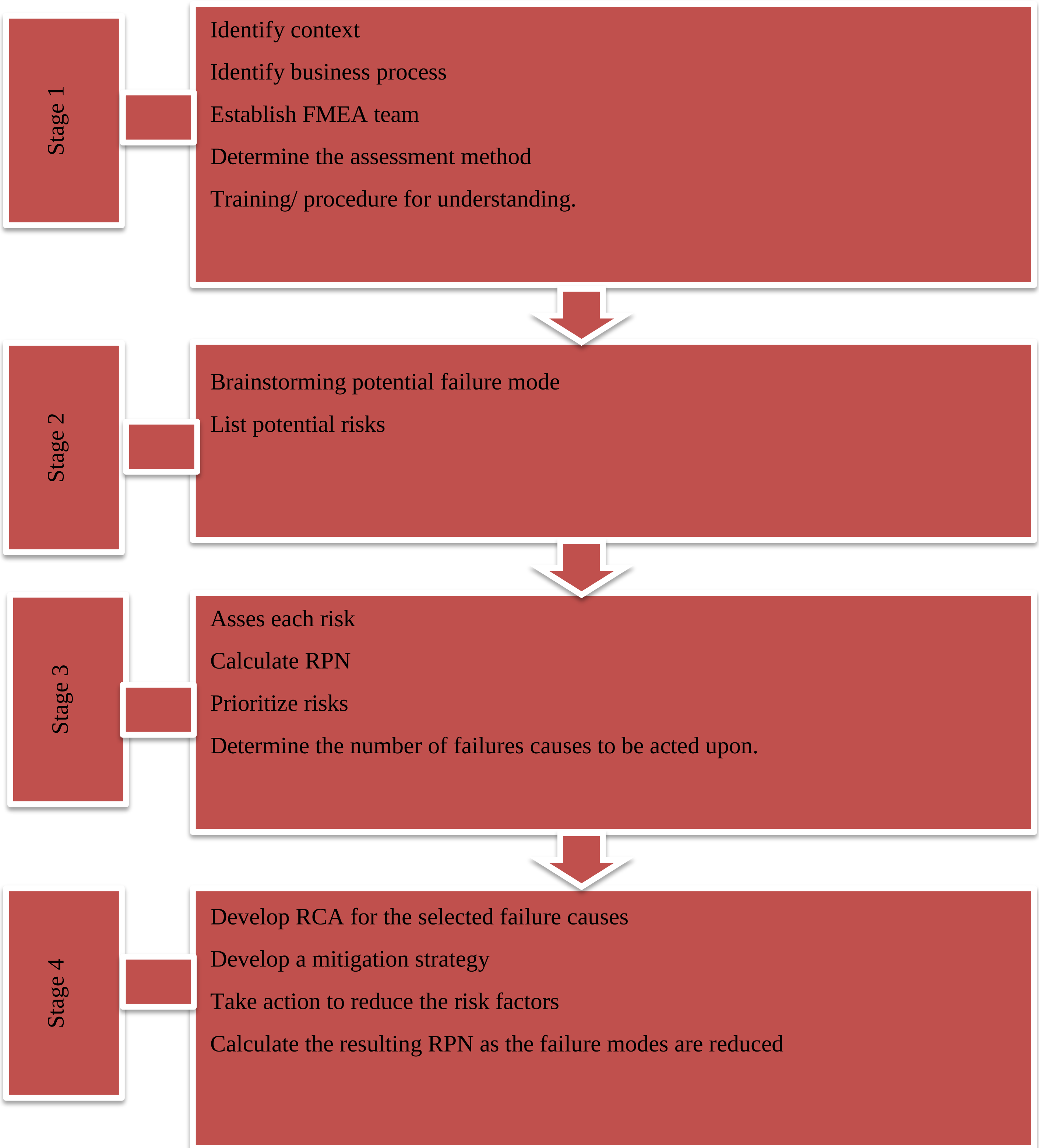


Figure 4 Improved FMEA framework

Chapter Five

5. Case study and result

A detailed practical case study is presented in this part of the study to unearth how the FMEA-enhanced reducing reject and rework is implemented in the apparel industry. This approach will enhance reducing risk consequences of the conventional FMEA framework which cannot fit in the apparel industry. In line with the technique of reasoning the severity, it diminishes the human inaccuracies throughout the severity rating activities. Furthermore, by the technique of reasoning the incidences of contributing elements, it helps expert stockholders the records of the efforts put in the requirements and function investigation, and it is potentially re-used at another time.

5.1 Stage one

The industry needs to identify several most serious defects that result in quality problems to take appropriate measures correspondingly in advance and prevent the incidence of rejects and rework. After preliminary screening, four potential failure modes (FM1, FM2, FM3, and FM4) remain for further evaluation.

5.2 Stage two

An FMEA team of five decision-maker experts, DME1, DME2, DME3, DME4, and DME5, has been formed to estimate the most severe failure modes. The risk factors, occurrence (O), severity(S), and detectability (D), have been well-defined according to the six-month historical data and the questionnaire replied to by all decision-maker experts.

5.2.1 Pareto presentation of six-month data

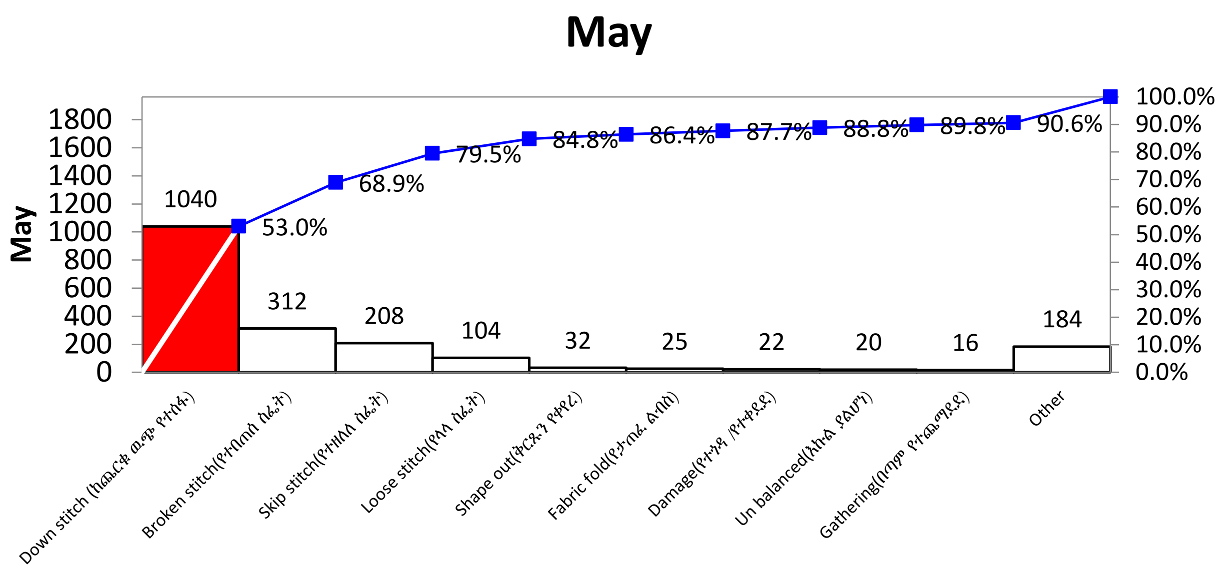


Figure 5 May defect records

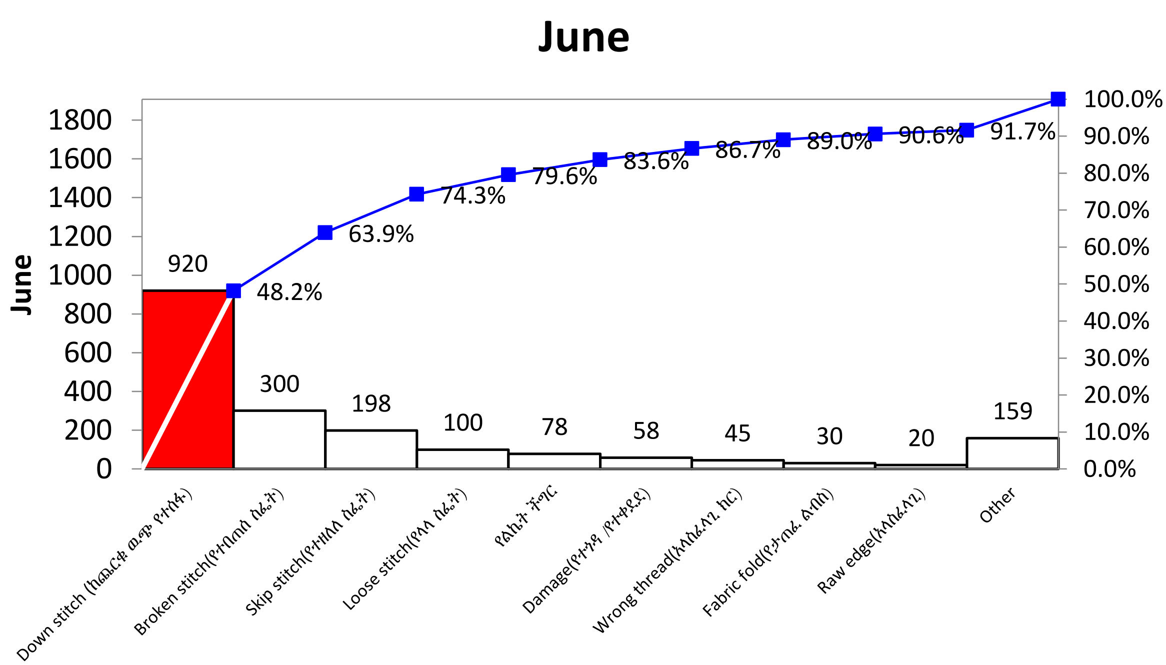


Figure 6 June defects

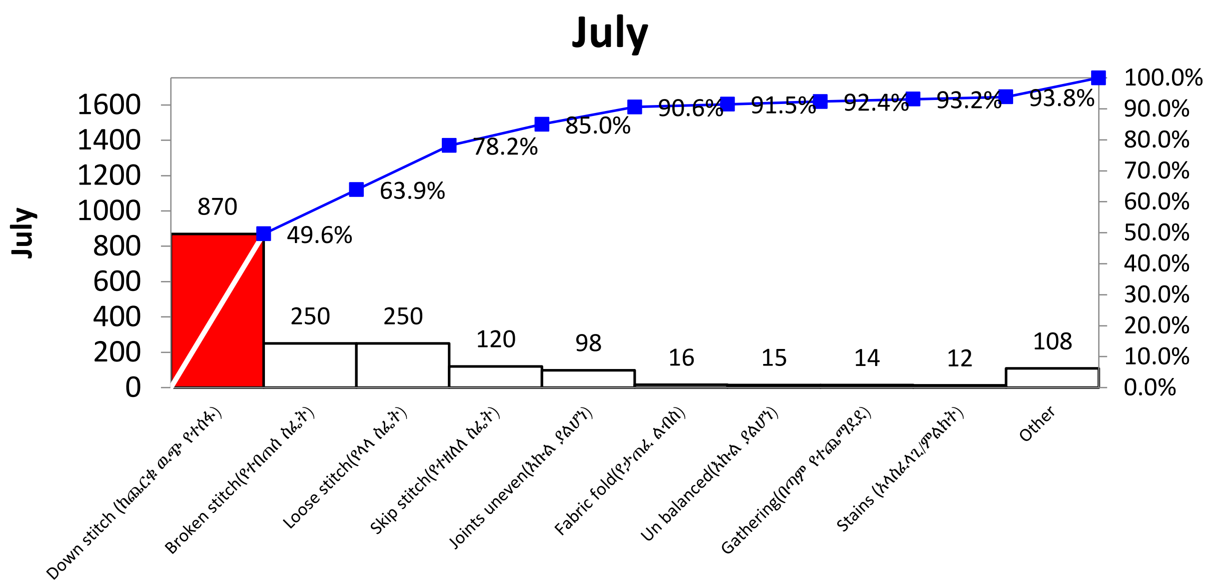


Figure 7July defects

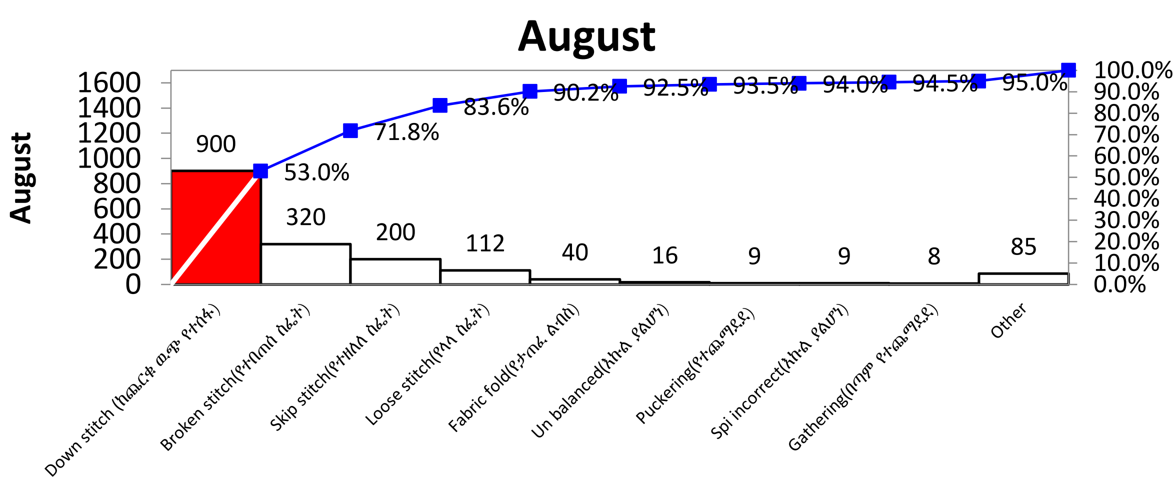


Figure 8August defects

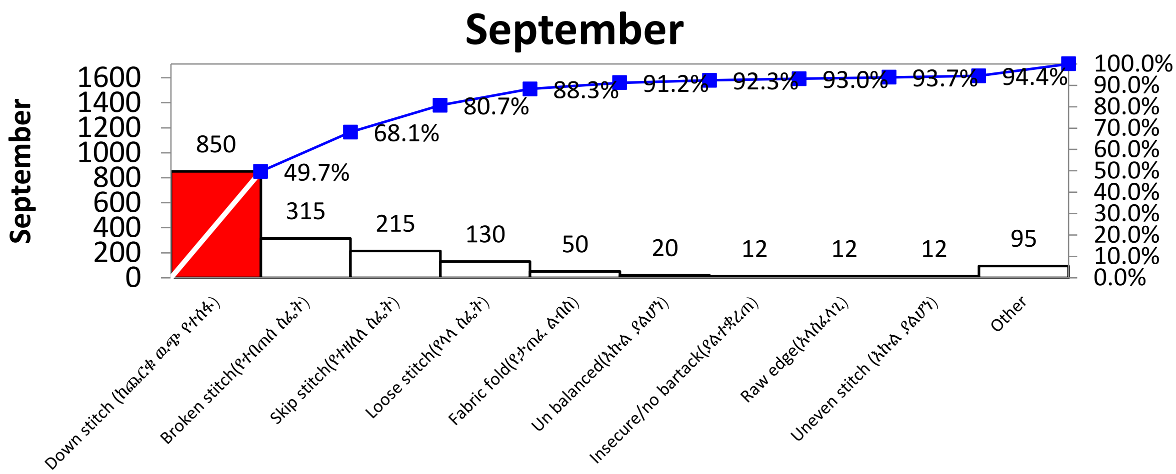


Figure 9 September defects

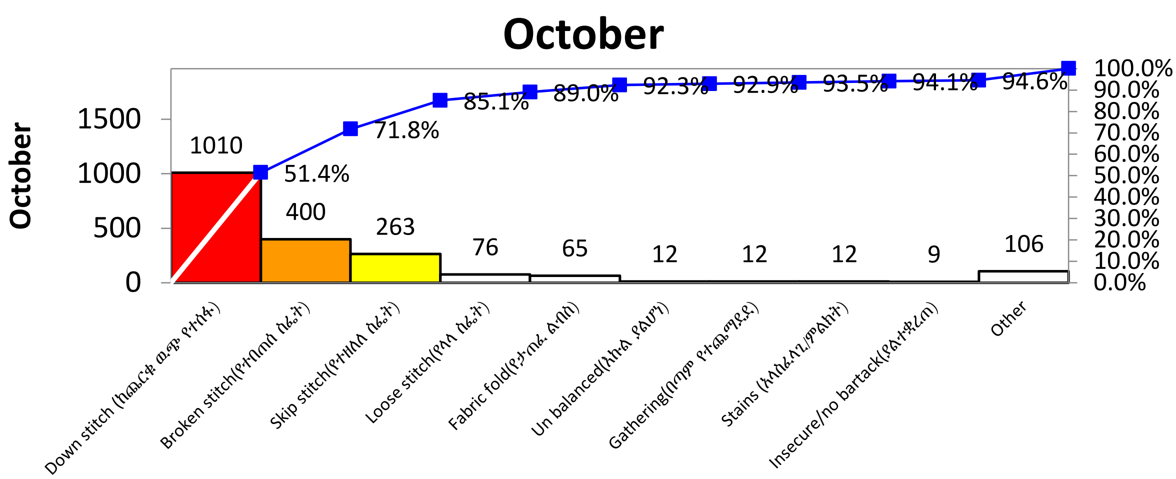


Figure 10 October defects

5.2.2 Severity assessment of defects

In this context, severity might be defined as the likelihood that a certain issue will cause a product to be returned and reworked in the garment sector. The term "severity" is used to describe the influence of a fault on a product, namely how serious it is and how it affects the functionality of the entire industry. The FMEA team establishes the severity as a parameter when they open a problem, and it primarily depends on the sample. Again, the technologies used to detect flaws vary amongst firms.

Regarding quality inspection and data analysis in the apparel business, the quality inspector (auditor) should assess the severity and location of the flaws in a garment. The classification assigned to defects includes major, minor, and critical defects. While looking at the textiles or clothing, the defects. The lot is accepted or rejected based on the classification, which is based on the severity of the problem. The impact on the garment's maintainability, the position of the fault, and the conspicuousness of the defect are considered when classifying the flaws as significant or minor. A team of experts from sales, production, and machine maintenance as well as selected operators and supervisors were given the chance to participate in determining the severity score of the defects in the prior lists. Severity is the intensity of failure of the effect on the product or end-user’s value(E. Pazireh, 2017). It is just the serious-ness of the defect effect(Ünal & Acar, 2016). It is measured on a scale from 1 to 10. The following table below illustrates the degree of severity effect measured through expert opinion.

Table 0-3 Severity Effect Measurement Scale

Severity of Effect:	
No Effect	1. None
Annoyance	2. Very Minor
	3. Minor
	4. Very Low
Loss or degradation of secondary function	5. Low
	6. Moderate
Loss or degradation of primary function	7. High
	8. Very High
Failure to meet safety/regulations	9. Hazardous with warning
	10. Hazardous w/o warning

Five groups of experts each containing three individuals from the quality, production, and marketing department involved to grade the severity of the listed most common defects. From the Pareto analysis, we have taken the top four defects accounting for the 80% of total defects in the company.

Table 0-4 Expert Severity Assessment of Defects

Code	Defect	Severity					all groups agreed after a focal group discussion
		DME1,	DME2,	DME3,	DME4	DME5	
D	Down stitch	6	8	8	7	9	8
B	Broken stitch	8	9	6	9	8	9
A	Skip stitch	9	7	6	9	8	9

C	Loose stitch	7	9	8	6	7	7

5.2.3 Degree of occurrence of the defects

Here the aim is to determine the possibility of the occurrence of the defect in a certain frequency fashion(E. Pazireh, 2017). It can be measured on a scale ranging from one to ten. The table below signifies the scale to determine occurrence taken from(E. Pazireh, 2017).

Table 0-5 Degree of Occurrence Measurement Scale

Range	Possible occurrence rate	Probability of occurrence
1.	<1 in 1,500,000	Nearly impossible
2.	1 in 150,000	Remote
3.	1 in 15,000	Low
4.	1 in 2,000	Relatively low
5.	1 in 400	Moderate
6.	1 in 80	Moderately high
7.	1 in 20	High
8.	1 in 8	Repeated failure
9.	1 in 3	Very high
10.	>1 in 2	Extremely high

From the six-month quality department record document, we have identified the occurrence rate of the most common defects identified in the pareto-analysis.

Table 0-6Degree of Occurrence of Defects

Code	Defect	Occurrence rate
D	Down stitch	8
B	Broken stitch	6
A	Skip stitch	5
C	Loose stitch	4

5.2.4 Detectability of the defect

This factor signifies the traceability of the defect by the operator or end-user (E. Pazireh, 2017). The table below illustrates the traceability scale of the defects.

Table 0-7 Defect Detectability Measurement Definition

Range	Probability	Detection
1.	Almost certain	The defect is obvious or there is 100% automatic inspection with regular calibration.
2.	Very high	All units are automatically inspected
3.	High	100% inspection surrounding out-of-control conditions
4.	Moderate high	Statistical process control is used with an immediate reaction to out-of-control conditions.
5.	Moderate	Some statistical process control is used in the process and the product is final inspected off line.
6.	Low	Manual inspection with mistake-proofing modifications
7.	Very low	All units are manually inspected
8.	Remote	The product is accepted based on no defectives in a sample
9.	Very remote	Occasional units are checked for defects
10.	Almost impossible	The product is not inspected or the defect caused by failure is not

		detectable.

According to the interview with the company quality department, all units are manually inspected for defects. Therefore, the value 7 is used for all selected defects.

Table 0-8 Detectability of Defects

Code	Defect	Detectability
D	Down stitch	7
B	Broken stitch	7
A	Skip stitch	7
C	Loose stitch	7

5.3 Stage three

Here under stage three of this new proposed FMEA framework for mitigating reject and rework in the apparel industry four list operations need to be conducted. Each of the listed failure modes needs to be assessed. Then risk priority number RPN) would be calculated based on the severity, detection, and occurrence score compiled by the FMEA team. Then defect prioritization could be done. Finally, under this stage; the number of defects that cause over 80% rejects and rework have been determined and acted upon it.

5.3.1 U- Chart data presentation and analysis

The “U” in U Chart is short for units, meaning “defective units per lot”. This most efficient control chart is used with data gathered in subgroups of various sizes. U-charts display the evolution of a process as shown by the number of nonconformities per individual item or set of individual items. Nonconformities are flaws or incidents that were observed in the sampled subgroup. They might be categorized as any defect that is present but ought not to be or as any defect that is absent but ought to be. Nonconformities include things like skip stitch, broken stitch, Puckering, Fabric defects, Pleat, Stains, and many more. U-charts are used to check for stability and predictability in the process as well as to track the impact of process improvement theories. For better illustration and understanding of the number of defective items whether the process is in or out of control in the listed 50 days a u-chart has been constructed. QL Marcos 2018 Excel plugins were employed for u-chart analysis. The u-chart indicates an out-of-control condition either when one or more points fall beyond the control limits, or when the plotted points exhibit some non-random pattern of behavior. Therefore, Table 5.1 below shows the evidence of the causes of variations in the u-chart.

The formula used to create the U chart is as follows:

Table 0-9Causes of variation in U-Chart

	Exceptional cases	Dates	Remark
1.	Points falling outside $\pm 3\sigma$	5, 12, 16, 39	
2.	Eleven successive points on some stable pattern	24-35	
3.	Nine successive points on alternating but normal pattern	41-50	

Table 0-10 U-Chart Analysis

Dates	Defective Items	Total inspected items	U	UCL	+2 sigma	+1 sigma	Average	-1 sigma	-2 sigma	LCL	X Error Bars	UCL Error Bars	2 Sigma Error Bars	1 Sigma Bars	1 Sigma Bars2	2 Sigma Bars	LCL Error Bars
1	64	800	0.08	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
2	75	750	0.10	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.001	0.001	0.000	0.000	-0.001	- 0.001
3	59	790	0.07	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	- 0.001	-0.001	0.000	0.000	0.001	0.001
4	68	780	0.09	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
5	152	785	0.19	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
6	82	780	0.11	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
7	84	790	0.11	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
8	69	795	0.09	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
9	86	800	0.11	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
10	120	750	0.16	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.001	0.001	0.000	0.000	-0.001	- 0.001
11	84	765	0.11	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
12	23	755	0.03	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
13	96	800	0.12	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	-	-0.001	0.000	0.000	0.001	0.001

												0.001					
14	95	800	0.12	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
15	85	800	0.11	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
16	175	765	0.23	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.001	0.001	0.000	0.000	-0.001	- 0.001
17	74	780	0.09	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
18	95	780	0.12	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
19	83	800	0.10	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
20	86	795	0.11	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
21	111	794	0.14	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
22	85	785	0.11	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
23	95	768	0.12	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
24	65	782	0.08	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
25	62	733	0.08	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.001	0.001	0.000	0.000	-0.001	- 0.001
26	63	764	0.08	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	- 0.001	0.000	0.000	0.000	0.000	0.001
27	580	800	0.07	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	- 0.001	-0.001	0.000	0.000	0.001	0.001
28	58	755	0.08	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.001	0.001	0.000	0.000	-0.001	- 0.001
29	65	785	0.08	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	-	0.000	0.000	0.000	0.000	0.001

											0.001					
30	64	782	0.08	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
31	65	780	0.08	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
32	76	754	0.10	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.001	0.000	0.000	0.000	0.000	-0.001
33	52	789	0.07	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	-0.001	-0.001	0.000	0.000	0.001	0.001
34	54	768	0.07	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
35	65	798	0.08	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	-0.001	0.000	0.000	0.000	0.000	0.001
36	86	756	0.11	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.001	0.001	0.000	0.000	-0.001	-0.001
37	85	789	0.11	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	-0.001	0.000	0.000	0.000	0.000	0.001
38	95	780	0.12	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
39	162	800	0.20	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
40	95	790	0.12	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
41	66	768	0.09	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
42	82	780	0.11	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
43	78	788	0.10	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
44	97	756	0.13	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.001	0.000	0.000	0.000	0.000	-0.001

45	76	789	0.10	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	-0.001	0.000	0.000	0.000	0.000	0.001
46	66	759	0.09	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.001	0.000	0.000	0.000	0.000	-0.001
47	78	800	0.10	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	-0.001	-0.001	0.000	0.000	0.001	0.001
48	94	768	0.12	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.001	0.000	0.000	0.000	0.000	-0.001
49	67	756	0.09	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	0.000	0.000	0.000	0.000	0.000	0.000
50	100	784	0.13	0.14	0.13	0.12	0.11	0.09	0.08	0.07	1.000	-0.001	0.000	0.000	0.000	0.000	0.001

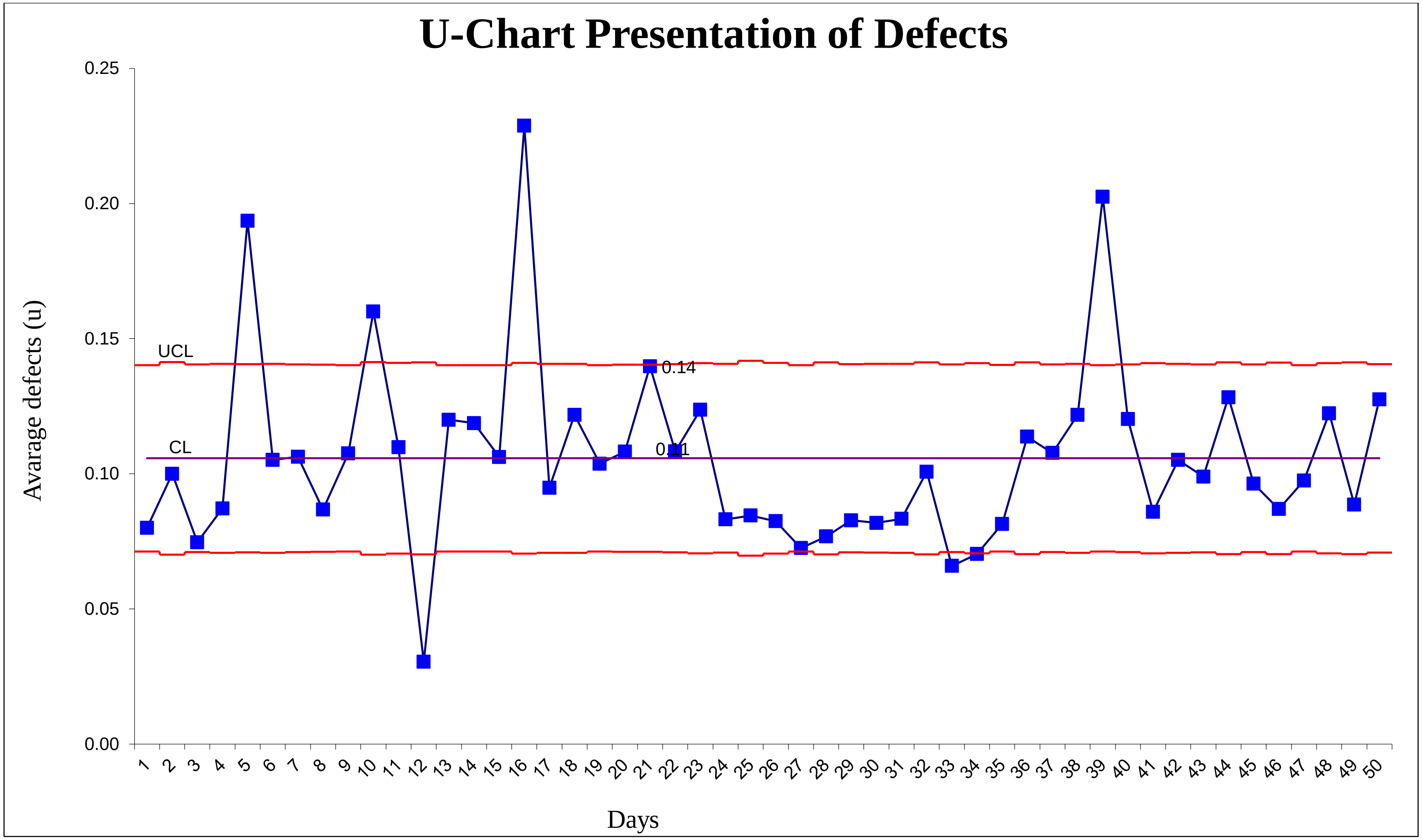


Figure 11 U-chart defect presentation

5.3.2 RPN calculation

Risk Priority Number (RPN); is the value obtained multiplying by defect occurrence, severity, and detection(Ünal & Acar, 2016). Therefore, "Occurrence" is the defect frequency, "Severity" is the seriousness of the selected defect, and "detection" is the probability of notification of the defect before it reaches the customer(Ünal & Acar, 2016).

RPN = Occurrence × Severity × Detection…………………………….……………… (1)

Table 0-11 RPN of Defects

Potential Failure Mode	Potential Effect(s) of Failure	Severity	Occurrence	Detection	R. P. N.
Down stitch	rework & reject	7	8	7	392
Broken stitch	rework & reject	9	6	7	378
Skip stitch	rework & reject	9	5	7	315
Loose stitch	rework & reject	7	4	7	196

5.4 Stage four

Under the final stage of the proposed FMEA framework around four lists of operations need to be addressed. Detailed and factual root cause analysis needs to be done for the selected defects that cause reject and rework in the apparel industry. The mitigation strategy for the selected defects could be developed. Following this, remedy action could be carried out on the causes of the selected defects. Finally, RPN needs to be again calculated to compare the performance of the developed FMEA framework.

5. Develop RCA for the selected failure causes
6. Develop a mitigation strategy for the selected factors
7. Take action to eliminate or reduce the high-risk factors
8. Calculate the resulting RPN as the failure modes are reduced

5.4.1 Root cause analysis of the selected defects

As per FMEA RPN calculation of six months past data from the quality department of Lucy Garment plc; we selected the top 4 defects that account for up to 80 percent of total defects in the company. Accordingly, down stitch, broken stitch, skip a stitch, and Loose stitch ranked top one to four respectively. The following part presents a detailed root cause and effect analysis of these four top-ranked defects in the selected case company.

5.4.1.1 Down stitch

The main cause for the occurring down stitch is lack of proper training. The needle-thread-fabric combination should match correctly to reduce down-stitch defects(Rahman et al., 2018).

Additional root causes for down stitch as per the expert's view and experiences.

i. Machine Malfunction: Down stitch can occur due to issues with the sewing machine, such as incorrect tension settings, worn-out needles, or malfunctioning feed mechanisms.
ii. Operator Error: Inexperienced or poorly trained operators may not have the necessary skills to maintain consistent stitch quality. Insufficient training or lack of attention to detail can lead to down-stitch problems.
iii. Material Defects: Poor quality or defective thread, fabric, or other sewing materials can contribute to down stitch problems.
iv. Inadequate Workstation Setup: Improper workstation setup, such as incorrect lighting, uncomfortable seating, or inadequate workspace, can affect the operator's ability to sew accurately.

Recommended actions to overcome down stitch in garment production

i. Regular Maintenance: Implement a preventive maintenance program for sewing machines to ensure they are in optimal working condition. This includes regular cleaning, lubrication, and timely replacement of worn-out parts.
ii. Training and Skill Development: Provide comprehensive training to operators on proper stitching techniques, machine operation, and quality control measures. Regular skill enhancement programs can help improve stitch consistency.
iii. Quality Control Measures: Implement strong quality control processes, including regular inspections and audits, to identify and rectify down stitch issues. This can involve conducting random checks, setting quality standards, and providing feedback to operators.
iv. Supplier Management: Work closely with suppliers to ensure the quality of materials used. Establish clear specifications and conduct regular quality checks on incoming

materials including following up the production process of the raw material to prevent defects that can lead to down stitch problems.

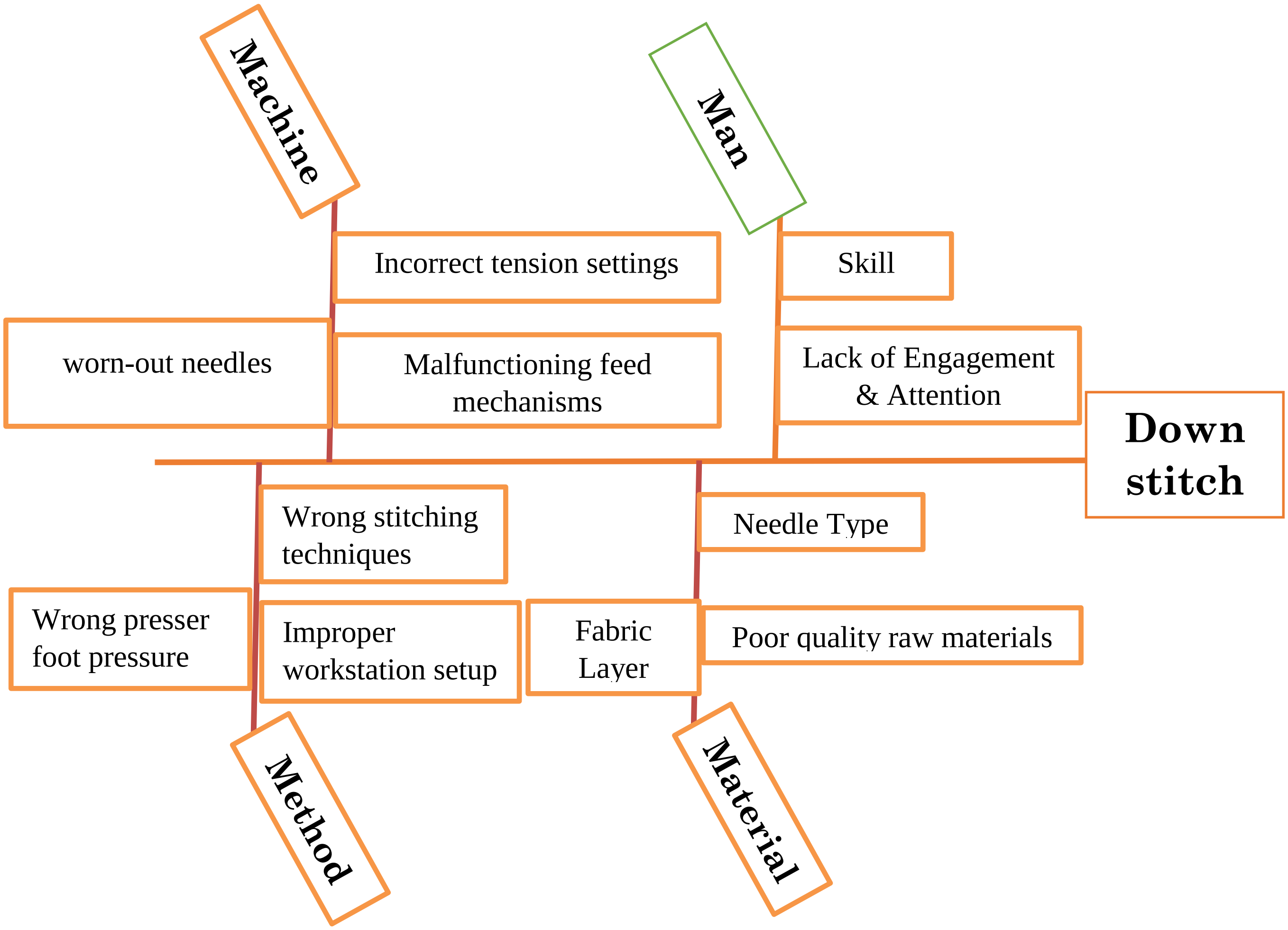


Figure 12 Down stitch RCA

5.4.1.2 Broken stitch

Broken stitch is created and increasing defects for the tendency of producing more and garment become tampered. The reporter has identified the major causes, which are responsible for man, machine materials, and methods. The cause-effect diagram for broken stitch is shown below(Rahman et al., 2018):

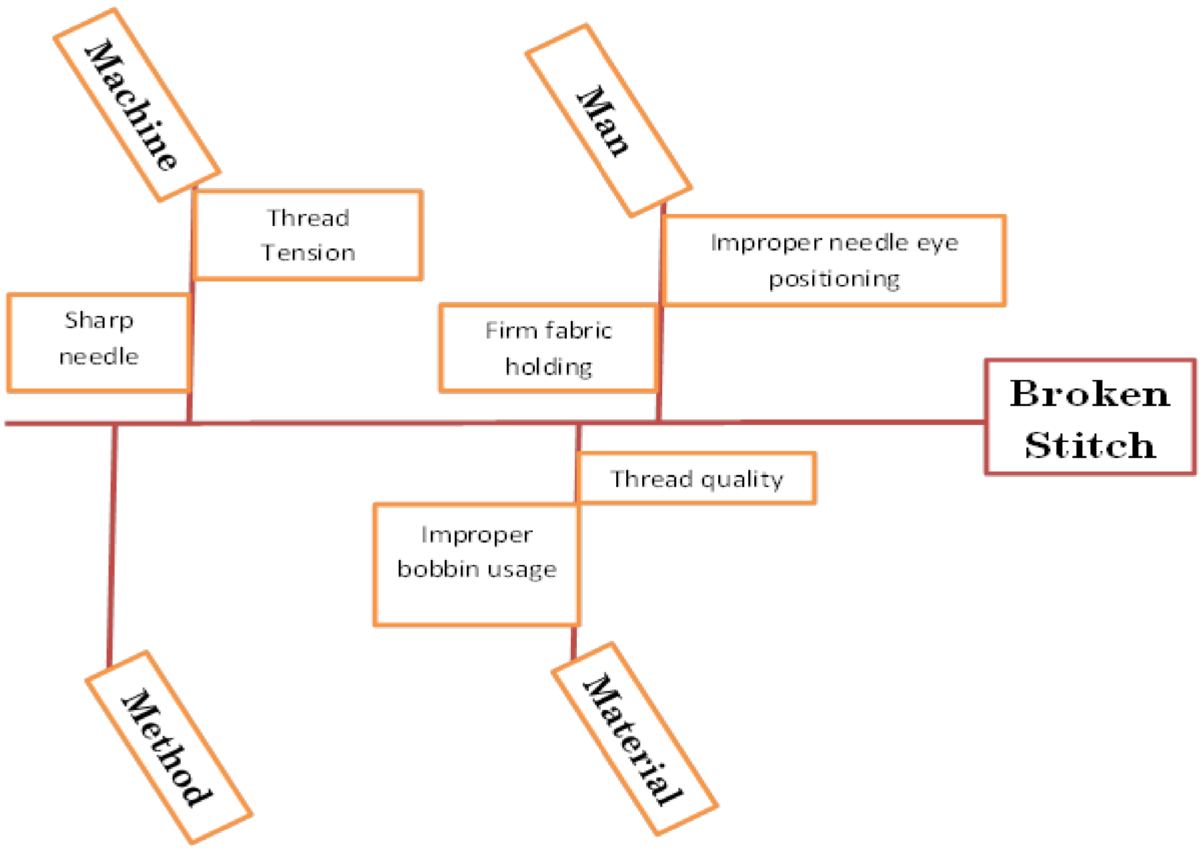


Figure 13 Brocken stitch RCA

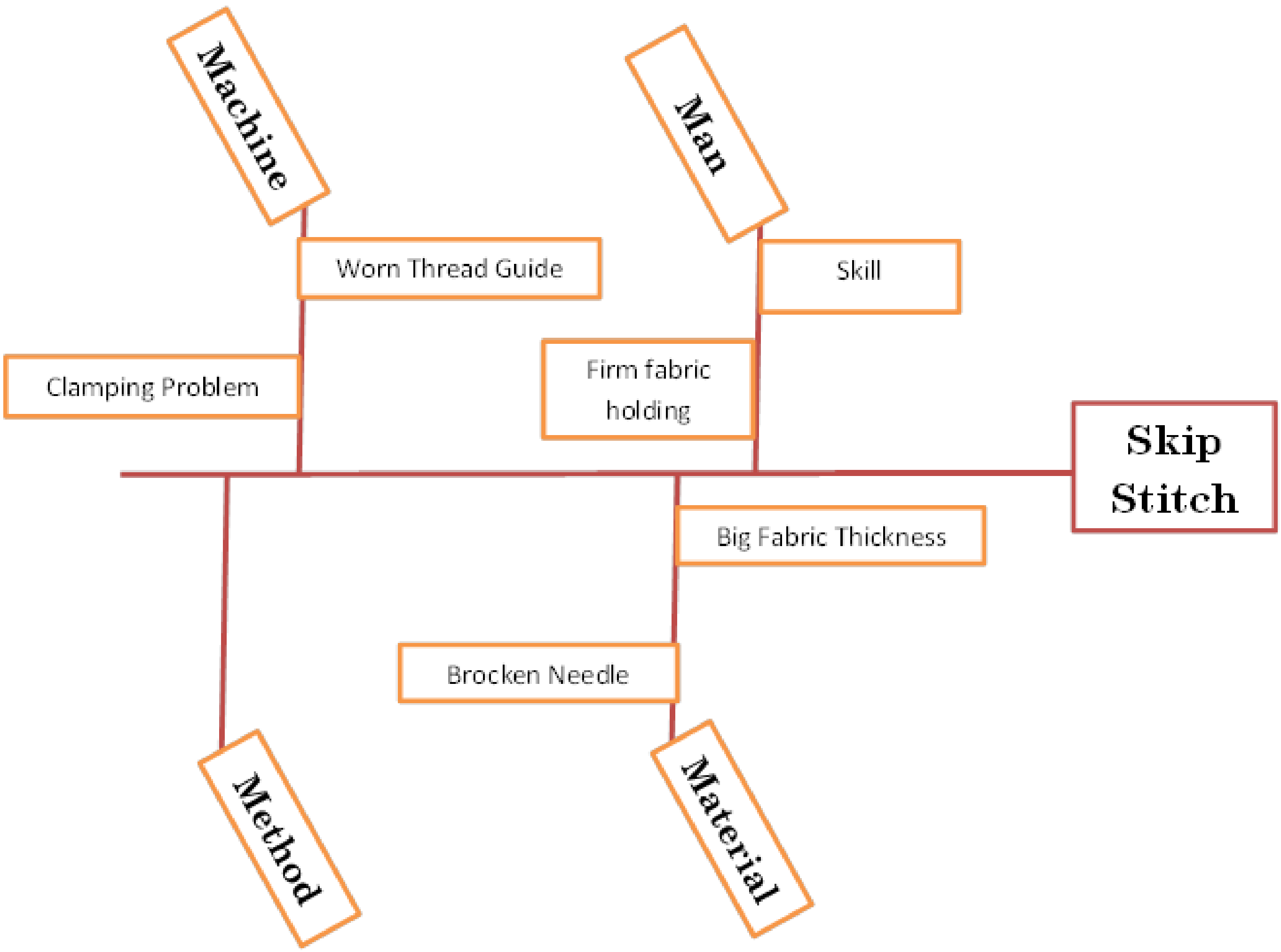
Broken stitches are caused when the thread runs out during sewing and broken stitches during the following of the finished product. High speed, operator carelessness, the sharp needle that cuts sewing threads, higher thread tension, improper bobbin, and low quality of thread.

Therefore, to mitigate these problems moderate speed that is compatible with the operator's skill has been recommended and implemented, and they have been advised to focus on their work for better quality achievement. Maintenance personnel have been trained to replace improper needles that cut thread, adjust the thread tension, and use compatible bobbins on time and immediately after problems start occurring. Additionally using a better-quality sewing thread has been recommended for the management.

5.4.1.3 Skip stitch

Skip stitch is another major defect for garments. This can be caused by rough handling of materials. For solving this operator should carefully handle the material during operation. Stitch per inch (SPI) of the machine may cause for skip stitch. The lower the SPI the higher chance for the skipped stitch to occur. Using appropriate SPI and regular maintenance to keep the machine in good working condition should be taken to get the continuous stitch. A needle worn out can also create a skip stitch, which can be solved by replacing the needle(Rahman et al., 2018).

Figure 14 Skip stitch RCA



5.4.1.4 *Loose stitch*

Improper handling of cut pieces, faulty feed mechanism, improper clamping, Fabric stretching, subsequent handling, Incorrect sewing tension, and Incorrect threading are the main common defect causes that result in the loose stitch. To mitigate these problems operators have been trained on how to handle materials as per their properties, how to adjust the thread tension check the stitch quality, and how to properly thread following the guides. We have discussed with the production and quality managers that it is better to use additional feeding mechanisms as work aids to facilitate the feeding process.

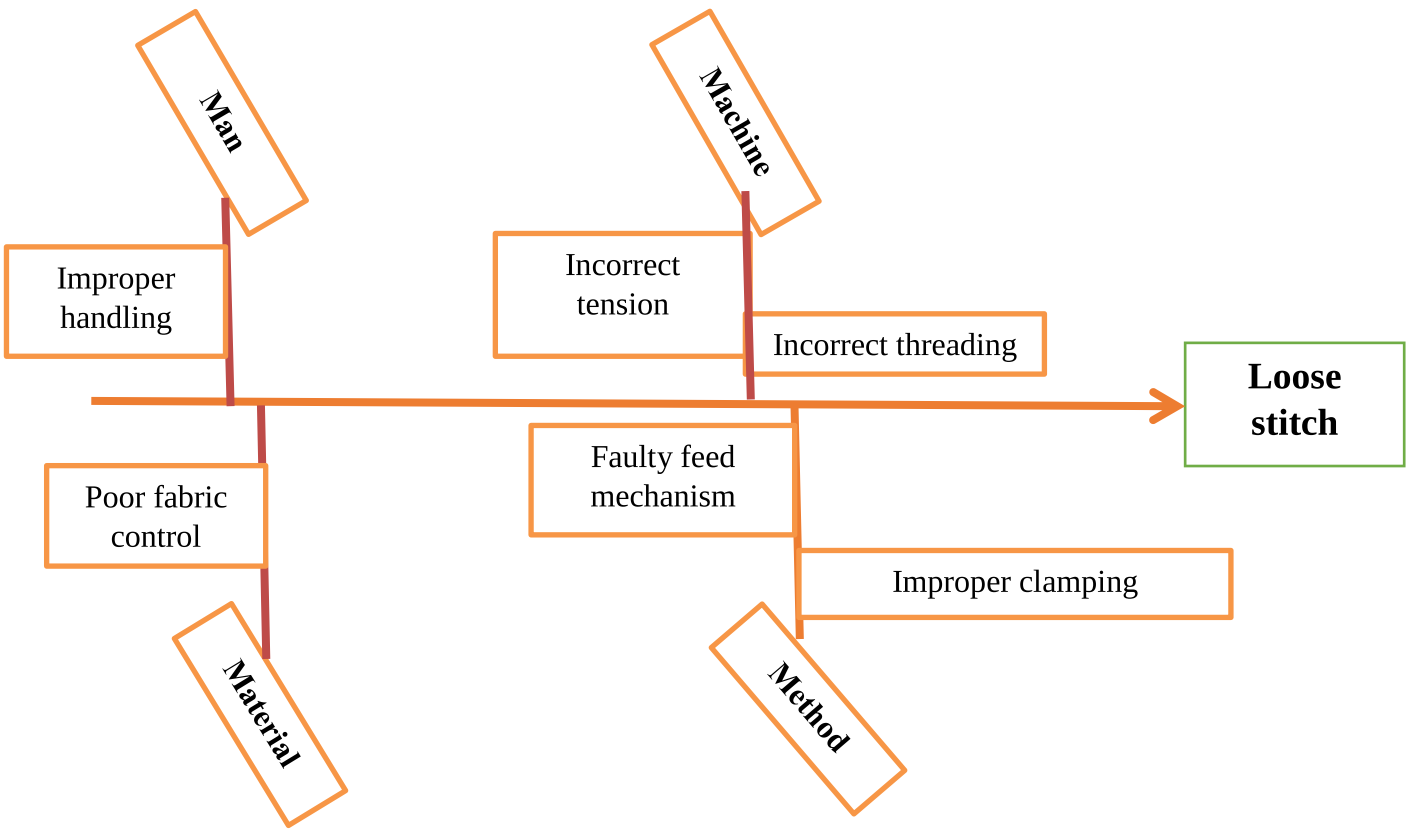


Figure 15 Loose stitch RCA

5.5 Validation of the developed FMEA model

5.5.1. Implemented actions

Table 0-12 recommended actions

Potential Failure Mode	Recommended Action(s)
Down stitch	Comprehensive trainings have been provided to operators on proper stitching techniques, machine operation, and basic maintenance skills.
	Strong quality control processes which include regular inspections and audits, that involve conducting random checks, setting quality standards, and providing feedback to operators.
	preventive maintenance programs for sewing machines have been implemented to ensure they are in optimal working condition. This includes regular cleaning, lubrication, changing needles, and timely replacement of worn-out parts.
	Little adjustments on thread tension, pressor foot, needle eye positioning, and feed dogs have been made.
Broken stitch	Maintenance personnel have been trained to replace improper needles that cut thread, adjust the thread tension, and use compatible bobbins on time and immediately after problems start occurring

	Operators have been advised to focus on their work for better quality achievement.
	A moderate speed that is compatible with the operator's skill has been recommended and implemented Additionally using a better-quality sewing thread has been recommended for the management.
Skip stitch	Using appropriate SPI and regular maintenance to keep the machine in good working condition has been recommended and implemented to get the continuous stitch.
	Worn-out needles must be changed on time and operators have been trained to make routine maintenance like changing needles to not wait for maintenance personnel to come and change the needles. This makes them take immediate action to problems like skip stitches.
	The process of carefully handling the material during operation as per the pattern and material property has been introduced for the operators.
Loose stitch	Operators have been trained on how to handle materials as per their properties, how to adjust the thread tension checking the stitch quality, and how to properly thread following the guides.
	We have discussed with the production and quality managers that it is better to use additional feeding mechanisms as work aids to facilitate the feeding process.

5.5.2. Recorded data after recommended actions have been taken

Table 0-13 recorded data after recommended actions

Days	Type of defects	Number of defects	Total production	Occupancy rate	Approximate value
1	Down stitch	68	1350	5.037037	5
	Broken stitch	67	1400	4.785714	5
	Skip stitch	58	1365	4.249084	4
	Loose stitch	56	1386	4.040404	4
2	Down stitch	65	1398	4.649499	5
	Broken stitch	54	1402	3.851641	5
	Skip stitch	54	1386	3.896104	4
	Loose stitch	56	1375	4.072727	4
3	Down stitch	66	1393	4.737976	5
	Broken stitch	67	1389	4.823614	5
	Skip stitch	57	1406	4.054054	4
	Loose stitch	55	1397	3.937008	4
4	Down stitch	64	1390	4.604317	5
	Broken stitch	66	1404	4.700855	5
	Skip stitch	55	1386	3.968254	4
	Loose stitch	58	1393	4.163676	4
5	Down stitch	64	1400	4.571429	5
	Broken stitch	59	1388	4.25072	4
	Skip stitch	57	1386	4.112554	4
	Loose stitch	56	1390	4.028777	4

RPN calculation after implementation of recommended action

Table 13 RPN calculation after implementation of recommended action

S no	**Types of defects**	**RPN calculation**			
		Severity	Occurrence	Detectability	RPN
1	Down stitch	7	5	7	245
2	Broken stitch	9	5	7	315
3	Skip stitch	9	4	7	252
4	Loose stitch	7	4	7	196

5.6 Result

In this study, the main objective was to develop an improved Failure Mode and Effect Analysis (FM0EA) approach that could be applied specifically in the garment industry to reduce reject and rework. By implementing this improved FMEA, the research sought to effectively identify and address potential failure modes, thus reducing the occurrence rate of defects.

Methods: To achieve the objectives, the research conducted an extensive review of existing FMEA methodologies and identified their limitations in the context of the garment industry. Based on this analysis, an enhanced FMEA framework specifically tailored to address the unique challenges faced in this industry has been developed. This improved FMEA approach integrated various factors such as fabric quality, stitching techniques, machinery settings, and workforce skills.

Results: The implementation of the improved FMEA approach in the garment industry yielded promising results. Through the identification and analysis of failure modes at each stage of the manufacturing process, the research able to pinpoint critical areas and develop targeted strategies for defect prevention and reduction. Furthermore, by using the improved FMEA, there was a significant reduction in the occurrence rate of defects. Statistical analysis of the data collected before and after the implementation of the new approach revealed a notable decrease in reject and rework rates. This improvement directly contributed to enhanced product quality, increased productivity, and reduced manufacturing costs.

Chapter Six

6. Conclusion, recommendation, and future works

6.1 Conclusion

The global rule that makes a firm competitive and sustainable is this ever-changing customer expectations is that; the ability of an organization to adapt to the demands imposed by a changing environment. Exceeding customer expectations through better quality, cheap price, faster delivery time, and being more agile are the only guarantees to survive and sustain with in the market (John M.Nicholas, 2005). Making the customers buy one's product the first time is easy. But making the customers come to themselves again and again is a difficult task. Therefore, the question of quality products comes here. The customer uses the product gives a grade and makes the decision to come again or not. Today many scholars are becoming fans of Joseph Juan's quality definition. He articulates quality as the quality of any good or service that should be defined from the customer's perspective or quality is fitness for use. This definition of quality is promising because; to make your customers buy your product you must listen to them.

The production of high-quality products requires the seamless interaction of every aspect of product creation. By emphasizing product quality, a company can increase productivity and increase profitability. By using Quality Function Deployment, managers can optimize product designs and minimize the difficulty associated with development changes within their projects (Mika Valtasaari, 2000).

This study aimed at improving FMEA methodology to be applied in the apparel industry for reducing rejects and rework. Using six-month quality department data and expert stockholders' views the study improved and validated the FMEA frame work to be applied in the apparel industry for reducing reject and rework.

This study analyzed six-month quality department records from Lucy garment plc. and identified four major defects that resulted in 80% of total reject and rework in the company. Accordingly, broken stitch, skip stitch, down stitch, and loose stitch are the major defects that result in rejects and rework in the Lucy garment manufacturing plc. Detailed Pareto illustration and U chart description have been carried out to verify the impact of the defects.

This thesis emphasized and used the Lucy garment factory to improve the apparel industry's rejection and rework rate. Both secondary data (i.e. review document) and primary data (i.e. from observation of the defect in the company) indicate that the rework rate is very high which results in lower competitive performance.

So far FMEA approaches for identifying and mitigating risk factors in the product development process have been used but the developed conventional FMEA frameworks are not in the best interest of using it for reducing rejection and rework in the apparel industry. For that reason, this study proposed the improved FMEA to reduce reject and rework in the apparel industry by taking the case study in the Lucy garment plc.

As per the six-month historical data on rejection and rework rate from the company, it was about 10% as it was stated in the problem statement. After conducting this research, the rate was deduced to 4.5%. therefore 5.5% improvement was achieved due to the finding of this research.

Finally, the researcher successfully developed an improved Failure Mode and Effect Analysis specifically tailored for the garment industry. By applying this approach, the research demonstrated its effectiveness in reducing reject and rework rates, ultimately improving product quality and operational efficiency. The implementation of this enhanced FMEA has great potential for widespread adoption in the garment industry, enabling manufacturers to optimize their production processes and minimize costly errors.

6.2 Recommendation

The first and foremost contribution of this work is the suggested Improved FMEA framework for reducing rejects and rework in the apparel industry. Furthermore, the following list of remedial actions is recommended to the case company for reducing reject and rework in the firm.

- Specialized training for workers is needed to tackle specific defects based on the outcome of the improved FMEA framework suggested in this work.
- Generally, as per this study's findings, workers need some form of reward and incentive to make them fully engaged in their work.
- Soft skill training like time management, attitude, communication, workplace ethics and safety, and productivity training are needed.
- Documentation and records of data needed more effort for better data management and building institutional memory for easy retrieval.
- Technological capability and ICT infrastructure online quality control need to be well planned for long-term solutions and the latest technologies need to be adopted for sustainable performance.

6.3 Future work

As a future work, this study recommends more macro-level studies are required instead of case companies for further deepening the application of the improved FMEA framework in the apparel industry for reducing rejects and rework.

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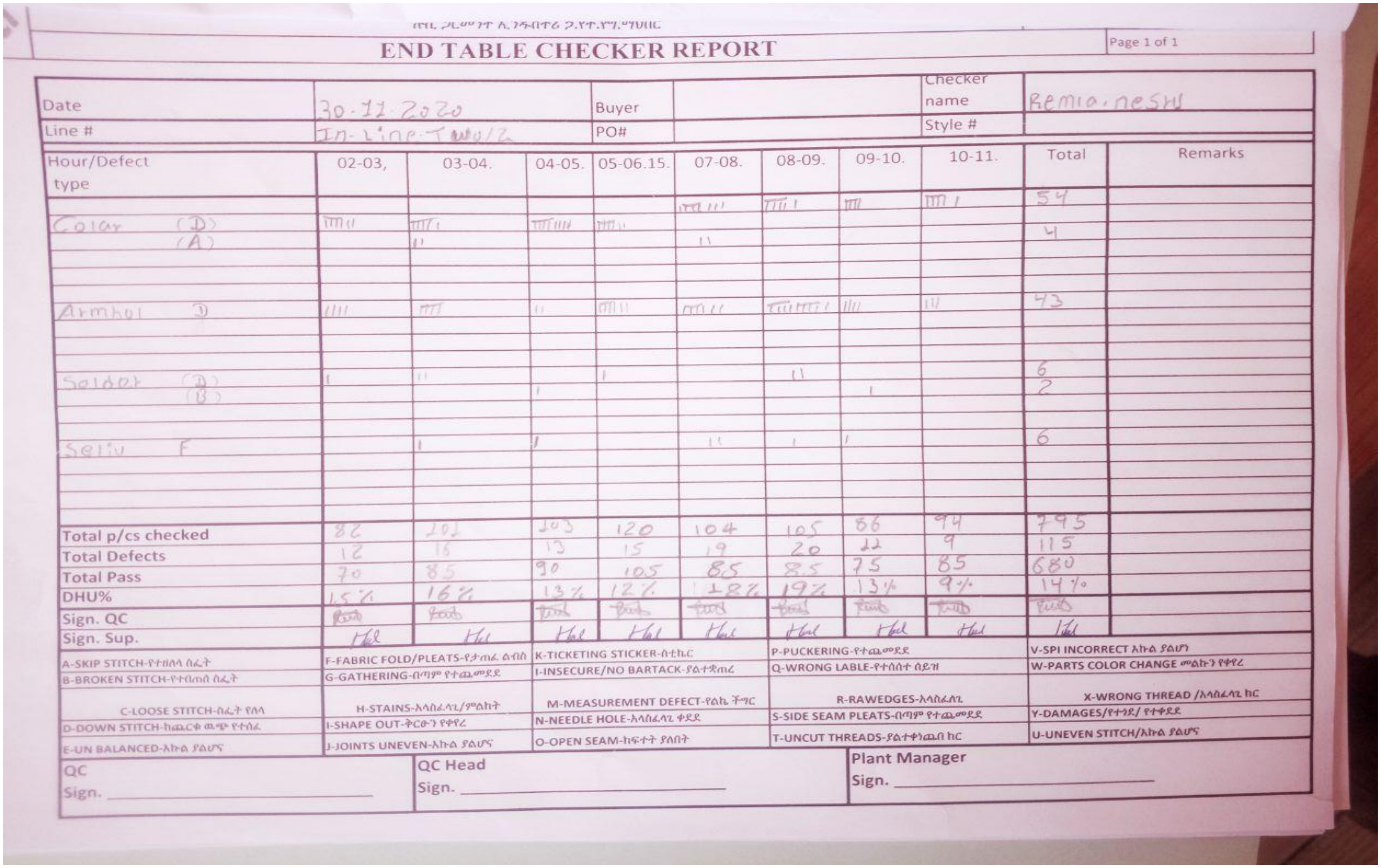
Appendix: A



Page 1 of 1

END TABLE CHECKER REPORT

Date	30-11-2020	Buyer		Checker name	Remia.neshi
Line #	In-Line-Two/2	PO#		Style #	

Hour/Defect type	02-03,	03-04.	04-05.	05-06.15.	07-08.	08-09.	09-10.	10-11.	Total	Remarks
Colar (D)									54	
(A)									4	
Armhol D									43	
Soldor (D)									6	
(B)									2	
Seliv F									6	
Total p/cs checked	82	101	103	120	104	105	86	94	795	
Total Defects	12	16	13	15	19	20	11	9	115	
Total Pass	70	85	90	105	85	85	75	85	680	
DHU%	15%	16%	13%	12%	18%	19%	13%	9%	14%	
Sign. QC										
Sign. Sup.										

A-SKIP STITCH-የተዘለለ ስፌት
B-BROKEN STITCH-የተበጠሰ ስፌት
C-LOOSE STITCH-ስፌት የላላ
D-DOWN STITCH-ከጨርቁ ወጭ የተሰፋ
E-UN BALANCED-እኩል ያልሆነ
F-FABRIC FOLD/PLEATS-የታጠፈ ልብስ
G-GATHERING-በጣም የተጨመደደ
H-STAINS-እላሰፊላጊ/ምልክት
I-SHAPE OUT-ቅርፁን የቀየረ
J-JOINTS UNEVEN-እኩል ያልሆና
K-TICKETING STICKER-ስቲከር
I-INSECURE/NO BARTACK-ያልተቋጠረ
M-MEASUREMENT DEFECT-የልኬ ችግር
N-NEEDLE HOLE-አላስፈላጊ ቀዳዳ
O-OPEN SEAM-ክፍተት ያለበት
P-PUCKERING-የተጨመደደ
Q-WRONG LABLE-የተሰሰተ ስይዝ
R-RAWEDGES-አላስፈላጊ
S-SIDE SEAM PLEATS-በጣም የተጨመደደ
T-UNCUT THREADS-ያልተቆነጨበ ክር
V-SPI INCORRECT እኩል ያልሆነ
W-PARTS COLOR CHANGE መልኩን የቀየረ
X-WRONG THREAD /አላስፈላጊ ክር
Y-DAMAGES/የተጎዳ/ የተቀደደ
U-UNEVEN STITCH/እኩል ያልሆና

QC Sign. ______
QC Head Sign. ______
Plant Manager Sign. ______

[illegible]

END TABLE CHECKER REPORT

Date	30.11.2020	Buyer		Checker name	Workie Tigabu
Line #	End line Two	PO#		Style #	

Hour/Defect type	02-03,	03-04.	04-05.	05-06.15.	07-08.	08-09.	09-10.	10-11.	Total	Remarks
Side seem	II		I	I	II	III	II	II	13	
front	I		I						2	
Arm hole F		III	II	II	I			I	9	
Planket			I		I				2	
Bottom D				I		II			3	
Shoulder (I)							I		1	
Collar (J)							I		1	
Total p/cs checked	73	88	95	109	89	90	79	88	711	
Total Defects	3	3	5	4	4	3	4	3	31	
Total Pass	70	85	90	105	85	85	75	85	680	
DHU%	4%	3%	5%	4%	4%	3%	5%	3%	4%	
Sign. QC	VII	VII	VII [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Sign. Sup.	Paul	Hel	Hel	Hel	Hel	Hel	Hel	Hel	Hel	

A-SKIP STITCH-[illegible]	F-FABRIC FOLD/PLEATS-[illegible]	K-TICKETING STICKER-[illegible]	P-PUCKERING-[illegible]	V-SPI INCORRECT [illegible]
B-BROKEN STITCH-[illegible]	G-GATHERING-[illegible]	I-INSECURE/NO BARTACK-[illegible]	Q-WRONG LABLE-[illegible]	W-PARTS COLOR CHANGE [illegible]
C-LOOSE STITCH-[illegible]	H-STAINS-[illegible]	M-MEASUREMENT DEFECT-[illegible]	R-RAWEDGES-[illegible]	X-WRONG THREAD /[illegible]
D-DOWN STITCH-[illegible]	I-SHAPE OUT-[illegible]	N-NEEDLE HOLE-[illegible]	S-SIDE SEAM PLEATS-[illegible]	Y-DAMAGES/[illegible]
E-UN BALANCED-[illegible]	J-JOINTS UNEVEN-[illegible]	O-OPEN SEAM-[illegible]	T-UNCUT THREADS-[illegible]	U-UNEVEN STITCH/[illegible]

QC Sign. ______	QC Head Sign. ______	Plant Manager Sign. ______

Appendix: B Defects from Lucy garment

Defect name	Code	Six month defects					
		May	June	July	August	September	October
Skip stitch(የተዘለለ ስፌት)	A	104	100	120	112	130	76
Broken stitch(የተበጠሰ ስፌት)	B	208	198	250	200	215	263
Loose stitch(የላላ ስፌት)	C	25	30	16	40	50	65
Down stitch (ከጨርቁ ወጭየ ተሰፋ)	D	1040	920	870	900	850	1010
Un balanced(እኩል ያልሆነ)	E	20	16	15	16	20	12
Fabric fold(የታጠፈ ልብስ)	F	312	300	250	320	315	400
Gathering(በጣም የተጨማደደ)	G	16	4	14	8	9	12
Stains (አላስፈላጊ/ምልክት)	H	12	6	12	6	6	12
Shape out(ቅርጹን የቀየረ)	I	32	5	6	3	4	5
Joints uneven(እኩል ያልሆነ)	J	14	4	98	6	5	6
Ticketing sticker (ስቲከር)	K	16	9	9	1	4	5
Insecure/no bartack(ያልተቋረጠ)	L	12	6	7	2	12	9
Measurement defect (የልኬት ችግር)	M	15	78	6	5	9	8
Needle Hole(አላስፈላጊ የተቀደደ)	N	6	9	5	6	6	9
Open seam(ክፍተት ያለበት)	O	5	6	9	8	5	9

Puckering(የተጨማደደ)	P	7	15	8	9	4	6
Wrong label(የተሳሳተ ሳይዝ)	Q	8	14	7	7	4	8
Raw edge(አላስፈላጊ)	R	9	20	9	6	12	4
Side seam pleat (በጣም የተጨማደደ)	S	15	16	6	5	9	5
Uncut threads(ያልተቀነ ጨበ ክር)	T	14	15	5	8	7	7
Spi incorrect(እኩል ያልሆነ)	V	16	16	3	9	8	6
Parts color change(መልኩን የቀየረ)	W	15	12	6	4	6	5
Wrong thread(አላስፈላጊ ክር)	X	14	45	5	7	4	8
Damage(የተጎዳ /የተቀደደ)	Y	22	58	8	6	5	6
Uneven stitch (እኩል ያልሆነ)	U	6	6	9	5	12	9

Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering (SMIE)

Industrial Engineering Program

Questionnaire for FMEA practices in apparel manufacturing firms

Dear respondent!

I am pleased to inform you that the aforementioned study aims to assess the FMEA practices in apparel manufacturing firms in Ethiopia. The study covers firm awareness about FMEA usage for reducing rejects and rework. For this purpose, we are approaching a number of organizations to participate in a survey relating to their experiences in implementing FMEA application practices. We would very much appreciate your participation since the research's success depends upon receiving the maximum number of responses. Your answer will be treated confidentially, and the information will only be used for this study.

We look forward to receiving your completed questionnaire as soon as possible and many thanks for your kind support and co-operation.

Yours sincerely,

Alemayehu Tsegaye

Section A: Demographic information Please tick (√) in appreciate the box

Your position	☐ Owner	☐ CEO	☐ Senior manager	☐ Manager	☐ Other (please specify):
Gender	☐ Male	☐ Female			
Your Age	☐ 21 – 30	☐ 31 – 40	☐ 41 – 50	☐ More than 50	
Firm Experience	☐ < 5 years	☐ 5 - 10 years	☐ 16 – 20 years	☐ 11 – 15 years	☐ More than 20 years
Number of permanent employees	☐ 5 - 49 employees	☐ 50 - 100 employees	☐ 101 - 150 employees	☐ 151 - 200 employees	☐ More than 201 employees

Section B. Interview Questions

To gather insights from the experts regarding the use of FMEA in the apparel industry:

1. Introduction:

- Can you please introduce yourself and provide a brief overview of your experience in the apparel industry?
- Have you had any exposure or experience with FMEA methodologies in your professional career?

2. Knowledge and Understanding of FMEA:

- How would you define FMEA (Failure Mode and Effects Analysis) in the context of quality management?
- What is your understanding of the purpose and objectives of FMEA?
- How familiar are you with the application of FMEA in other industries, such as manufacturing or automotive?

3. Current Usage of FMEA in the Apparel Industry:

- In your experience, how commonly is FMEA practiced in the apparel industry?
- Have you personally encountered any instances where FMEA was used in the apparel industry? If yes, could you provide some examples?

4. Suitability of FMEA for the Apparel Industry:

- Considering the dynamic and fast-paced nature of the apparel industry, do you think FMEA is a suitable tool for identifying failure modes and improving product quality?

- What are the unique challenges in implementing FMEA in the apparel industry, if any?
- Are there any specific aspects of the apparel industry that might require adaptations or modifications to the traditional FMEA framework?

5. Potential Benefits and Limitations of FMEA in the Apparel Industry:

- In your opinion, what are the potential benefits of using FMEA in the apparel industry, particularly in terms of reducing rejects and improving product quality?
- Are there any limitations or drawbacks that you foresee in implementing FMEA in the apparel industry?

6. Customization and Integration of FMEA in the Apparel Industry:

- How do you think the FMEA framework can be customized to better align with the unique characteristics of the apparel industry?
- Do you have any suggestions on integrating FMEA with other quality improvement methodologies or tools in the apparel industry?

7. Challenges and Barriers to Implementing FMEA in the Apparel Industry:

- What are the potential challenges or barriers that might hinder the successful implementation of FMEA in the apparel industry?
- Are there any specific resources or support that would be required for organizations to adopt FMEA effectively?

8. Education and Awareness:

- Do you think there is a need for increased education and awareness about FMEA in the apparel industry? If yes, how can industry professionals be better educated about the benefits and application of FMEA?

9. Success Stories and Best Practices:

- Have you come across any success stories or best practices where FMEA was effectively implemented in the apparel industry?
- Are there any specific recommendations or lessons learned from those success stories that can be shared?

10. Future Outlook:

- How do you see the potential adoption and usage of FMEA evolving in the apparel industry in the coming years?
- What do you think are the key factors that would drive or hinder the widespread adoption of FMEA in the apparel industry?

11. Closing Remarks:

- Do you have any additional comments or insights regarding the use of FMEA in the apparel industry?
- Is there anything else you would like to share that we haven't covered in this interview?

Appendex: Details of the eperts for the study

Details for 12 experts in the context of the use of FMEA in the apparel industry:

1. Expert A:

- Quality Control Manager at a leading apparel manufacturing company.
- Over 15 years of experience in quality assurance and process improvement in the apparel industry.
- Familiar with FMEA methodologies and their applications in manufacturing and supply chain management.

2. Expert B:

- Production Manager at a high-end fashion brand.
- 10 years of experience in overseeing production processes and ensuring product quality in the apparel industry.
- Limited knowledge of FMEA but interested in exploring its potential benefits.

3. Expert C:

- Process Improvement Specialist at a textile manufacturing facility.
- 8 years of experience in identifying process bottlenecks and implementing improvements in textile production.
- Familiar with FMEA methodologies from previous work in the automotive industry.

4. Expert D:

- Quality Assurance Manager at a global apparel sourcing company.
- 12 years of experience in managing quality control processes across multiple apparel suppliers.
- Limited knowledge of FMEA but interested in learning about its applications in the apparel industry.

5. Expert E:

- Fashion Designer and Owner of a sustainable clothing brand.
- 10 years of experience in the apparel industry, specializing in design and product development.
- Limited knowledge of FMEA but curious about its potential impact on product quality.

6. Expert F:

- Supply Chain Manager at a sportswear manufacturing company.
- 7 years of experience in managing supply chain operations and ensuring product quality in the apparel industry.
- Familiar with FMEA methodologies and their applications in supply chain risk management.

7. Expert G:

- Research and Development Manager at a textile research institute.
- 10 years of experience in conducting research on textile materials and processes.

- Limited knowledge of FMEA but interested in exploring its potential applications in textile innovation.

8. Expert H:

- Quality Assurance Analyst at a fast fashion retailer.
- 5 years of experience in conducting quality inspections and implementing quality control measures in apparel production.
- Familiar with FMEA methodologies and their applications in quality improvement.

9. Expert I:

- Operations Manager at a mass-market apparel manufacturing company.
- 8 years of experience in managing production operations and optimizing manufacturing processes in the apparel industry.
- Limited knowledge of FMEA but interested in exploring its potential benefits.

10. Expert J:

- Sustainability Manager at a fashion industry association.
- 6 years of experience in promoting sustainability practices in the apparel industry.
- Familiar with FMEA methodologies and interested in exploring their potential for improving sustainability performance.

11. Expert K:

- Textile Engineer at a research and development center.

- 7 years of experience in developing textile materials and technologies for the apparel industry.
- Limited knowledge of FMEA but interested in understanding its potential applications in textile innovation.

12. Expert L:

- Process Engineer at a garment manufacturing company.
- 9 years of experience in optimizing manufacturing processes and ensuring product quality in the apparel industry.
- Familiar with FMEA methodologies and their applications in process optimization.