A Novel Hybrid Approach of QFD- Monte Carlo – DMAIC For Risk Prioritization in Textile Sector

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Dedication

This remarkable accomplishment is dedicated to my parents and siblings, whose unwavering love and support provided the foundation for its creation.

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I would like to convey my sincere thanks to Allah Almighty for the many favors and guidance that have been fundamental to my progress in completing this thesis. I begin my quest with much humility and gratitude.

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Sufyan Sikander

ABSTRACT

In recent years, particularly in the aftermath of COVID-19 pandemic, there has been a drastic decline in the number of production orders in the realm of home textile industry. This abrupt decline in production volume has significantly contributed to an increase in competition within the industry, exacerbating the already-difficult task of maintaining customer satisfaction. As a result, it has become imperative for the industry to deftly navigate such ongoing challenges; therefore, this scholarly work delves into systematic approach to efficiently improve production processes in textile sector. It begins by understanding critical customer needs, including higher quality, on-time delivery, improved working conditions, cost-effectiveness, and safety audits within facilities. Thereafter, customer requirements are translated into technical specifications using the Quality Function Deployment (QFD). The study employs Monte Carlo simulation to prioritize risks and uses statistical tools like Pareto charts in Minitab software to analyse current risk conditions. As it is observed that home textile sector has remained an untapped domain, devoid of significant research, the application of this integrated approach in the home textile sector, and the commencement of research within textile industry at large, underscore the novelty of this study. Also, innovating beyond conventional DMAIC approach, this study pioneers a novel matrix that comprehensively encapsulates the entire spectrum of defects, transcending traditional matrices. Consequently, corrective measures suggested by experts and literature are implemented and evaluated in a pilot run, demonstrating the impact of improvements on the production processes. This research offers a structured, data-driven approach to enhance product quality, meet customer expectations, and mitigate prioritized risks in home textile manufacturing industry.

Keywords: Voice of customer (VOC); Quality function deployment; DMAIC; pareto chart; Monte Carlo simulation; solutions; cause and effect analysis.

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DMAIC	Define, measure, analyse improve and control.
VOC	Voice of customers
QFD	Quality function deployment
HOQ	House of quality
MCS	Monte-Carlo simulation
LP	Lean production
5S	Sort, set, shine, standardize, sustain
SMED	Single minute exchange of die
PDCA	Plan-do-check-act
FMEA	Failure mode and effect analysis
LT	Lean thinking

VSM	Value stream mapping
OEE	Overall equipment effectiveness
DMADV	Define, measure, analyze, design, verify
SS	Six sigma

CHAPTER 1: INTRODUCTION

The following topics are mentioned in this chapter: research background and goal of this study, industrial setting, research rationale and the objectives of the research. It also includes the investigation issue and presentation of the situation. The thesis structure is also supplied at this section's end.

1.1 Background

Over the past several years, the home textile industry has seen increasing emphasis on improving product quality, satisfying customer demands, and maintaining the safety and well-being of workers within production facilities. A full awareness of customer expectations, which are frequently stated as increased product quality levels, on-time delivery, improved working conditions, cost-effectiveness, and the enforcement of regular safety audits, has been of the utmost importance in this industry (Iqbal & Grigg, 2021).

Previous research makes it clear that the production process should be modified so that it corresponds with the client's actual requirements.Click or tap here to enter text. Research known as the Define, Measure, Analyze, Improve, and Control (DMAIC) study has been implemented in order bring about process improvement in the facility (Thomaidi et al., 2017). This was done to get a better alignment between the production goals and the expectations of the customers.

Listening to the Voice of the consumer (VOC) is the first and most important phase in the process. This step enables us to comprehend the genuine requirements of the consumer from every angle and to comprehend their preferences (Iqbal & Grigg, 2021). VOC analysis is a useful tool that can be used to discover and prioritize customer desires. This coincides with research emphasizing the benefits of adopting customer-centric approaches to harmonize production techniques within an organization (Ankar-Brewoo et al., 2022)

After that, the House of Quality tool of quality function deployment process has been utilized as proven to compare and reduce the gap that exists between the technical requirements of the organization and the requirements of the customers (Wambaugh et al., 2019). Thomaidi et al. (2017), stated that it is possible to use it as an efficient method for converting client requirements into technical requirements to guarantee that the facility is in alignment with the customer.

To analyze the relative importance of the technical requirements that are associated with various processes and to prioritize them in an efficient manner (Thomaidi et al., 2017) Monte Carlo simulation was utilized. Monte Carlo simulation is a helpful statistical technique that highlights the actual nature of criticality of the risks that are associated with various processes that lead to satisfied customer requirements (Li et al., 2016). Monte Carlo simulation is a useful tool for determining the nature of risks and quantifying them, which in turn assists in the process of making decisions regarding the prioritizing of risks (Hosseinzadeh et al., 2023).

The use of Monte Carlo simulation for risk prioritization is also consistent with the research approach of Paul Friedman. In their study, the authors mentioned the implementation of this tool in several different manufacturing sectors for the purpose of risk assessment, prioritizing, and mitigation (Paul Friedman et al., 2020).

Briefly, the purpose of this research is to demonstrate that the implementation of a customer-driven strategy inside the DMAIC framework can lead to improvements in production processes within the home textile industry. Through the implementation of the Voice of Customer analysis, Quality Function Deployment (QFD), and Monte Carlo simulation, objective is to not only improve product quality and the processes that are linked with it, but also to address cost-effectiveness, thereby contributing to the expansion of this business.

1.2 Industrial setting

The textile industry is the largest contributor to Pakistan's overall GDP, accounting for 8.5 percent. Additionally, it provides employment to 45 percent of the country's total workforce. Pakistan, being the fourth largest cotton producing nation globally, sources most of its raw materials for cotton yarn production domestically. This strategic arrangement significantly enhances the cost-effectiveness and profitability of the cotton yarn industry in Pakistan. These contributions are sufficient to substantiate the fact that the prosperity of Pakistan is heavily reliant on the textile industry. Extensive research is necessary to improve and advance the manufacturing sector.

1.3 Research Rationale

Ensuring the provision of high-quality products and services to customers is the primary obligation of any manufacturer. To achieve this objective, it is crucial for the industry to establish high quality standards that aim for minimum defects and a minimal rework ratio. This will help reduce additional production costs and ensure timely delivery of the product to the client. Each customer representative that visits the industry for assessment often prioritizes the quality of the products, competitive pricing, a clean and safe working environment, and on time delivery. Therefore, the industry must consider the following aspects to get an edge in the competitive climate of the Pakistani textile sector. The objective of this research is to use the DMAIC approach in the home textile sectors of Pakistan to determine the primary factor influencing buying customers, assess the present situation, and provide solutions for improved outcomes.

1.4 Research Objectives

The study's objective is to produce an effective methodology that can highlight the current state of the industry and then provide proposed solutions for improvement. This thesis will address following goals mentioned:

- To define the actual requirement of the customer that should be considered.
- To translate the customer requirements to the technical requirements of the home textile industry.
- To identify the potential risks related to the technical requirements.
- To prioritize the risks associated with the manufacturing process and highlight the critical risks associated with the manufacturing process.
- To determine and improve the current state of the prioritized risks.

1.5 Research Problem

The race and competition of getting a higher share of the market has increased a lot in the current century. Especially after the higher inflation rate across the world due to covid-19, buying power of most of the consumers of the world has decreased significantly in last 3 to 4 years (Puig et al., 2022). So, this competition is working as a driving force for all the manufacturing companies to improve the quality of the product, timely shipments, cost minimizations making diverse products in shorter delivery times and many more. So, quality products in the specified time are now essential to retain their customers.

Keeping a customer-centric approach to fulfill customer desires for satisfaction contains immense importance to survive in the market. Listening to the voice of the customer and aligning processes accordingly can aid to achieve small improvements with larger benefits in terms of customer satisfaction. In a textile production process, there are several procedures through which a product passes before reaching carton packing like cutting, stitching, and several quality checks. During all these production processes, there are several risks associated with them related to quality of the product, production and the factors affecting it, machine maintenance, workplace safety & environment and resource management.

To cope with these problems, this research deals with the problem of high-quality defect ratio that increase the rework and wastage of the product that as a result increases the cost of making a product and the time it takes to make the product in the home textile sector. There are diverse types of textile industries specialized in making several kinds of products. These types include Denim industry, knitwear, hosiery, home textile, apparel, towel, and shoes industry. As the product nature, number of operations and type of operation to manufacture the product are different in every industry, problems related to quality defects and their ratio is also pretty much different from each other. Therefore, this research tends to apply DMAIC methodology on the highlighted requirements of the customer that are working with the several home textile sectors of Pakistan for completing their order.

1.6 Problem Statement

Home textile sector of Pakistan have been facing a significant decline in the manufacturing orders after covid-19 as the buying power of the consumer got effected. Due to this decline in orders, it is necessary to gain a competitive advantage over the other textile industries to survive in the market. Competitive advantage can only be gained by using a customer centric approach to align the industry goals and manufacturing processes to the desires of the customer. It is important to identify and prioritize risk related to different departments that can affect customer satisfaction and further minimize them to bring improvement in the manufacturing facility.

1.7 Thesis Structure

The first chapter of this research offers an overview of the research's subject matter, including aspects such as the research's background, objectives, rationale, aims, and the research issue it seeks to address. Furthermore, it highlights the significance of the industry's setting and the impact that the research has.

The second chapter will be based on a comprehensive examination of the pertinent prior research. The scope of the research will include the theoretical framework, previous studies undertaken by researchers on the topic under discussion, and the application or significance of this research to the company.

The third chapter will cover the research methods. This talk will primarily concentrate on the research paradigm, research environment, and study design. Furthermore, it will provide the justification for using this research approach. Furthermore, it will illuminate the limitations imposed on the study methodology.

The fourth chapter of the thesis will provide a comprehensive examination of the findings, their analysis, and the subsequent interpretations and arguments.

The conclusion is included in the last and fifth chapters. It will give a summary of the investigation carried out throughout the research. Furthermore, it will elucidate the theoretical foundations and practical advancements that the study has provided. Furthermore, it will provide insight on the constraints of the study and provide guidance for future directions that other scholars should pursue.

The last portion will focus on the compilation of references, appendices, and questionnaires.

CHAPTER 2: LITERATURE REVIEW

2.1 GENERAL

This chapter focuses on assessing the current corpus of knowledge pertaining to the subject matter of this investigation. Furthermore, it also examines the existing research deficiency that requires reduction, the theoretical framework that the study will rely on, and the specific problems that this study aims to answer.

2.2 EVALUATING EXISTING KNOWLEDGE AVAILABLE ON THE RESEARCH

2.2.1 Application of DMAIC methodology and its evolution

In the modern era, all industries and businesses strive to attain high quality and efficiency. Management is dedicated to ensuring the production and delivery of flawless products, solutions, or services (Hewan Taye Beyene & Advisor, 2016). This involves promoting the concept of getting things right the first time and eliminating defects, as well as providing training and motivation to employees. Environmental protection is also integrated into all activities, and staff members are actively involved in achieving organizational excellence as narrated by (Girmanová et al., 2017).

Companies and organizations generate waste either directly or indirectly throughout the production process. It is crucial to eliminate waste as it is a significant contributor to increased costs and decreased productivity within companies, posing a threat to their long-term sustainability (Makwana & Patange, 2021).

In recent years, the SS technique has gained significant popularity and is widely used in numerous organizations and sectors (Maryani & Hardi Purba, 2021.). In the late 1980s, the Motorola Company first used this methodology, which utilized the acronym SS to describe the process for assessing flaws and enhancements in quality (Kurnia et al., 2020). Other firms, including GE, 3M, and AlliedSignal, also played a leading role in adopting the SS technique. This adoption resulted in significant cost savings, amounting to millions of dollars starting from the 1990s (Ajmera et al., 2017) .

The Six Sigma (SS) methodology consists of two approaches: DMAIC (Define, Measure, Analyze, Improve, Control), which is used to improve existing products or processes, and DMADV (Define, Measure, Analyze, Design, Verify), which is used to design and implement novel processes or products with a focus on achieving high performance in Six Sigma (Kurnia et al., 2020; Makwana & Patange, 2021; Baptista et al., 2020)

Lean Production (LP) was initially used inside the Toyota Production System(Makwana & Patange, 2021). It was created as a novel mindset that promotes the reduction or elimination of operations that do not add value, while also enhancing the efficiency of activities that bring value (Makwana & Patange, 2021). The techniques and strategies used in LT (Lean Thinking) includes just-in-time, Kaizen, supply chain management, Kanban, and quality circle (Maryani & Hardi Purba, 2021)

Baptista et al. (2020) have stated that different industries utilize a range of tools and techniques, including VSM (value stream mapping), 5S (sort, set in order, shine standardize, sustain), visual management, Kaizen, standard work, and PDCA cycle. These methods aid in identifying waste, reducing waste, and enhancing overall equipment efficiency and production process efficiency. Several firms are adopting Lean methodologies due to their ability to meet customer demands, enhance labor efficiency, reduce inventory levels, and maximize equipment use in the textile sector (Akram et al., 2023)

Ahmad et al. (2018) investigated value stream mapping technique to identify inefficiencies, employed Total Productive Maintenance (TPM) to enhance quality, increase production, and minimize mechanical equipment failures in a manufacturing organization. The benefits of various systems such as Standard work, 5S, Visual Management, Kanban, Line balance, OEE, and SMED have been extensively examined. This study paper serves as a comprehensive and supportive resource for the pursuit of lean manufacturing (Habib et al., 2023)

Kurnia et al. (2020) employed the DMAIC methodology to decrease defects and enhance the efficiency of elastic tape manufacturing firm. They conducted a cause-and-effect diagram analysis to determine the underlying source of the difficulties. It has been determined that DMAIC is a very methodical strategy for enhancing quality, whereas cause and effect matrix, quality analysis, and Fault Detection Control (FDC) can assist in identifying potential causes of failure (Kurnia et al., 2022) .

Barbosa et al. (2014) study has shown that the DMAIC model has a key role in enhancing the value of the process and improving the competitiveness of the aviation painting shop. The objective of this research is to minimize the duration of the painting cycle, ensure that design tolerances are met consistently, achieve repeatability and standardization, minimize the number of individuals involved in the activity, save costs by using template materials, and enhance the reliability of the plotting procedures. The researchers utilized a DMAIC model based on laser-plotting systems and determined that this approach enhances the process and boosts the company's competitiveness.

Vinodh et al. (2016) demonstrates the implementation of DMAIC methodology to minimize weld flaws in valve components. The researchers employed the VSM approach to analyze the present condition and utilized the Taguchi method to optimize the weld process parameter. By applying DMAIC, they have successfully decreased weld faults by 42% and achieved cost savings of INR 250,000.

Marques & Matthé (2017) utilized the DMAIC approach to enhance the six-sigma level and diminish the rate of rejection of the window handle at an aluminum die casting manufacturing firm in Portugal. Following meticulous Pareto analysis and cause and effect research, they identified four pivotal elements accountable for the elevated rejection rate. The experiment's design was conducted using a 24 complete factorial approach, and the procedure was later optimized to decrease the rejection rate. Following a successful implementation, the company's SS level has risen from 2.3 to 3.1. The number of defects managed fell from 1.47 to 0.36, and the rate of rejection reduced from 79% to below 25%.

Ishak et al. (2019) utilized the DMAIC model to enhance the six-sigma level of the process of thermoforming firm and employed DOE methodologies to optimize the process. They have collected three months' worth of production data to assess the present degree of Six Sigma (SS) in the organization. The current sigma level was determined to be 3.64095. The design of experiment approach was employed to ascertain the substantial impact of the elements influencing the manufacturing process. Following the optimization of the process and the effective deployment of the DMAIC model, it has been determined that the firm has achieved an enhanced SS level of 4.566704.

The DMAIC technique is employed as a strategic way to attain process enhancement and excellence inside an industrial company. It involves the identification and analysis of vital criteria, which are crucial for increasing product quality and achieving success (Supriyati & Hasbullah, 2020). The DMAIC methodology is a useful problem-solving strategy that may be used to address machine malfunctions. The DMAIC analysis is utilized to enhance the capacity of the hot-rolled mill machine and eliminate downtime in a specific process within the aluminum sector (Marques & Matthé, 2017). Process control is a technology designed to efficiently gather and evaluate data, enabling performance monitoring (Mkwanazi et al., 2021). The control chart integrates sophisticated term chart data with statistical control data to detect process alterations over time that are unlikely to be attributed to random occurrences (Tekletsadik, 2023). Control charts are highly advantageous in manufacturing, management, and service sectors. They offer prompt feedback on crucial variables (Bajaj et al., 2018).

A Pareto diagram may be used to categorize and analyze the various causes that contribute to a rise in nonconforming items. FMEA is a methodical examination of failure modes with the goal of averting failures (Mutlu & Altuntas, 2019). It is a proactive procedure conducted prior to implementing new or modified goods or operations. The ultimate objective is to entirely eradicate all instances of failure. The immediate objective is to reduce or completely eradicate failures (Ishak et al., 2019). Research learning involves studying and analyzing past research that is relevant to the field of automobile component research. Six Sigma is a methodical and customer-focused approach that attempts to enhance both the efficiency and the quality of processes, goods, and services (Hewan Taye Beyene & Advisor, 2016). It achieves this by utilizing statistical tools and the scientific method to evaluate data and make informed decisions (Ajmera et al., 2017)

The application of the Six Sigma DMAIC methodology can enhance the efficiency and quality of a manufacturing enterprise. The methodology provides a systematic approach to identify, measure, analyze, improve, and control the reasons for variation in operational processes. By optimizing the operation variables and implementing effective control plans, the study aims to improve and sustain the performance of the process yield. Six Sigma enhances the performance of the important operational process, resulting in more efficient use of resources, less variability, and a uniform high-quality of the process output (Akram et al., 2023).

Hasan et al. (2019) have studied the manufacturing process analysis and explored the potential application of the DMAIC technique to the textile procedure. The main topics addressed in this article are the feasibility of choosing and executing Six Sigma initiatives and the methodologies for ongoing enhancement after project completion. To apply the Six Sigma quality system, a systematic and continuous improvement process method is devised, considering all aspects of the manufacturing process. The chosen model is suitable for small to medium-sized enterprises in terms of practicality and cost-effectiveness. It is seen as a solution that will yield favorable outcomes by examining the interactive aspects of knowledge management (KM) concepts with the Six Sigma deployment process. Additionally, this study explores how KM concepts, including updated elements, can be integrated into the structured, systematic, and efficient framework of Six Sigma for project deployment. The initial step involves analyzing several existing methodologies that pertain to the integration of Six Sigma and Knowledge Management (KM) to determine the potential benefits and advantages.

Abbes et al. (2022) presents a technique for examining a procedure in a clothing production company. Through the implementation of the DMAIC Six Sigma approach, they anticipated uncovering the primary underlying factors responsible for delivery delays. The project report presents a systematic approach for establishing, quantifying, evaluating, enhancing, and managing the delivery metric.

The job's main objective is to mitigate faults, hence reducing the rates of rejection and rework (Mkwanazi et al., 2021).Click or tap here to enter text. This study offers a set of suggestions for improving waste management and control in the garment sector, specifically for shorts and trousers. The guidelines are based on the application of six sigma approaches. The DMAIC methodology is implemented and tested in the Karle garment industry to identify the main causes of defects and take corrective actions. The percentage of defective products is compared with that before the adoption of corrective actions, resulting in an increase in the sigma level from 2.8 to 3.38. The use of the DMAIC approach of six sigma to reduce the incidence of faults in a specific textile industry. This is a systematic strategy aimed at minimizing defects using the five steps of the DMAIC methodology, which are define, measure, analyze, improve, and control (Habib et al., 2023).

2.2.2 Application pareto analysis & cause and effect analysis

The Pareto chart is an effective tool for quality control and issue identification, as it ranks the probable effects from highest to lowest. The Pareto principle, also referred to as the "80/20 rule," states that 80 percent of abnormalities in a system are caused by a specific 20 percent. Merely 20 percent of the potential factors. The primary objective is to provide 20 percent of resources and attention to the most significant reasons due to constraints in both resources and time (Bajaj et al., 2018).

Erdil (2019) additionally stated that a Pareto chart is constructed by scaling a histogram into a vertical bar graph. Subsequently, the underlying factors are visually presented in a prioritized manner, facilitating comprehension, and directing focus towards the accurate issue.

Cause-and-effect diagrams, often known as causal diagrams, were first proposed by Ishikawa in 1968 (Bajaj et al., 2018). Pareto analysis is employed to prioritize the fundamental causes, with the outcomes of a Pareto analysis often presented in a Pareto chart (Gobena & Kumar, 2008). The Pareto chart displays a range of elements or issues in a ranking manner (Gobena & Kumar, 2008).

Ishikawa (1976) introduced cause-and-effect diagrams as a visual representation of the underlying reasons leading to a certain occurrence (Hossen et al., 2017). The cause-and-effect diagram has been widely popular for identifying the underlying causes of many situations since its introduction (Islam et al., 2017).

A cause-and-effect diagram, also referred to as a 'fishbone' diagram, is a useful tool for brainstorming and categorizing the causes of an issue. It offers a more organized and systematic approach compared to other brainstorming tools for identifying the origins of an issue (Tekletsadik, 2023).

The Pareto chart is a valuable tool for analysing non-numeric data, such as causes, types, or classifications. It helps prioritize areas where action and process modifications should be concentrated. This chart is widely employed to identify downtime and other forms of wastage. The system uses bar graphs to categorize problems according to their frequency, severity, type, or source. It then presents them in a size-based presentation, highlighting the most critical issues. The data is ranked in descending order of frequency of occurrences (Islam et al., 2017). The concept was formulated by Vilfredo Pareto, an Italian economist and sociologist, who performed a study in Europe during the early 1900s focusing on the distribution of income and poverty. The concept of the 'vital few and trivial many' is a universally recognized premise. The 80/20 rule was created based on this premise, with the following significance. A considerable proportion of the outcomes for many phenomena may be attributed to a small fraction, specifically 20%, of the underlying causes (Erdil, 2019; Gobena & Kumar, 2008; Hossen et al., 2017; Islam et al., 2017).

Quality is a measure of both the legitimacy of a company and the happiness of its customers. Each industry tries to ensure a superior standard of product (Jou et al., 2022). Defects are crucial in determining the efficiency of the clothing production plant. If a problem is discovered at the most recent inspection, it indicates that the faulty product has progressed significantly before the deformity is detected (Erdil, 2019). The expenses incurred in the production of a defective garment are entirely wasted, as the product is not eligible for export (Patil et al., 2017). Modifications can sometimes make damaged goods suitable for export, but this incurs additional costs that are not beneficial to a factory owner.

Abdus Samad et al. (2018) examined the seven wastes of lean manufacturing and the implementation of lean manufacturing principles in the textile sector. The author employed many tools and techniques such as Gemba, Waste Relations Matrix, Cause & effect analysis, ranking, and statistical methods to identify and analyse the seven wastes in lean manufacturing. An analysis is conducted on the seven major inefficiencies in lean manufacturing, and it is determined that defects represent the most important wastage in the textile production business. The author proposed a set of pertinent lean strategies to effectively remove or decrease faults. Embroidery flaws or imperfections occur when the material hinders the penetration of the sewing needle. This depends not only on the regions inside the cloth, but also on factors such as needle count, needle size, sewing machine setting, and stitching thread.

H. E. Kim (2021) seeks to address the quality issues in the knitting industry by identifying the main causes of 80% of the defects and giving effective solutions for the most significant ones. To address the quality issue, data was collected by direct observation, interviews, check sheets, and records. These data were then analysed using the Pareto approach and through focus group discussions. Upon analysing the data, the four significant textile faults (Needle line, Hole, Thread variation, and Lycra jump) have been identified. It is imperative to address these textile defects to reduce the rejection rate by 80%. The analysis revealed that the current rejection rate of 7.87% may be reduced to 1.574%, resulting in a significant decrease of 6.296%. This indicates that the monthly decrease in the price of fabric denial online is related to a drop of 5533.6 kg, which significantly impacts the entire output in the region. The research has identified a set of recommendations, countermeasures, and standard operating procedures (SOPs) that are recommended for implementation by the company.

In their review, Gupta 2016 highlighted the significant potential of utilizing Six Sigma (DMAIC) and Lean Six Sigma (LSS) in Manufacturing Systems to effectively minimize or eliminate production errors (Gupta, 2016). Implementing Six Sigma (DMAIC) and Lean Six Sigma (LSS) offers significant benefits in reducing or eliminating manufacturing faults (Mughal, Khan, Kumar, et al., 2020). It was discovered that the prevalence of faulty garments produced in the sewing room varied depending on the design of the garment, ranging from 7.3% to 27.5%. Among the many defects that occur in fabric, it is opening, and oil stains account for 18 to 43% of the total defects across diverse designs. Hence, doing a meticulous material examination before sewing would effectively reduce defects to a substantial extent (P P, 2020).

Existing research demonstrates the importance of Pareto analysis and cause-and-effect diagram as crucial tools for analysing and identifying faults in manufacturing or process industries. Effectively implementing them minimizes unproductive downtime and maximizes equipment uptime, resulting in enhanced production over an extended duration. Pareto analysis and cause-and-effect diagram are considered fundamental methods in the field of overall quality management (Patyal & Maddulety, 2015).

2.2.3 Monte Carlo simulation and its application

Monte Carlo Simulation is a specific form of simulation that entails creating distributions by means of random sampling across inputs. This simulation technique has several uses in project risk management. H. Wang et al. (2014) examined how uncertainty and ambiguity, specifically in terms of iteration and overlapping, affect the scheduling of product development projects. Similarly, Tokdemir et al. (2019) introduced a method that utilizes Monte Carlo Simulation to evaluate the risk of project delays. In contrast, EROL et al. (2016) examined how lean manufacturing approaches affect both the duration and variability of projects.

Risk identification is a crucial step in the initial phase of the risk management process as it establishes the foundation for analysis. Several contemporary studies primarily concentrate on the identification of hazards in building projects. Qazi & Akhtar (2020) introduced a method that evaluates risks based on the associated decision problem and subsequently chooses the most effective strategies to mitigate those risks at the beginning of a project.

On the other hand, Derakhshanfar et al. (2019) created a terminology and classification system for delay risks by incorporating data from multiple articles and conducting qualitative analysis. The study employed a questionnaire survey to identify the primary risks associated with project delays in the construction industry in Australia. The study also examined how these risks interacted at various stages of the project. Furthermore, S. Y. Kim & Le (2021) conducted an analysis of the relevant literature and put out a methodology for categorizing risks in Public Private Partnership (PPP) transportation projects.

Many studies in the risk analysis stage utilize the Monte Carlo Simulation technique. Ünsal-Altuncan & Vanhoucke, (2024) utilized Monte-Carlo Simulation to propose new techniques for monitoring projects with uncertain durations. K. Wang et al., (2015) presented a unique formulation and algorithmic approach to minimize operational expenses in a building energy system, and subsequently employed Monte-Carlo Simulation to verify the findings.

The use of the 95th percentile in chemical risk assessment has a well-established background in relation to risks who have higher exposure of those who have higher amounts of the chemical in their bloodstream due to a combination of exposure and toxicokinetic (Bode et al., 2016; Qazi & Akhtar, 2020).

Koulinas et al. (2021) conducted a study on the Monte Carlo risk prioritization of engineering projects using various percentile values. The simulation results provide the following values for the overall project duration: a minimum of 569.91, a maximum of 677.38, and a mean of 618.78. Additionally, the standard deviation of the make span is calculated to be 20.72. These figures demonstrate that the constructor is unable to finish the project within the original project period of 562 days, as calculated by the Critical Path Method (CPM). Furthermore, the project has an only 20% likelihood of completion within the strict time limit of 600 days. Additionally, there is a 95% probability that the total duration of the project will be less than 656.09 days. Furthermore, the values obtained at certain percentiles (5%, 25%, 50%, 75%, 90%, and 95%) were identified (Koulinas et al., 2021). The technique we used, which combines multicriteria analysis and simulation, reinforces the notion that the project is in danger of not being completed within the specified time constraints.

Hosseinzadeh et al. (2023) evaluated the health hazards faced by workers exposed to BTEX. The standard risk assessment approach was used, and Monte Carlo simulation was carried out using Crystal Ball software with 10,000 trials to assure the stability of the simulation. The risk assessment findings are conveyed by statistical values, primary percentiles of 90% & 95%, and probability distributions. A sensitivity analysis was conducted to determine the key input parameters in the predicted risk. Sensitivity analysis determines the impact of input parameters on the output of the model. A sensitivity number larger than zero signifies a positive connection with the risk outcome, whereas a sensitivity value less than zero shows a negative association with the risk result. The parameter's influence on the model's output intensifies with heightened sensitivity.

2.2.4 Risk analysis in manufacturing industries.

Risk analysis is conducted to apply risk management measures, mitigate risks, reduce occupational accidents, and enhance the dependability of production and service systems (Mutlu & Altuntas, 2019). In respect to the type and extent of risk, the primary phases of risk analysis are as follows: identifying the threats and risks, understanding the cause-and-effect relationships, including exposure and vulnerabilities to risks, and characterizing the potential risk (Ferraz et al., 2017).

Willquist & Törner (2003) categorized the safety analysis techniques used in evaluating occupational hazards in the food production business as: tendentiously reactive, impartially proactive, and tendentiously proactive. (Stave & Törner (2007) classified the elements that lead to accidents throughout the operational phases in food production systems as either visible or unseen risk factors. In addition, Zafra-Cabeza et al. (2008) developed a risk analysis action plan by identifying circumstances of ambiguity in the cogeneration system to mitigate potential losses resulting from uncertainty and lack of knowledge.

Kuşan et al. (2017) conducted a study on various risk analysis software used in construction management. The software examined included @Risk, CRIMS, Decision Pro, Crystal Ball, iDecide, Monte Carlo, Precision Tree, Predict Risk Analyser, Risk+, Open Plan Professional, REMIS, and Ris3Risgen'. Furthermore, a comprehensive examination was conducted on the risk analysis methods often used in construction engineering, including benefit analysis, probability tree analysis, sensitivity analysis, and Monte Carlo simulation techniques.

(Goerlandt & Reniers, 2016) conducted a comprehensive review of the available research in the area and specifically focused on the limited number of studies that have studied the reliability and precision of the quantitative risk analysis methodologies presently used in risk assessment procedures.

Akyildiz & Mentes (2017) used fuzzy Analytic Hierarchy Process (AHP) and fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) techniques to evaluate the hazards associated with cargo vessel accidents. In addition, Zwirglmaier et al., (2017) devised a technique that enables the identification of prospective failure scenarios, their associated adverse consequences, and the odds of these failure scenarios occurring. The process of human reliability analysis (HRA) and probabilistic risk assessment (PRA) was used to convert human mistakes into digital format. Additionally, a Bayesian network model was implemented to identify the cognitive factors that contribute to human errors. Rostamzadeh et al. (2015) introduced a risk analysis methodology that focuses on attributes that have a direct influence on accidents in the construction sector.

2.2.5 QFD and its application

QFD, which was created and implemented at the Mitsubishi Heavy Industries Kobe Shipyard in Japan during the early 1970s, is a quality management system that is focused on meeting customer needs and preferences (Opaleye et al., 2020). This phenomenon has been adopted by a much greater number of companies in the United States since the mid-1980s Implementing QFD well may provide several benefits, such as reducing design costs and time to market, fostering collaboration across teams, and more (Camgöz-Akdağ et al., 2016). One defining attribute of the Quality Function Deployment (QFD) system.

The customer's voice is integrated into the marketing, R&D, engineering, and production stages of product enhancement. The translation process employs a graphical tool known as a House of Quality (HoQ) that combines the inputs (WHATs) of each stage with the outputs (HOWs) of that stage. The first stage of Quality Function Deployment (QFD) involves gathering data on client needs and assessing their respective significance. The relationship between customer requirements and design targets, as well as the customer's satisfaction with the company's product compared to its competitors and the current design target levels, is discussed in reference (Franceschini & Maisano, 2015).

Typically, during the early phase, the information included in the House of Quality (HoQ) is used to prioritize the design objectives and describe the desired levels of those objectives. Aydin et al. (2023) developed an approach that involves prioritizing design aims and expressing their relative relevance ratings. The obtained rating may be used as weighting factors-criteria in the Mult objective optimization problem, where numerous goals are consolidated into a single objective using the weighting factors.

MOSKOWITZ & KIM (1997) presented conventional Quality Function Deployment (QFD). The levels of design objectives for the destination are determined subjectively. Initially, comparable mathematical programming approaches to specify the desired levels of design objectives was proposed. Then study enhanced the approximation equations that describe the integration of design goals by including the subjective opinion of the designer, while linear regression models that are well-suited to the given data set was mentioned in the study. This is a dataset including customer and technical competitive assessment data. When a well-planned experiment is not deemed completely inappropriate, these impressions may still be valuable. The equations are used as constraints in the optimization problems to get the ideal values for the design objectives.

Quality is a fluid notion that refers to surpassing expectations. It encompasses a viable and enduring. There is a correlation between meeting customer expectations and a rise in consumer demands. Organizations rely on continuous advancements, creativity, and invention to effectively adapt to unpredictable changes and perspectives (Shi & Peng, 2020). Quality has emerged as a crucial factor in consumers' happiness and expectations when choosing between competing goods and services. Hence, comprehending and cultivating excellence is a pivotal factor that drives commercial triumph, expansion, and establishes a competitive advantage. Developing quality and effectively integrating it into the broader company plan leads to a significant return on investment (Aydin et al., 2023).

The House of Quality (HoQ) is used to collectively calculate the final-absolute weightings of the technical standards (Opaleye et al., 2020). The determination of precise weights for the technical criteria and their priority is a crucial aspect in the stages of Quality Function Deployment (QFD). One of the primary theoretical challenges in applying QFD is the consideration of multidimensional categorized data variables (Camgöz-Akdağ et al., 2016). The rating data of these categorical factors vary from individual to individual and from case study to case study. When prioritizing the technical needs, QFD examiners frequently fail to properly integrate the various information obtained from ordinal variables and omit some sections of QFD, HoQ. In each matrix structure of QFD, several heuristics have been established to mitigate variance, precariousness, and ambiguity. Errors made throughout the QFD processes, such as incorrect selection and simplification of rating ranks, improper implementation of methodologies, or failure to integrate diverse matrices, may lead to disappointment in the whole process(Shi & Peng, 2020).

QFD, or Quality Function Deployment, is a set of effective product development methods that originated in Japan. It aims to integrate the principles of quality control from manufacturing operations into the process of evaluating new products. The fundamental characteristics of QFD involve gathering market demands through the utilization of actual customer statements, referred to as the Voice of the Customer (VoC) (Shi & Peng, 2020).

QFD also emphasizes the implementation of multidisciplinary teamwork and employs a comprehensive matrix known as the "House of Quality" to convey information, strategies, and decisions. The benefits of implementing Quality Function Deployment (QFD) are outlined as follows (Opaleye et al., 2020)

- Minimizing design modifications
- Cutting design and manufacturing costs
- Enhancing quality
- Enhancing and prolonging customer pleasure

The phrase "voice of the customer" (VoC) refers to the explicit and implicit demands or desires of the consumer (Iqbal & Grigg, 2021). The customer's feedback may be obtained via several means, such as direct conversations or interviews, surveys, focus groups, customer requirements, observations, warranty data, field reports, complaint logs, and so on. The data is used to establish the necessary quality characteristics for a supply component or material to be integrated into the process or product (Iqbal & Grigg, 2021). The key aspects of QFD are its focus on meeting consumer demands by incorporating their direct feedback (VoC), its facilitation of collaboration, and its use of a comprehensive matrix for gathering information, generating ideas, and making choices. The matrix often referred to as the "House of Quality" is frequently used to fully implement Quality Function Deployment (QFD) (Shi & Peng, 2020)

Akao defines Quality Function Deployment (QFD) as a systematic approach to design quality that aims to meet customer satisfaction by incorporating their design requirements and key quality assurance criteria into the manufacturing process. Quality Function Deployment (QFD) is a method used to validate the quality of a design throughout the design phase of a product. Some researchers highlight that when QFD is performed well, it has shown a reduction in development time by 50% to 66%. This serves as a significant additional benefit (Phruksaphanrat & Tipmanee, 2010).

2.3 Research Gap

Upon extensive analysis of relevant literature, it becomes apparent that there is a notable lack of study in home textile manufacturing, particularly in relation to bedding items, crates, and coddlers. Although several studies have extensively examined process improvement approaches and the use of DMAIC concepts in the textile industry, most of this study has focused on denim, clothing, and garment production. The crucial difference is in the fact that home textile manufacture presents a specific range of difficulties, including various flaws, varied fabric characteristics, and diversified operational complexities, which have not been sufficiently addressed in the current body of literature.

Furthermore, there is a notable lack of research in the textile manufacturing field that utilizes Monte Carlo simulation, which creates an interesting gap in risk prioritizing approaches. Although this simulation approach has been widely used in many industries such as construction, supply chain management, and sustainability prioritization of risks, its application in the textile manufacturing field has not been fully explored.

In addition, the combination of Quality Function Deployment (QFD), Monte Carlo simulation, and DMAIC for comprehensive process optimization is an area that has not been well investigated in textile research. Although numerous studies have examined these approaches separately, there has been little research on their combined use specifically in the framework of textile manufacturing processes. The lack of extensive research hinders the creation of a strong framework that may effectively improve the quality, efficiency, and risk management techniques in the home textile business.

It is crucial to address these areas of study that are currently lacking to make progress in the field and provide practical insights for both practitioners and scholars. Gaining a more detailed comprehension of the distinct difficulties in home textile production, along with employing advanced techniques such as Monte Carlo simulation and integrated approaches involving QFD and DMAIC, will not only enhance scholarly discussions but also significantly enhance industry practices in this area of the textile sector.

2.4 Theoretical Framework

The DMAIC (Define, Measure, Analyze, Improve, and Control) approach, which was first created by W. Edwards Deming in the 1950s, serves as the theoretical foundation for this study. The standardized and data-driven approach to problem-solving that DMAIC offers is applied to a variety of situations and industries (Baptista et al., 2020; Akram et al., 2023) .

The framework incorporates Quality Function Deployment (QFD), which was first used in Japan in the late 1960s and refined by Mitsubishi's Kobe Shipyard in 1972 (Opaleye et al., 2020). In the first two stages of the DMAIC, QFD is essential for methodically identifying client needs and converting them into technical specifications. This guarantees that product specifications and customer demands are in line (Shi & Peng, 2020).

To handle risk and uncertainty in the DMAIC improvement phase, the framework also incorporates the Monte Carlo simulation approach, which was created in the early 1700s (Qazi & Akhtar, 2020). By quantifying and examining the effects of risk variables, Monte Carlo simulation offers a methodical way to prioritize risks.

Within the framework, the integration of these elements creates a sequential flow. The first step of the research is using QFD to understand client needs, which are then translated into technical specifications. Using a House of Quality, the link between these aspects is investigated. The next step involves prioritizing risks using Monte Carlo simulation, after which the improvement phase concentrates on resolving and minimizing the discovered risks.

This theoretical framework sets a systematic technique that specifically targets current research deficiencies and offers a thorough manual for professionals in the home textile sector. The study aims to enhance knowledge in process improvement methodologies specific to home textile manufacturing by integrating QFD, Monte Carlo simulation, risk prioritization, current condition analysis, and practical implementation of solutions in a systematic manner.

2.5 Research questions

1. What are the requirements of the customer?
2. What are the technical requirements that will aid to meet those customer requirements?

3 What are the specific risks that can affect negatively on meeting technical requirements?
4 What is the current state of the identified risks?

CHAPTER 3: METHODOLOGY

3.1 Method

In the methodology, first step is to understand the customer requirement to align the industry goals and objectives of the industry. So, the voice of customer is employed in the define phase of DMAIC methodology (Kurnia et al., 2022). In home textile, customer sends the customer to the marketing department that include what kind of product they are looking for with all the specifications. Then after sharing the samples of products the manufacturing company makes are shared. For successful award of order, auditors from the customer conducts audit of the facility to check the working conditions of the company, its quality standards and portfolio of successful orders. Certifications like ISO 9001, ISO 14001, Mold and moisture certification, Jacy penny audits also aid to satisfy customer related to facility environment. Those primary requirements from the customers are then related with the technical requirements of the company on order to meet voice of customer (VOC) through house of quality (Camgöz-Akdağ et al., 2016).

3.2 Define Phase

3.2.1 Voice of Customer

Voice of customer for this research is obtained from the different customer queries that came from the requirements that marketing department listens to when dealing with their customers of the specific region. To understand these customer (retailer) requirements in detail, semi structured expert interviews were carried out. For the interview, the question asked are shown below:

1. What are the requirements of the customer (retailer) from the product?
2. What are their evaluation criteria of customer for the manufacturing industry before awarding order?
3. What kind of concerns or complaints are faced from the retailer end?
4. What are the things that customer examines during their audit of the industry?

These questions were then asked from the experts of the fields from marketing department, production department, quality department and external audit associated with home textile industry of Pakistan. Interviewees were selected based on purposive sampling. The experts that were interviewed are given in Table 3.2:

Table 3.1 Summary of interviewees profile

Expert	Department	Experience	Worked in different textiles	Worked with different Customer brands
Expert A	Production	15 years	Yes	Yes
Expert B	Quality	28 years	Yes	Yes
Expert C	Marketing	21 years	No	Yes
Expert D	Maintenance	12 years	Yes	No
Expert E	Buying house auditor	11 years	Yes	No

The requirements are related to the different departments of the facility. These customer requirements were collected over the period of two months The Customer requirements that were determined are given below in the Table 3.2.

Table 3.2 Customer Requirements

Related to	Customer Requirement
Conformance to specifications	The product must have no defects. (Yadav et al., 2023)
	The product must be according to the approved Sample

Cost Effectiveness	The product should be low cost. (Carulli et al., 2013)
	There should be no extra charges related to the order. (Alzoubi et al., 2022)
Workplace Safety	There must be proper fire exits for the facility. (Khan et al., 2020)
	Fire hose and reels must be installed. (Khan et al., 2020)
	Regular safety audits must be conducted. (Khan et al., 2020)
Delivery time	Orders must be near completion during external audits.
	Orders must be delivered on the agreed-upon time.
Competitive Environment	The facility must have the required features of the desired product.
	The manufactured order must be according to market standards (Dey & Mahamud, 2020)

Table 3.2 makes it abundantly evident that customers have preferences, which are the basis for evaluating and selecting the manufacturer to fulfil their orders. These preferences are based on the preferences of the customers. The key thing that any consumer wants to look for is a product that comes close to meeting the necessary quality levels as well as the product specification. The marketing department of every textile industry maintains frequent contact with the client to inquire about the preferences of the customer regarding the type of product they are looking for. Most of the time, customers provide the marketing department with their designs and specifications, which are then communicated to the product development department. This allows the marketing department to communicate the product requirement to the product development department that allows it to develop the product's construction. This begins with the selection of the required fabric quality that the customer is looking for, followed by the designing and printing of the

fabric, and finally moving on to the final stage, which is stitching from the sampling department, which is responsible for making the final product to show to the customer.

While this is going on, the marketing department and merchandisers are watching the resources necessary to fulfil the order and the costs associated with producing the goods. Following that, the customer is given a product sample tailored to their specifications, along with an analysis of the associated costs. Following the conclusion of fruitful negotiations between the marketing department and the customer, the order is awarded, and the process of acquiring the necessary fabric and accessories is started. In a comparable manner, the textile sector has its own design and control area, which is where they have a variety of items that they specialize in designing and manufacturing. The portfolio of products that the industry is manufacturing is also given to the customers, which also leads to the product meeting or exceeding the customer's expectations in terms of what they want from the product. Following this, the identical steps of sharing samples, determining the cost, and determining the amount of time necessary to finish the order are discussed.

3.2.2 House of Quality

Next, after defining the requirements of the customer for successfully winning the order, the next stage was to translate the customer requirements, which are displayed in Table 3.2, into the technical requirements of the production company, which in our case is the home textile industry. There was participation from a variety of departments, each of which was connected to the work description of their respective departments. These departments include the department of quality control, the department of production, the department of employees' health, safety, and compliance, the department of maintenance, the department of procurement, and the department of human resources. The Table 3.3 provides the translated technical requirements that must be met to satisfy the standards that were developed by the customer:

Table 3.3 Technical Requirements

Department	**Technical Requirements**

Quality	Inline defect and rework percentage must be between 5 and 10%.
	There should be no major defects during the prefinal inspection and external audit.
	The B-grade ratio must be lower than 1%.
Production	The order must be completed 3 days before vessel booking.
	Hourly production progress must be monitored.
EHS & Compliance	Facility safety standards must be followed.
	Fire hydrant expiration dates must be monitored.
	The aisles must be clear.
Maintenance	Machine condition should be best for production.
	There must be no oil leakage, needle breakage, or overheating.
	There should be a proper overhaul record.
Procurement	Stitching accessories must be procured on time.
	Accessories must be of the required quality.
HR	A worker's attendance should be checked regularly.
	Workers' wages and rights must be monitored.

Table 3.3 provides an overview of the technical criteria that must be met to fulfil the needs given by the client. These requirements ought to be incorporated into the standard operating procedures that the relevant department must adhere to. The next thing that must be done is to examine the connection between the requirements of the customers and the technical requirements that can fulfil those objectives.

To evaluate their relationship, a house of quality was constructed, and the criteria used were strong, medium, weak, or no relationship, with scores of 9, 3, and 1 accordingly. The link between the technical criteria may be highly positive, negatively negative, or strongly negative. The firm that was used to test the after results was company A. This company was then compared to two other companies operating in the home textile sector in Pakistan to ascertain where the other two companies stand in relation to the customer needs that were discussed earlier.

It was established that this status was determined by conducting interviews with professionals who had worked in a variety of home textile businesses and who continued to maintain connections with professionals from other industries. As you can see from thre Figure 3.1 that quality of the product, its conformity with the specifications, delivery time and a better product as compared to the market is what satisfies the customer requirements the most. Relationship of customer requirements with the technical requirements were calculated with the likert scale of (1-3-9) showing weak, medium and strong relationship respectively. Similarly, interrelationship of the techinal requirments were also mentioned in Figure 3.1. After calculating relative importance among the customer requirments and the techinal requirments, next step is to calculate the absolute weights. Formula used to calculate absolute weights is given in equation 3.1 (Iqbal & Grigg, 2021):

$$AW = \sum (w * ci) \qquad (3.1)$$

In the equation that was just shown, the letter 'AW' stands for the absolute weights of, which are computed in the manner that is depicted in Figure 3.1 that was presented earlier. The letter 'w' represents the relationship score between the customer and the technical demand, while the letter 'ci' represents the relationship score between the customer and the specific requirement. It can be seen from that the requirements related quality department are more important to the customer followed by the maintenance department requirements that also directly effects the cost and quality of the product. So, from these house of quality results, we can see that the technical requirements related to quality, production, maintenance, and employee health & safety (EHS) are important from customer perspective and the risks related to them should be investigated further.

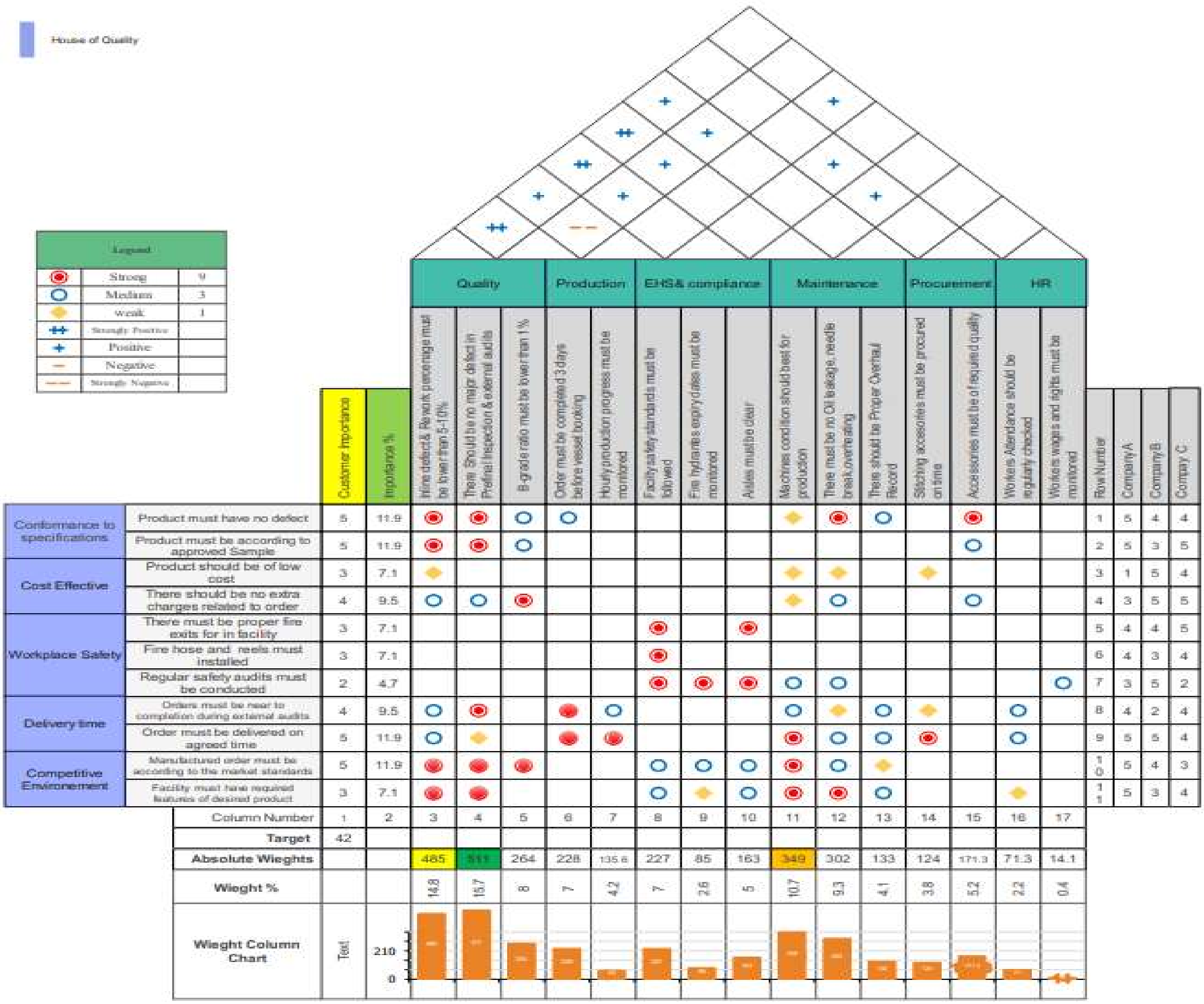


Figure 3.1: House of Quality highlighting relation of Customer and technical requirements

Table 3.4 House of quality results

Department	Technical Requirements	Absolute Weights	Weight %
Quality	Inline defect and rework percentage must be between 5 and 10%.	485	14.8
	There should be no major defects during the prefinal inspection and external audit.	511	15.7
	The B-grade ratio must be lower than 1%.	264	8
Production	The order must be completed 3 days before vessel booking.	228	7
	Hourly production progress must be monitored.	135.6	4.2
EHS & Compliance	Facility safety standards must be followed.	227	7
	Fire hydrant expiration dates must be monitored.	85	2.6
	The aisles must be clear.	163	5
Maintenance	Machine condition should be best for production.	349	10.7
	There must be no oil leakage, needle breakage, or overheating.	302	9.3

	There should be a proper overhaul record.	133	4.1
Procurement	Stitching accessories must be procured on time.	124	3.8
	Accessories must be of the required quality.	171.3	5.2
HR	A worker's attendance should be checked regularly.	71	2.2
	Workers' wages and rights must be monitored.	14	0.4

So, Table 3.4 shows that the absolute weights related to quality, maintenance production and EHS department are higher. So, risk related to technical requirements of these departments are required to be investigated further.

3.3 Measure Phase

3.3.1 Monte Carlo analysis

For Monte Carlo analysis, the first thing that needs to be done is to determine the risk that is connected to the technical requirements that were derived from the customer requirements during the defined phase.

Various metrics have been proposed in the risk management literature to assist risk managers in prioritizing risks and allocating resources to the most critical risks. These metrics include risk priority number risk index, Value at Risk (VaR), conditional VaR (CVaR). Most existing risk measurements primarily prioritize hazards based on their predicted levels rather than representing the real distribution of risk (risk profiles). Risk metrics, such as Value at Risk (VaR) and Conditional Value at Risk (CVaR), cannot be easily applied to risk matrices since the qualitative character of the scales employed in standard risk matrices and does not allow for their adaptation. The constraint in utilizing risk measurements is particularly evident when it comes to risk matrices that assess the influence of risks upon project performance indicators, such as quality and sustainability, which are subjective (Qazi et al., 2021)

Hence, this study introduces novel metrics that encompass the complete spectrum of hazards, which may be utilized in conjunction with conventional risk matrices.

The traditional risk matrix is often divided into three zones of risk exposure: low, medium, and high. The partitioning strategy, which involves selecting boundaries among risk exposure zones, reflects the risk attitude of the decision-maker. The risk-exposure value of a factor of risk, or RE_{Ri}, may be calculated by multiplying the probability and effect values related to the risk factor Ri, as seen in Equation (3.2). The estimation of all potential risks related to individual risk variables is represented using a risk matrix (Qazi et al., 2021).

The equation (3.2) represents the relationship between risk exposure, probability, and impact of risk Ri where i is the risk number (Qazi et al., 2021).

$$RE_{Ri} = P_{Ri} \times I_{Ri} \qquad (3.2)$$

Instead of using a single point estimate, the strategy involves conceptualizing the risk signature of individual hazards as a probability distribution. This means that each risk is assigned an individual probability value throughout each risk exposure zone of the risk matrix, which is represented by Zj. The decision-maker establishes three risk exposure zones, namely high (Z_H), medium (Z_M), and low (Z_L) (Qazi et al., 2021)

$$RS_{Ri} = [\mathrm{P}(\mathrm{Ri} \in Z_L), \mathrm{P}(\mathrm{Ri} \in Z_M), \mathrm{P}(\mathrm{Ri} \in Z_H)] \qquad (3.3)$$

Were,

$$\sum_{\mathrm{j}} \mathrm{P}(\mathrm{R_i} \in \mathrm{Z_j}) = 1 \,\forall\, \mathrm{i} \qquad (3.4)$$

To prioritize risks based on their probability distributions across different risk exposure zones and identify any dominant risks, an indicator function $I_{Ri \in Z_j}$ is used. This function determines whether the risk factor R_i falls within the risk exposure zone Z_j (refer to Equation 3.5). A dominating risk is found only in the high-risk exposure zone, whereas a non-dominated risk is completely confined to the low-risk exposure zone, as indicated in equations (3.6) and (3.7) respectively (Qazi et al., 2021).

$$I_{Ri \in Z_j} = \begin{cases} 1 \; if \; R_i \in Z_j \\ 0 \; if \; R_i \notin Z_j \end{cases} \tag{3.5}$$

$$I_{Ri \in Z_L} = 0; \; I_{Ri \in Z_M} = 0; \; I_{Ri \in Z_H} = 1 \tag{3.6}$$

$$I_{Ri \in Z_L} = 1; \; I_{Ri \in Z_M} = 0; \; I_{Ri \in Z_H} = 0 \tag{3.7}$$

To accomplish this, we needed to be aware of the reviews provided by the experts linked with the various departments of the home textile business in Pakistan. Interviews, literature, and questions from customers were used to obtain information about potential risk associated with the departments and their processes. To obtain the overall risk exposure score, a questionnaire was developed after all the potential dangers that were linked with the relevant department were identified. These questions are taken primarily by directly translating the technical requirements mentioned in Table 3.3 and from the interviews from the experts and some were referred from the literature review collectively highlighting all the risks that are related to the industry standard process and procedures. This questionnaire was designed to determine the probability of the specific risk and the impact it would have if it occurred. It was decided to use a Likert scale that ranged from 1 to 5 to estimate the probability and impact of each danger. The Process flow diagram for prioritizing risks on the conventional risk matrix-based approach is given in Figure 3.2:

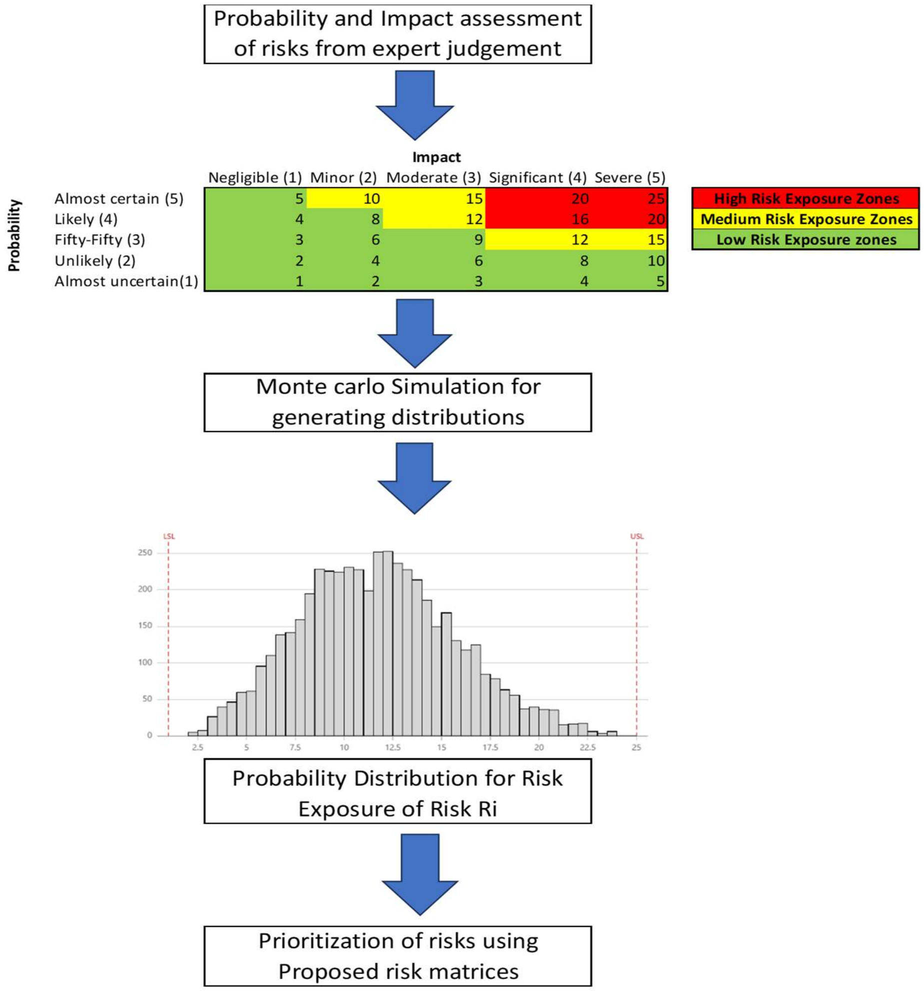
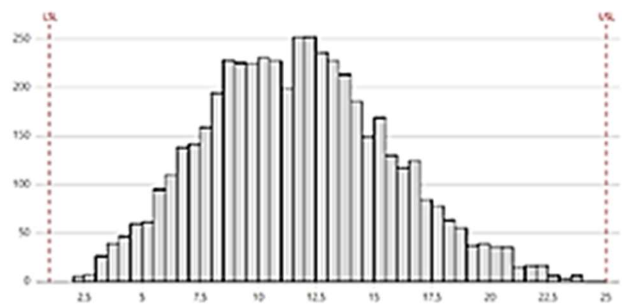
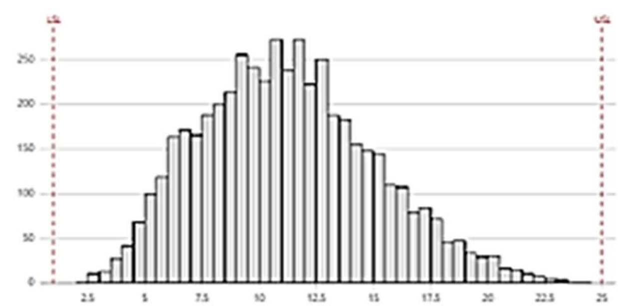
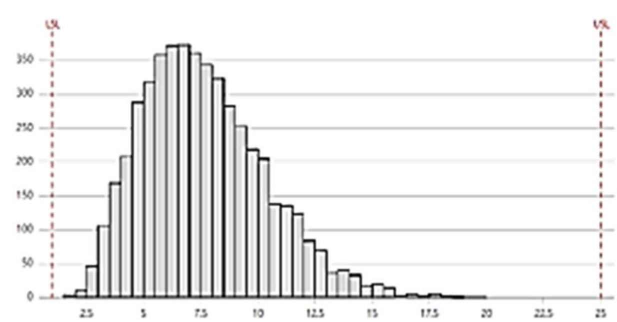


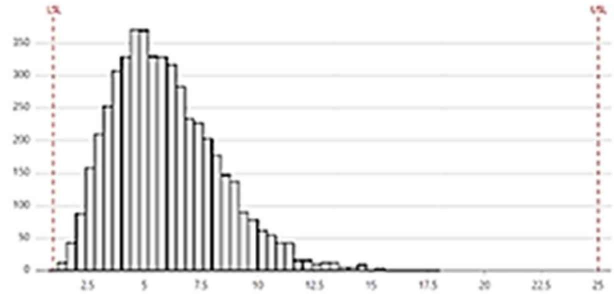
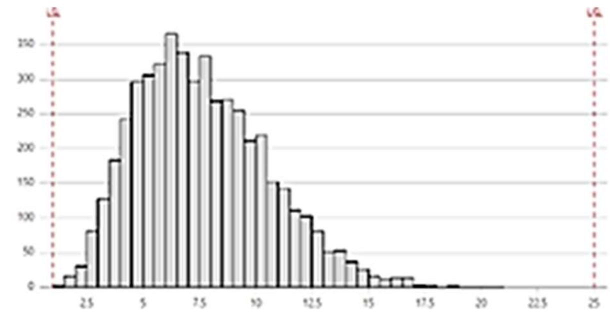
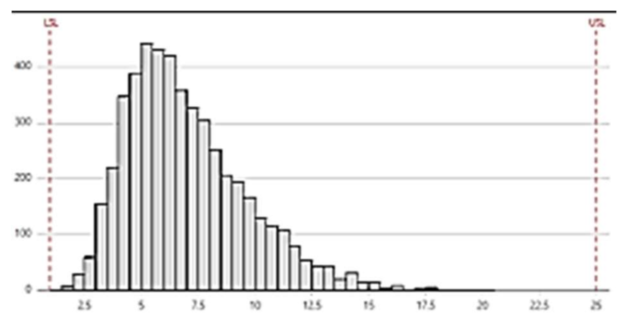
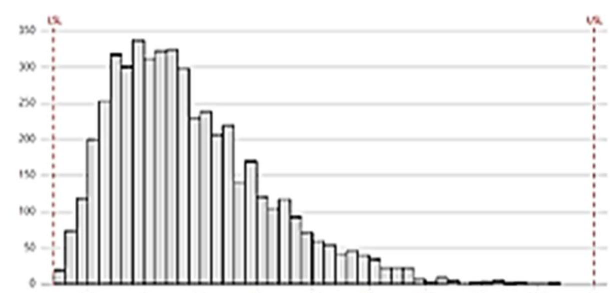
Figure 3.2: Process flow to conduct Monte Carlo simulation (Qazi et al., 2021)

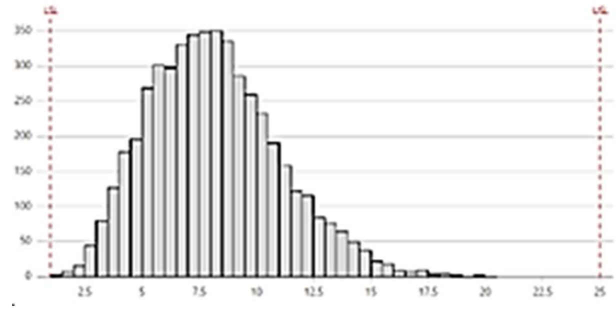
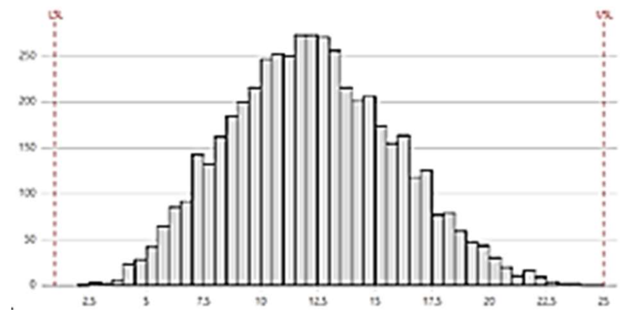
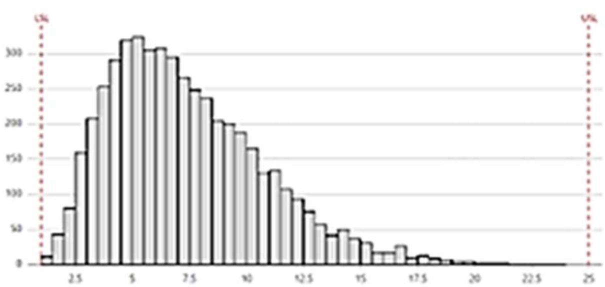
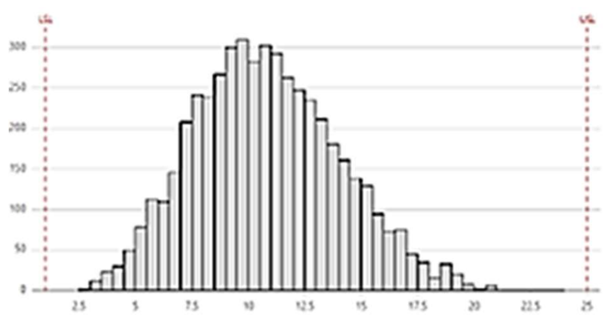
The survey questionnaire utilized a 5-point Likert scale to gather the likelihood and effect estimates of risks from 31 experts (refer to Figure 3.2). The data was imported into an Excel spreadsheet including information on all the experts. Subsequently, a simulation model was created in MINITAB WORKSPACE by using the standard deviation and mean values of probability and impact given by each expert. A total of 5000 simulation runs were conducted for each individual risk using the Monte-Carlo simulation approach.

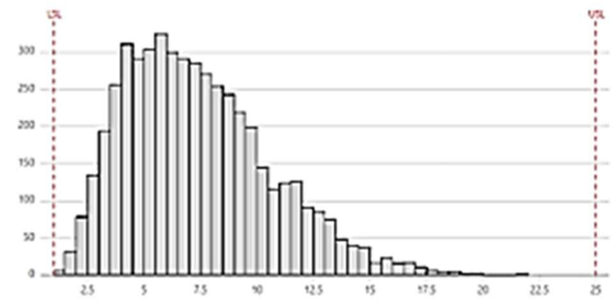
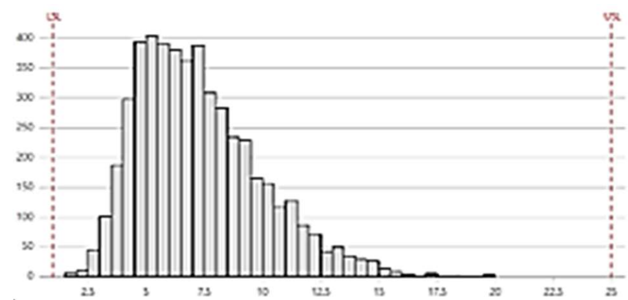
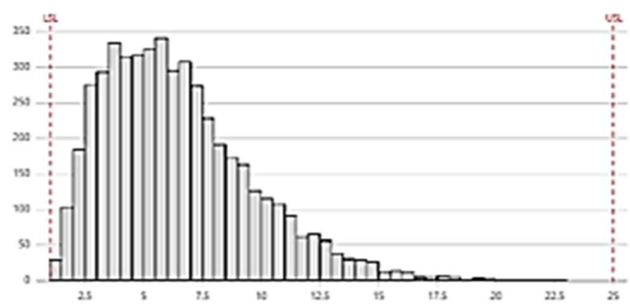
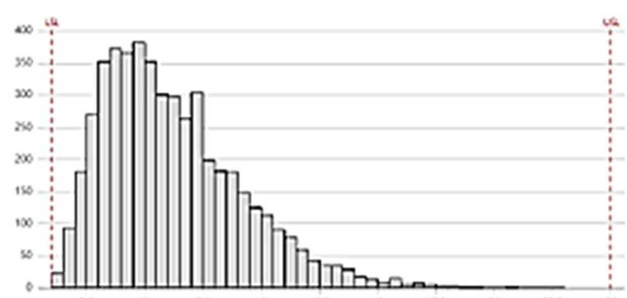
The risks can be prioritized based on exposure scores ranging from medium (12–16) and high (16–25) risk exposure zones. These zones might be categorized as crucial and unacceptably high-risk exposure zones, accordingly (Qazi et al., 2021). The risks their mean and standard deviation values and monte Carlo simulation results are highlighted in Table 3.5.

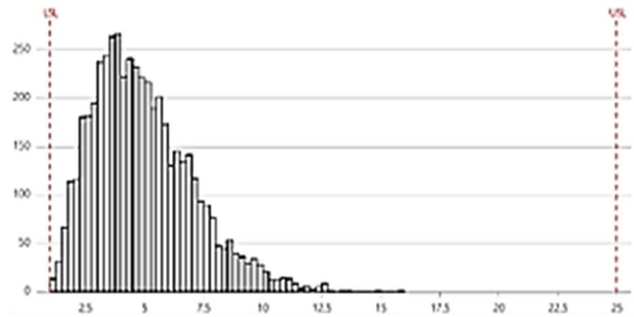
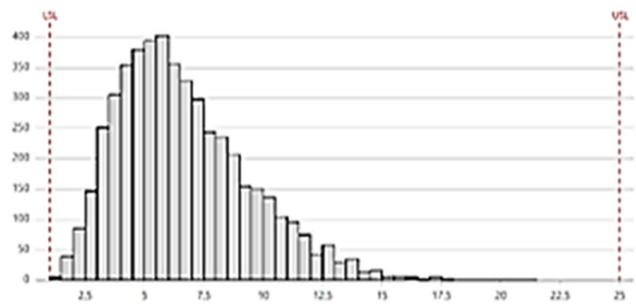
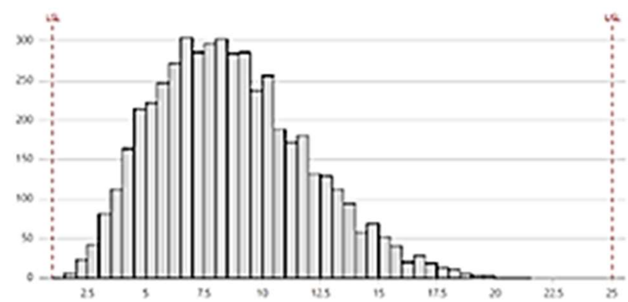
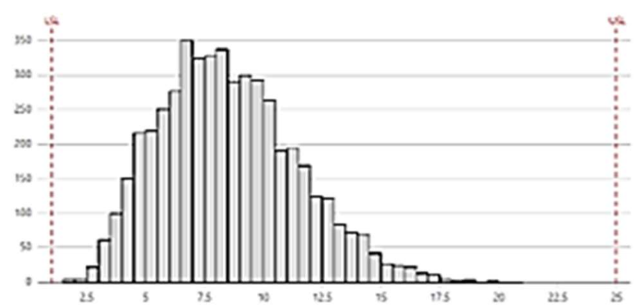
Table 3.5 Distributions of risk related to home textile.

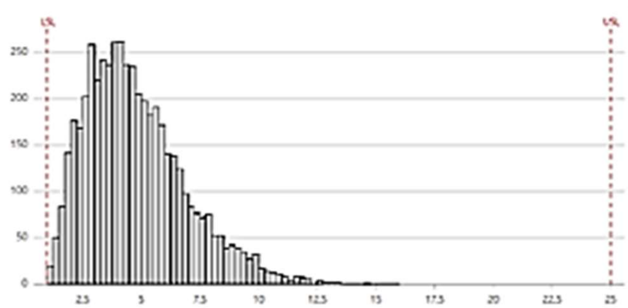
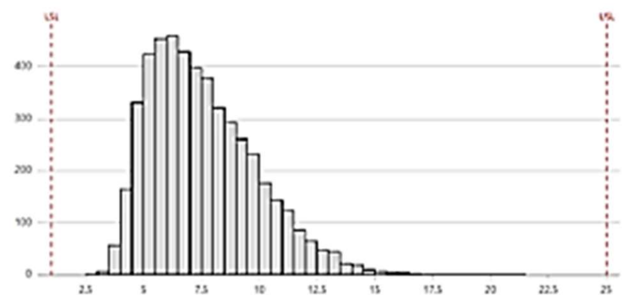
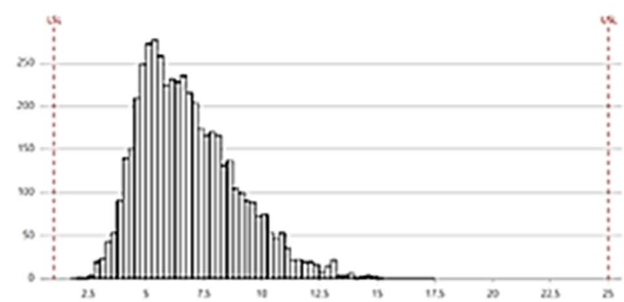
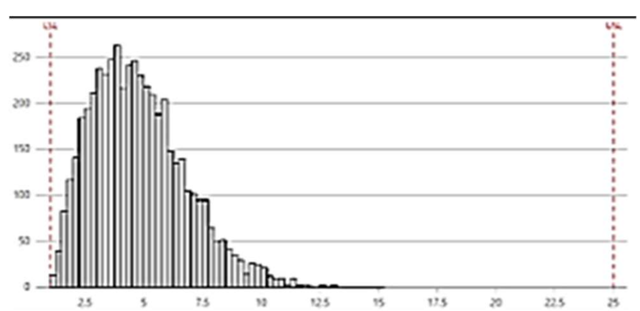
Distributions for risks related home textile				
Risk ID.	**Description**	**Mean**	**Standard deviation**	**Risk Exposure Distributions**
R1Q1	Quality defects ratio is higher than 5% in the inline inspection, so the operator was stopped to check the issue	11.5392	4.0249	
R2Q2	Defects of the operator were not caught in the line and articles was further stitched and unloaded from the switch track	10.8797	3.8284	
R3Q3	Fabric defects were not detected at folding inspection and caught after stitching operations	7.2256	2.7131	

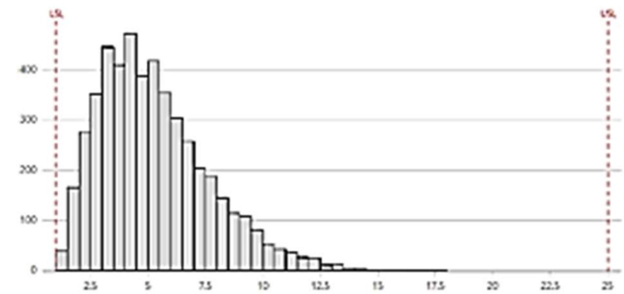
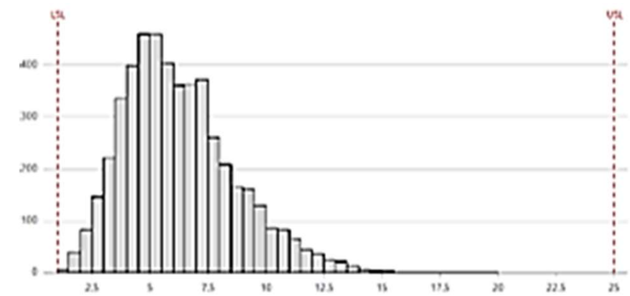
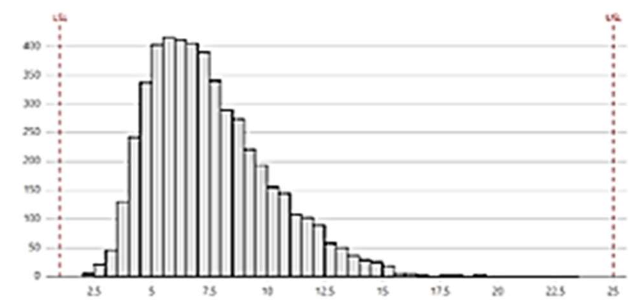
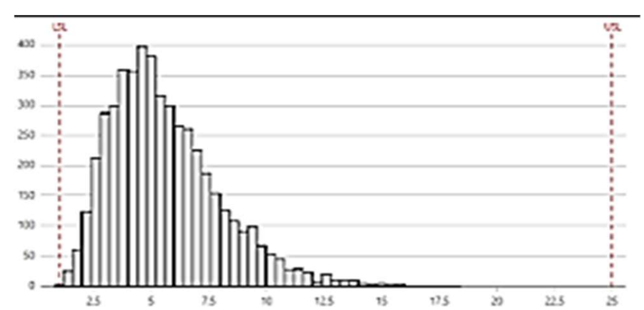
R4Q4	Major defects were more than acceptance quality level was found in prefinal inspection resulting in failure of inspection	5.6491	2.3552	
R5Q5	Found defects were not reworkable and the article gets rejected/B-grade	7.3189	2.9417	
R6Q6	External auditor fails the external inspection due to major issues found in packed articles when checked.	6.5602	2.7257	
R7Q7	There was no QC checked identification on the checked articles/cartons	6.5396	3.4758	

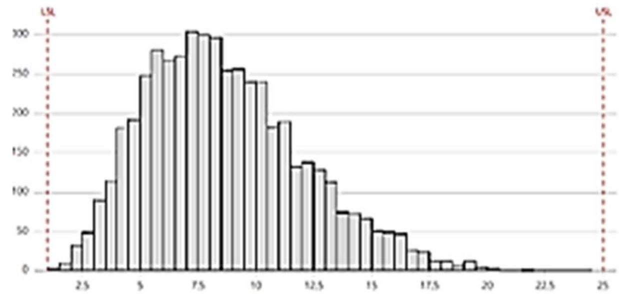
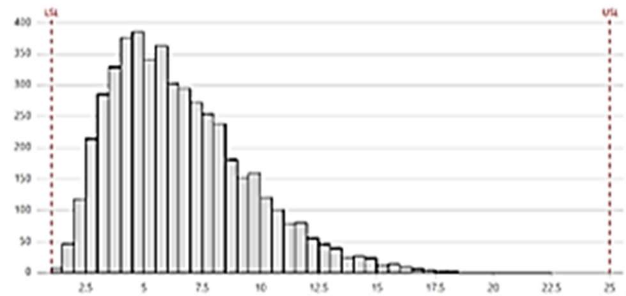
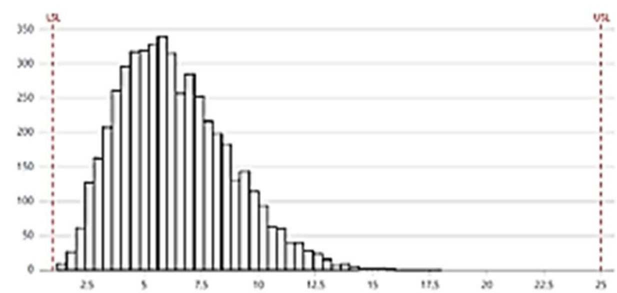
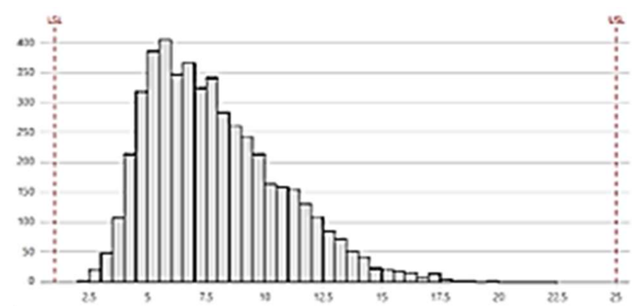
R8P1	Produced pieces per day were falling behind the takt time & hourly target	7.9443	2.8877	
R9P2	Due to greater rework ratio, production efficiency has dropped	12.1099	3.6355	
R10P3	Bottlenecks in the line slowing down the production process	6.8473	2.3619	
R11P4	Machine issues creating hurdles in meeting target efficiency	10.6119	3.2476	

R12P5	Loss time due to changeover of the article reduced produced minutes	7.0218	3.2783	
R13P6	Shipment target was lagging the shipment exit date	6.9059	2.7745	
R14ES1	Production floor does not have operator SOP required by customer	5.8447	3.2353	
R15ES2	Article defects cannot be traced back to the operator due to no identification sign of article	5.7266	3.0775	

R16ES3	Packed cartons were not placed on the pallet	4.5754	2.1465	
R17M1	Machine is leaking oil producing oil stains on the fabric	6.2781	2.8123	
R18M2	Machine is breaking thread frequently resulting in defects and time loss	8.498	3.2271	
R19M3	Machine is not giving required quality on defined RPM and SPI (Stitches per inch)	8.3604	2.9631	

R20M4	Machine overhaul is due and must be sent to workshop	4.3309	2.1559	
R21Q8	Customer complains about some defects after the shipment receiving	7.1758	2.2821	
R22Q9	Customer rejects whole shipment for not meeting required quality standards	6.4372	2.0904	
R23P7	Stitching unit does not have the capacity of making the certain volume of order in specified time	4.6738	2.0954	

R24P8	Manufacturing unit did not have the required machine resources for meeting product specification	4.8058	2.4587	
R25ES4	They are no fire extinguishers or hose reels available in the manufacturing unit	5.9806	2.4726	
R26ES5	Building does not meet the required safety standards	7.0856	2.5844	
R27ES6	Safety/fire exit pathways are not specified in the unit	5.2171	2.3638	

R28M5	Machine is breaking the needle causing extra needle loss and loss time	8.2645	3.5064	
R29ES7	Needle guard and eye guard are not installed in the machine	6.1048	2.9638	
R30P9	Fabric cutting was not received at the specified time.	5.9144	2.4504	
R31ES7	Response time in case of hazard or accident is very high	7.3893	2.9137	

Here, RQ, RM, RP and RES represents the risks related to quality, maintenance, production and employee health and safety departments, respectively. The distributions show the frequency of risk exposure values ranging from 1 to 25 on 5000 iterations performed. It can be seen from the distribution that R1, R9 and R11 that the frequency of risk exposure value from 10 to 17.5 are higher ranging above 150 values. In R9 and R11, risk exposure values of 12 to 15 are going above frequency of 250 indicating the critical nature of these risks as compared to others.

3.3.3 Risk Prioritization

For the risk prioritization, the data was analysed with a help of MINITAB WORSPACE software to simulate data up to 5000 iterations for each risk identified. The risk identified are mentioned in Table 3.5 are prioritized based on the **95th percentile value** that shows the risk mitigation when risk occurring probability is higher (Qazi et al., 2021).

Table 3.6 Risk Prioritization through Monte Carlo Simulation

Risk ID	Mean Risk Exposure (Before Monte Carlo simulation)	Mean Risk Exposure (After Monte Carlo simulation)	Risk at high 95% percentiles	Risk at Medium 50% percentiles	Standard deviation
R1	12.5484	11.7093	18.616	11.5392	4.0249
R9	12.6452	12.2777	18.458	12.1099	3.6355
R11	11.7742	11.1564	17.924	10.8797	3.8284
R2	10.9355	10.8642	16.559	10.6119	3.2476
R28	8.6774	8.6892	15.047	8.2645	3.5064
R18	8.8065	8.698	14.459	8.498	3.2271
R19	8.5484	8.631	14.003	8.3604	2.9631
R10	6.7097	7.3903	13.708	6.8473	2.3619
R7	5.9677	7.1618	13.704	6.5396	3.4758
R12	6.7742	7.4954	13.595	7.0218	3.2783

R31	5.8387	7.9447	13.520	7.3893	2.9137
R8	8.0323	8.1822	13.363	7.9443	2.8877
R5	7.7419	7.6816	13.102	7.3189	2.9417
R14	5.4194	6.4535	12.602	5.8447	3.2353
R13	6.0645	7.3797	12.533	6.9059	2.7745
R3	7.2903	7.5331	12.399	7.2256	2.7131
R26	5.7742	7.5355	12.356	7.0856	2.5844
R15	4.9677	6.2774	12.326	5.7266	3.0775
R6	5.3871	7.0632	12.254	6.5602	2.7257
R29	5.6774	6.5334	11.994	6.1048	2.9638
R17	5.8065	6.678	11.941	6.2781	2.8123
R21	6.1613	7.5085	11.725	7.1758	2.2821
R25	5.1290	6.3205	10.890	5.9806	2.4726
R22	5.2903	6.7805	10.738	6.4372	2.0904
R30	5.9032	6.2523	10.723	5.9144	2.4504
R4	5.3871	5.9734	10.404	5.6491	2.3552
R27	4.3871	5.6087	10.027	5.2171	2.3638
R24	4.0000	5.2377	9.918	4.8058	2.4587
R16	4.1935	4.9479	9.058	4.5754	2.1465
R20	3.4839	4.7211	8.881	4.3309	2.1559
R23	4.0323	4.9198	8.803	4.6738	2.0954

It is clear from Table 3.6 that the top three risks that were prioritized based on the Monte Carlo simulation are associated with the maintenance and quality department. According to the information in Table 3.6, the risks at 95th percentile value scores ranging from 17 to 25 were the most significant in the high-risk exposure zone. Those with risk exposure scores between 12 and 16 were considered to have a medium risk exposure, which were represented A description of the risks that have been prioritized can be seen in Table 3.5:

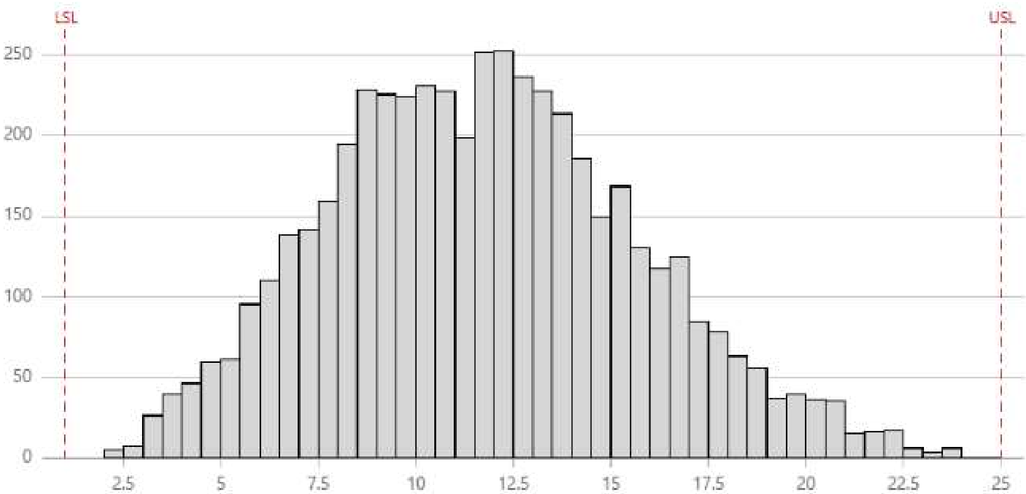


Figure 3.3 Monte Carlo simulation result of R1Q1.

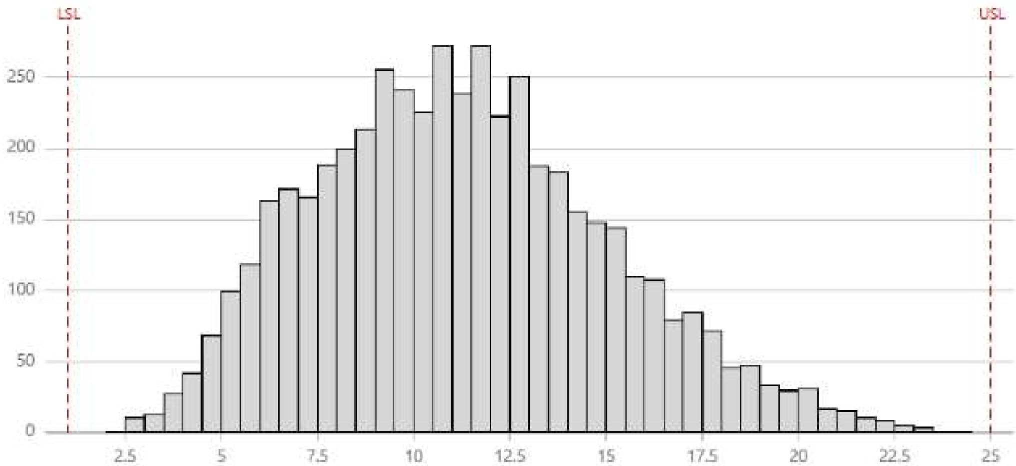


Figure 3.4 Monte Carlo simulation result of R9P2

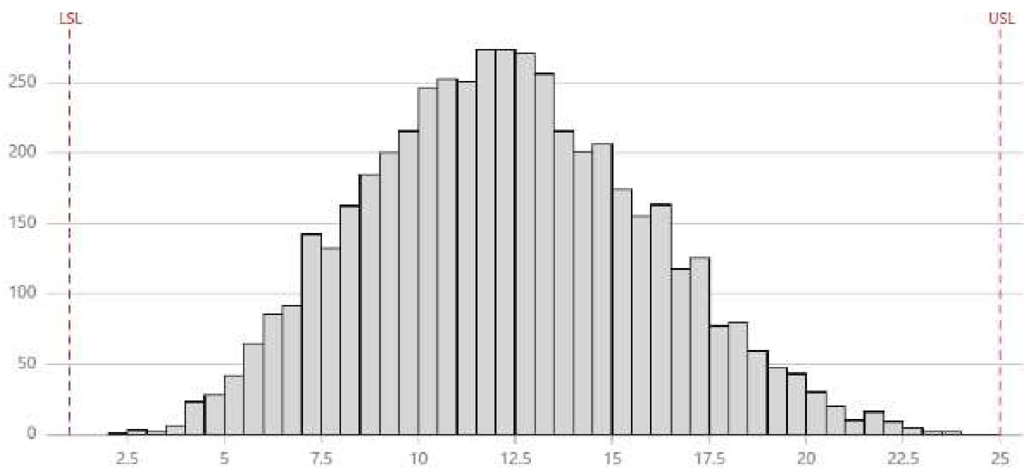


Figure 3.5 Monte Carlo simulation result of R11P4

3.3.4 Risk Exposure analysis

The Risk Exposure taken from the probability and impact score of on the Likert scale of 1 to 5 could range from 1 to 25 as shown in the average response scores shown in Table 3.6. For better improvement of the production processes, it is better to work on the risk first that lie in high exposure zone. For that, threshold risk exposure taken for the process in accordance with the responses taken is 16 and the target line is taken as 12. The Figure 3.6 graph shows the risk exposure of the prioritized along with number of risks that lie above threshold value.

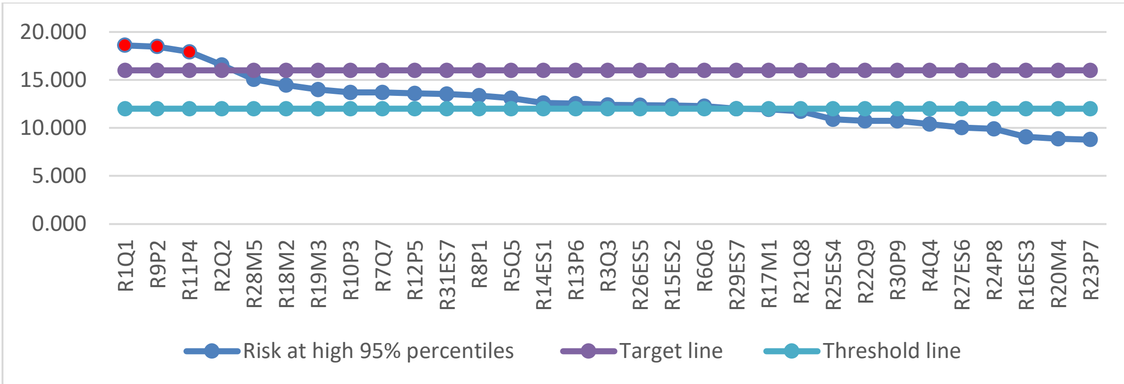


Figure 3.6 Risk Exposure distribution graph (Qazi & Simsekler, 2021)

So according to Figure 3.6 highlighting risk exposure with respect to threshold line and target line shown above, there would be 3 risk exposure zones i.e., high risk exposure zone, medium risk exposure zone and minimal risk exposure zone.

3.4 Analyze Phase

Now to improve the process, it is important to analyse the current condition of the top 3 prioritized risks. For that reason, current state of the top 3 risk identified in Table 3.6 Current state of the prioritized risks is stated in ahead:

3.4.1 R1Q1: Quality defects ratio is higher than 5% in the inline inspection, so the operator was stopped to check the issue.

During stitching in each stitching line, inline inspection is carried out using a traffic light system approach. During this inspection, an inline quality checker examines three different components of the operator to identify any significant or minor defects. If all the pieces are in good condition, the operator will be given green for that round. If the checker discovers one or two minor flaws, he will give the operator a yellow card and advise them to improve the quality. In some cases, the checker will even inspect more than three pieces to comply with the double sampling technique. If the yellow operator has some faults once more during the subsequent round, the machine is halted, and the situation is investigated in depth to determine if the defects that are occurring are the result of the operator or whether the machine issue is the cause of the flaws.

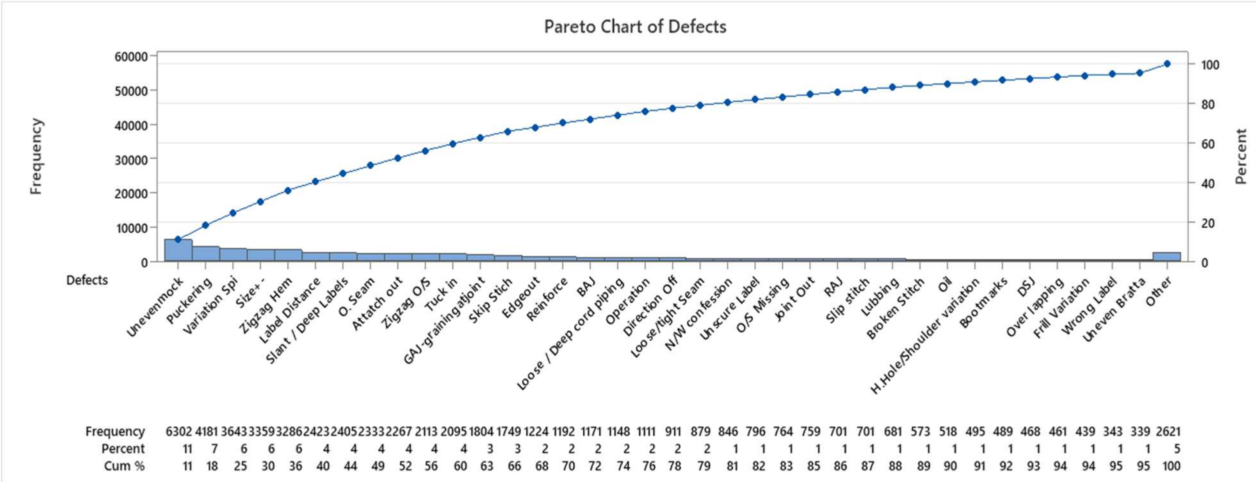


Figure 3.7 Pareto analysis of inline quality defects.

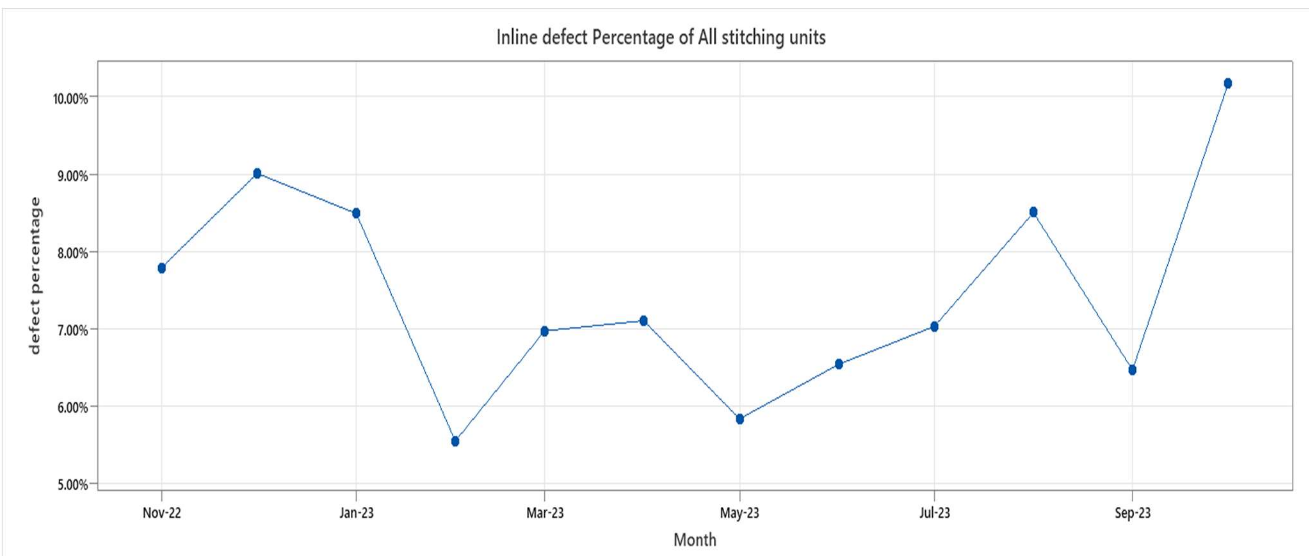


Figure 3.8 Scattered plot monthly defect percentage.

As a result, the inline quality of one year was obtained from one of the most prominent home textiles in Pakistan, and the percentage of inline defects that they currently have was studied. A Pareto analysis was performed on the defect data from one year in

Figure 3.7 and the results revealed the top flaws that were contributing to an increase in the percentage of inline defects that uneven mock, puckering, SPI variation, uneven hem, and insecure label.

Figure 3.9 Stitching inline defects**.**

The Figure 3.9 shows the glimpse of the top defects highlighted in the pareto diagram found during the process. These defects are the of the main source of increasing inline defect percentages above 5%. The defect percentages over the period of one year are highlighted in Figure 3.8.

In Figure 3.8, this can be clearly seen that defect percentage remains above 5% which is required to be lowered by mitigating the defects. This can be done by understanding the cause of those defects. For that, Cause and effect diagram is used.

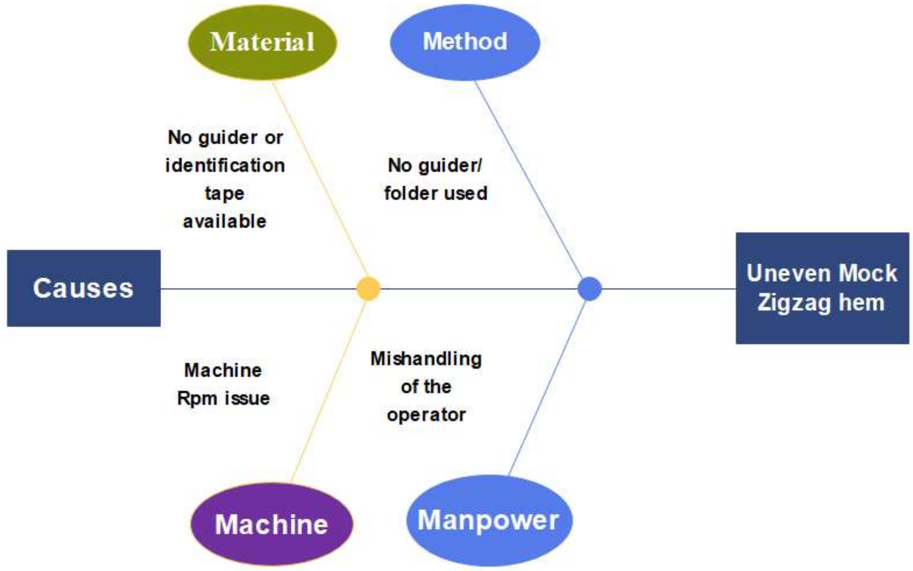


Figure 3.10 Cause & effect diagram of Uneven mock and zigzag hem

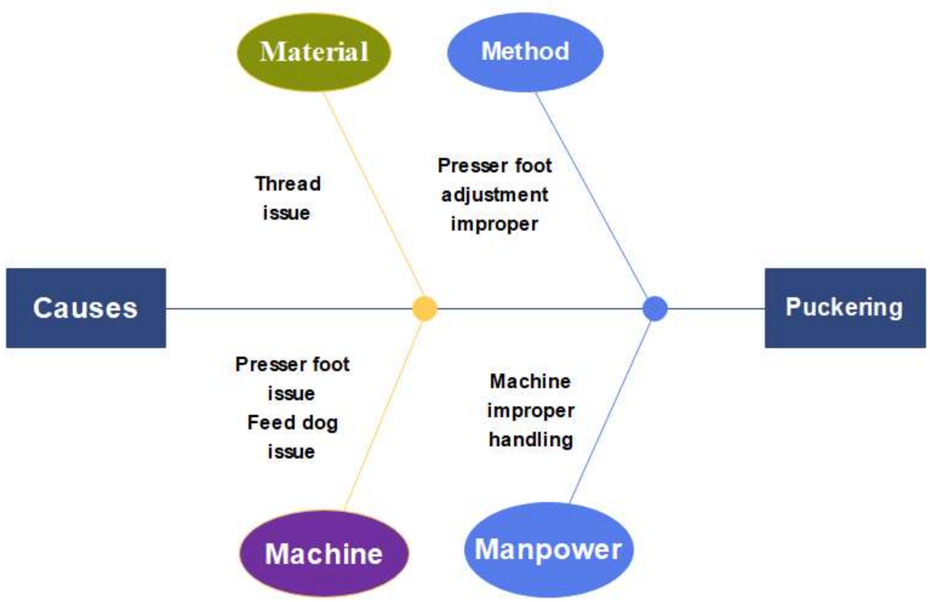


Figure 3.11 Cause & effect diagram of Puckering

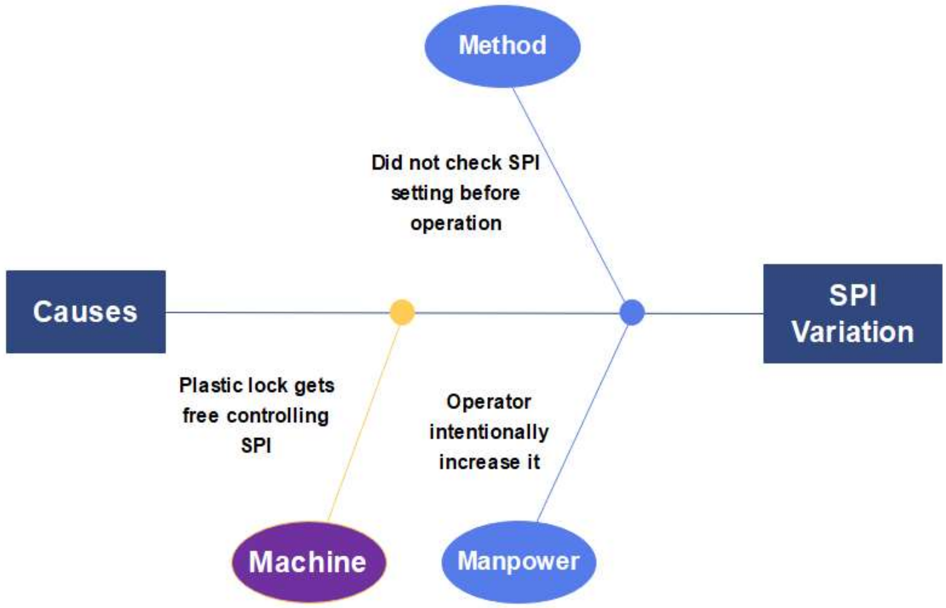


Figure 3.12 Cause & effect diagram of SPI Variation

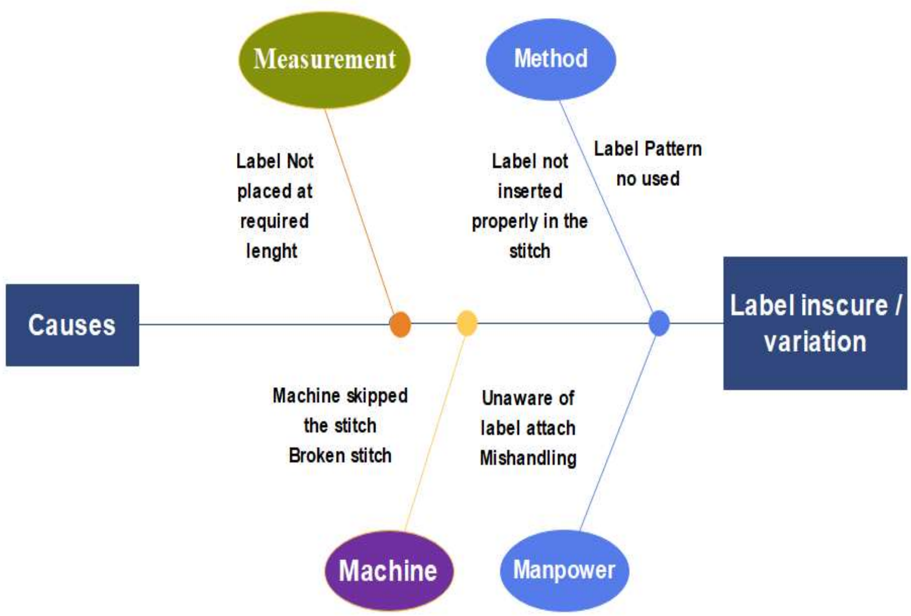


Figure 3.13 Cause & effect diagram of Label issues

The cause-and-effect diagrams that were mentioned earlier in relation to the range of defects that were highlighted make it possible to clearly see the major causes of the defects that occurred. These major causes are primarily due to the operator's lack of knowledge or improper skill, the operator's failure to follow the standard method or procedure when performing the specific operation of stitching, the operator's failure to use required gadgets such as a guider or folder, and machine issues that are also highlighted in the topic 3.4.3 regarding machine problems.

3.4.2 R9P2: Due to greater rework ratio, production efficiency has dropped.

Now, some of the faults are required to be reworked from the same workstation which created it. This rework results in loss of time and efficiency of the workstation. the rework percentage over the period of one year is mentioned in Figure 3.14.

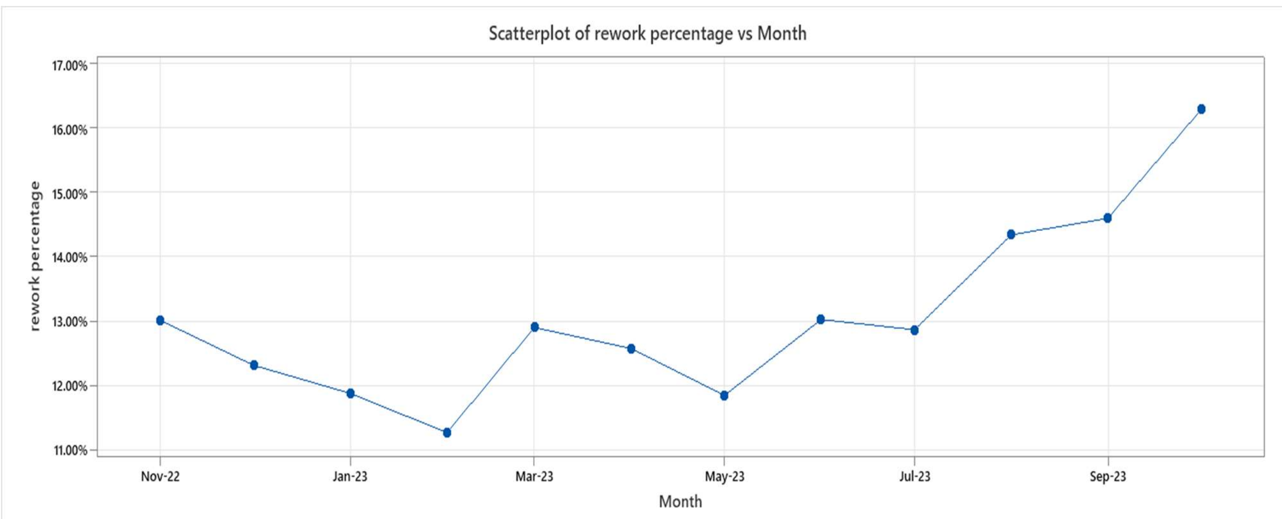


Figure 3.14 Rework percentage

It is clear from looking at Figure 3.14 that a larger inline fault ratio that is greater than 5% has a substantial impact on the rework percentage. This is the primary issue of any manufacturing sector, and it is something that has to be investigated seriously, as experts have also pointed out with their scores. The amount of rework that is indicated in Figure 3.14 over the course of one year is far higher than 10%, which is a condition that should be considered concerning. Therefore, in order to reduce the percentage of rework, it is necessary to minimize the percentage of inline defects, which is directly related to the percentage of rework.

3.4.3 R11P4: Machine issues creating hurdles in meeting target efficiency.

The maintenance department, which is also under the authority of the stitching department of the home textile industry in which we conduct pilot runs, is responsible for monitoring any machine-related issues that may arise within the stitching department. Imperfections brought about by problems with the machine are brought to the quality department's attention, and the machine mechanics responsible for rectifying the issue are called upon. It is the mechanic's responsibility to resolve the issue and then record it on the preventative maintenance card attached to the machine. The card should include the operator's name, the machine number, and the amount of time that the unit was down.

It was via the usage of this data that the machine problems that occurred over the course of a period of six months and the frequency with which they occurred were identified. All the time lost due to these problems was also considered to determine the amount of time wasted by each machine to achieve the desired level of efficiency for the line and the unit. The Pareto analysis and loss time due to machine issues are presented in Figure 3.15 and Figure 3.16, respectively, and it focuses on the overall frequency of each machine issue that happened over the course of a period of six months and the total amount of time that was lost because of each machine issue during the same time.

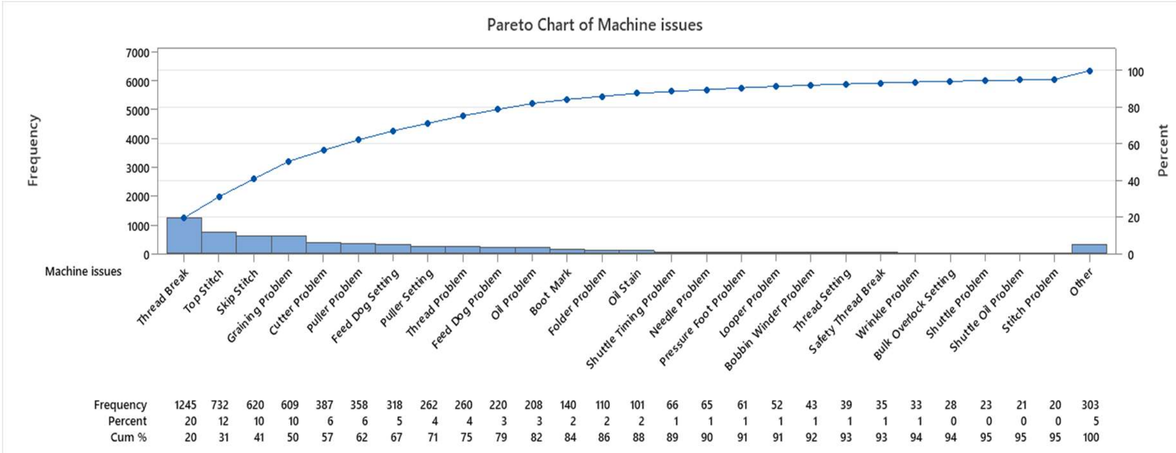


Figure 3.15 Pareto Analysis of machine issues

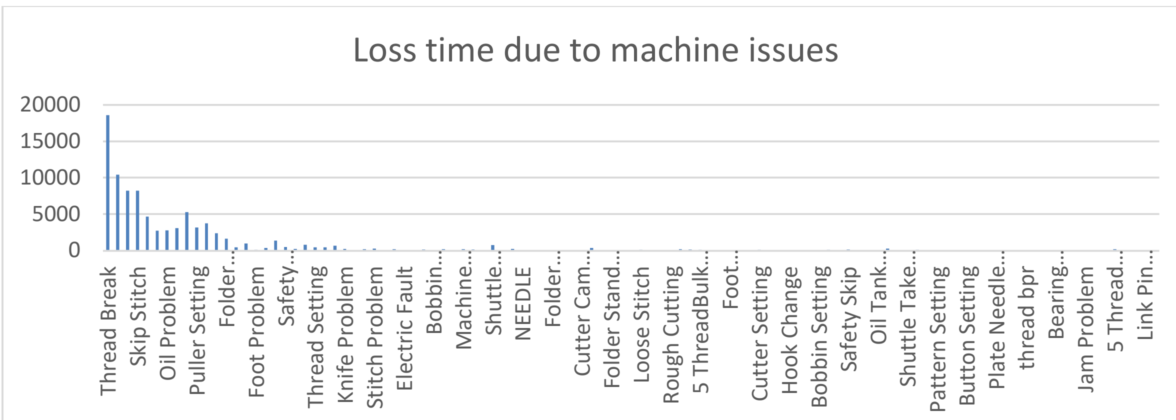


Figure 3.16 Loss time due to machine issues

The expenditure of time not only leads to a reduction in the efficiency of the machine, line, and unit, but it also results in a loss of cost for the industry. Table 3.7 According to the calculations, the cost per minute (CPM) is 0.05 dollars. The CPM information was obtained from the reports compiled by the department of industrial engineering.

Table 3.7 Loss of time and cost due to machine issues.

Months	Machine issue loss time (Minutes)	lost CPM at 0.05$
May-23	11,804	$ 590.20
Jun-23	9,692	$ 484.60
Jul-23	9,505	$ 475.26
Aug-23	11,035	$ 551.75
Sep-23	12,034	$ 601.70
Oct-23	11,073	$ 553.65

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Improve

From the above-mentioned current analysis related to the risk prioritized, viable solutions were required that were again asked from the experts. Then after collecting solutions from the experts related to the identified problem, solutions were implemented in the stitching unit for testing. Pilot runs were conducted in one of the prestigious home textile industries and then results of recorded for one month for mitigation of each prioritized risk.

4.1.1 Solutions testing and pilot run.

From the pareto analysis performed on the quality defects data shown in Figure 3.7 over the period of 1 year, it is evident that most occurring defects that are increasing our defect percentage above 5% are:

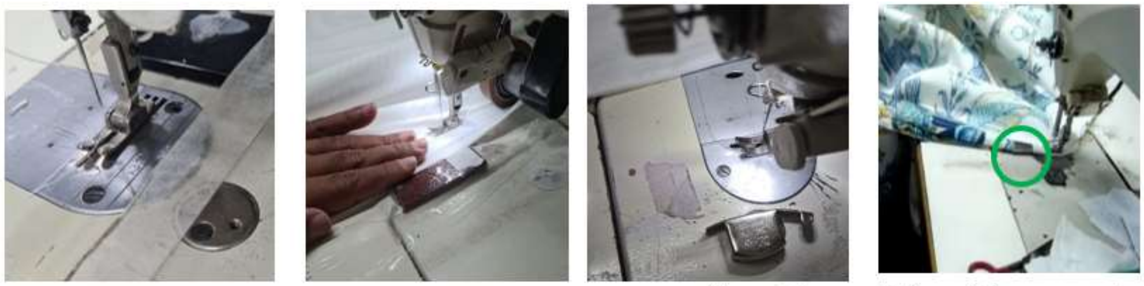
1. Uneven Mock
2. Puckering
3. SPI variation
4. Deep label/ Unsecure label
5. Zigzag Hem

So, to reduce these defects and rework, experts of the field were asked about the solutions related to the mentioned problems.

After asking from the experts, best solution for improving product quality were found to be related to improve the method of performing specific operations in which above defects are high, training and guidance of the operator for improving their skill to handle machine and operation and monitoring condition of the machine. The required solutions are mentioned in Table 4.8:

Table 4.8 Top Defects and their solutions

Defects	Solution
Uneven Mock Zigzag hem	• Use guider/folder guider for even stitch. (P P, 2020; Patil et al., 2017) • Use Tape/marking on machine table for gap measurement. • Check operator handling to use guider properly (Hewan Taye Beyene & Advisor, 2016; Islam et al., 2017; M Masum Alam et al., 2018; Mughal, Khan, & Kumar, 2017; Zaman & Zerin, 2017)
Puckering	• Check/change the feed dog. • Operator machine handling should be improved. • Front reverse size variation should be removed with scissors.
Variation SPI	• Guide operator in inline quality, fix the stitch per inch so that they cannot be changed. (Mughal, Khan, & Kumar, 2017) • Check plastic lock/pin in machine for SPI control
Label Variation	• Operator should be guided about the saving margin. • Marking patterns should be made. (M Masum Alam et al., 2018; Mughal, Khan, & Kumar, 2017; Zaman & Zerin, 2017) • Check label inserted correctly.



: Tape use for uneven mock | Wood block for uneven mock | Magnet guider used for | Folder used for uneven mock.

Figure 4.17 Minimizing uneven mock defects.

The solutions were implemented in those lines of the unit that are designated to make pillows, shams, flat sheet, bed spread, and duvet set. Figure 4.17 shows glimpses of the solution implementation.

In Figure 4.17, it was fixed that the operator must utilize tape or a guider as a reference to maintain an even length throughout the entire mock. This was done to minimize the uneven mock that was occurring in the articles. In the first place, tape and a wood block were utilized as a guider was used to significantly improve the operator's precision. However, to make more improvements, a magnet guider made of steel was tested. This resulted in a significant reduction in the fault, which in turn led to the operator being happy. In addition, the maintenance staff procured folders of any hem size and attach them to the machine, which resulted in an increase in both the precision and the efficiency of the operation. There was a prominent level of importance placed on the understanding of operators in relation to the manner of certain operations; hence, each operator was guided and made aware of the product demand to achieve better results.

When it comes to puckering and SPI variation, it was recommended that the front reverse size variation be examined during the loading process. This was done to ensure that the puckering issue would not arise because of the front reverse issue. In addition, it was recommended that every operator should inspect the machine on the rough fabric before beginning production. This is done to identify any potential issues with the presser foot, feed dog, and SPI variation at the initial stage of production, which will help to reduce the likelihood of these problems occurring thereafter.

For mitigating the label insecure and label variation issues. The operator was initially trained and guided regularly at the start about the amount of margin they can give while inserting label in the hem so that label can be stitched properly. Moreover, as mentioned by the experts' patterns and marking procedure was used in the pilot run to check the difference in the results in the one and half month period that proved to be working in minimizing defect.

Now, to reduce the machine issues that was also reason of increasing the defect percentage in the lines, preventive maintenance procedures required some improvements. Most of the machines were in use without proper maintenance record that was resulting in the major issues like thread tension, thread breakage and needle breakage issues. The Table 4.9 mentions the top issues mentioned in the Table 4.8 along with its reason of occurrence:

Table 4.9 Machine issues and their solutions

Machine issues	**Solutions**
Thread Break Top Stitch	• Machine dirt/fluff must be cleaned. (Akther Liza et al., 2020; P P, 2020; Patil et al., 2017) • Thread quality should be checked and changed if required. • If thread is inserted improperly. Check if thread is passing every required loop. (Hasan et al., 2019; P P, 2020; Patil et al., 2017) • Check needle condition if there is any wear and tear and change if required. • Check and clean needle plate if there is any fluff in it. • Check and adjust needle tension. • Check needle bar if there is any looseness in it. • Check the timing, damage and oil blockage of shuttle resolve it.

Graining Problem	• Check and resolve Upper thread and bobbin thread adjustment. • Any looseness in the bobbin thread and tension spring thread should be eliminated
Skip Stitch	• Check the timing, damage and oil blockage of shuttle resolve it. (Akther Liza et al., 2020; Hasan et al., 2019; Patil et al., 2017) • Check the cleaning of the bobbin and the shuttle and clean the fluff (M Masum Alam et al., 2018; Mughal, Khan, & Kumar, 2017; Zaman & Zerin, 2017)
Puller Problem	• Check for the speed of the puller motor. (Akther Liza et al., 2020)

After implementing all the solutions that are taken from the experts and the literature related to the defects overall due to man, machine, material, and method, the results after implementation were collected and presented in the graphical visuals. These solutions were implemented in stitching lines containing Flat Sheet, Pillow and Euro sham of queen and king sizes.

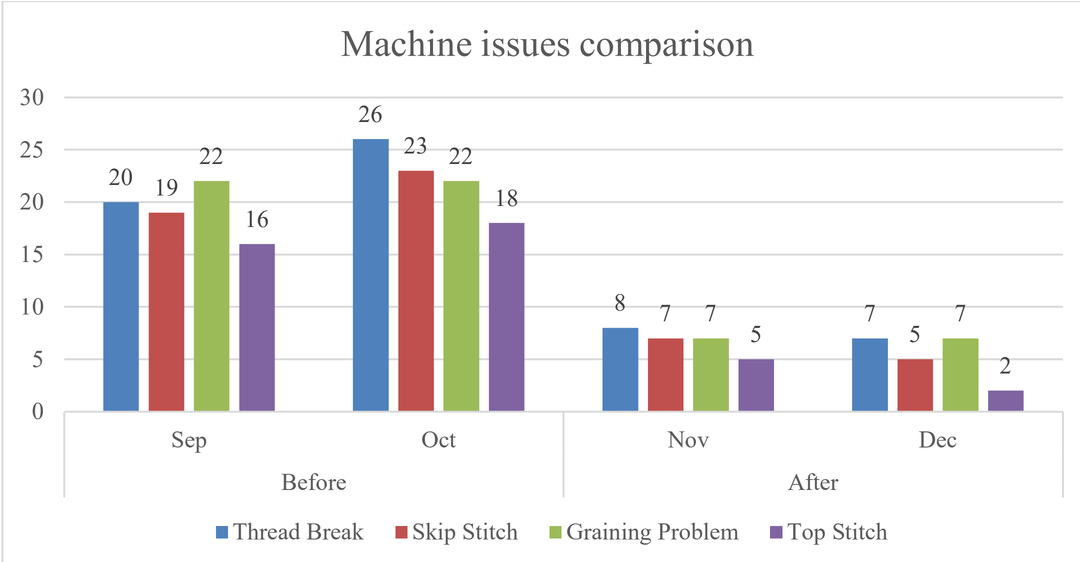


Figure 4.18 Machine issues pre and post solution implementation

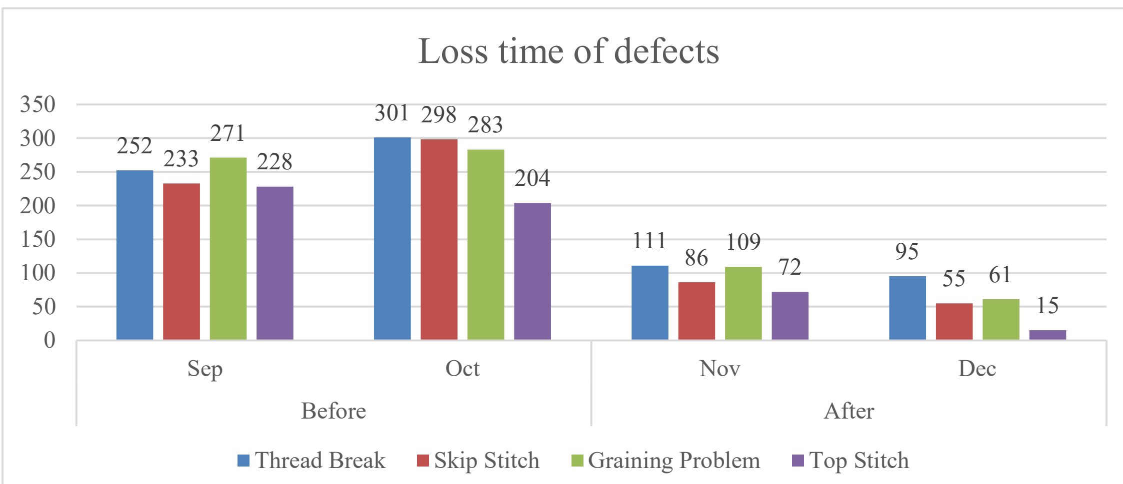


Figure 4.19 Loss time pre and post solution implementation.

Table 4.10 Loss cost comparison in pilot run stitching unit

Month	Machine loss time (Minutes)	Loss CPM at ($)
May	1940	97

Jun	**1655**	82.75
Jul	**1566**	78.3
Aug	**1843**	92.15
Sep	**1864**	93.2
Oct	**1891**	94.55
Nov	**1116**	55.8
Dec	**1061**	53.05

Table 4.10 shows that after the implementation of the solution in the target pilot run stitching unit, significant decrease in the lost cost was observed in the 2 months indicating the success of the solutions implemented in the pilot run.

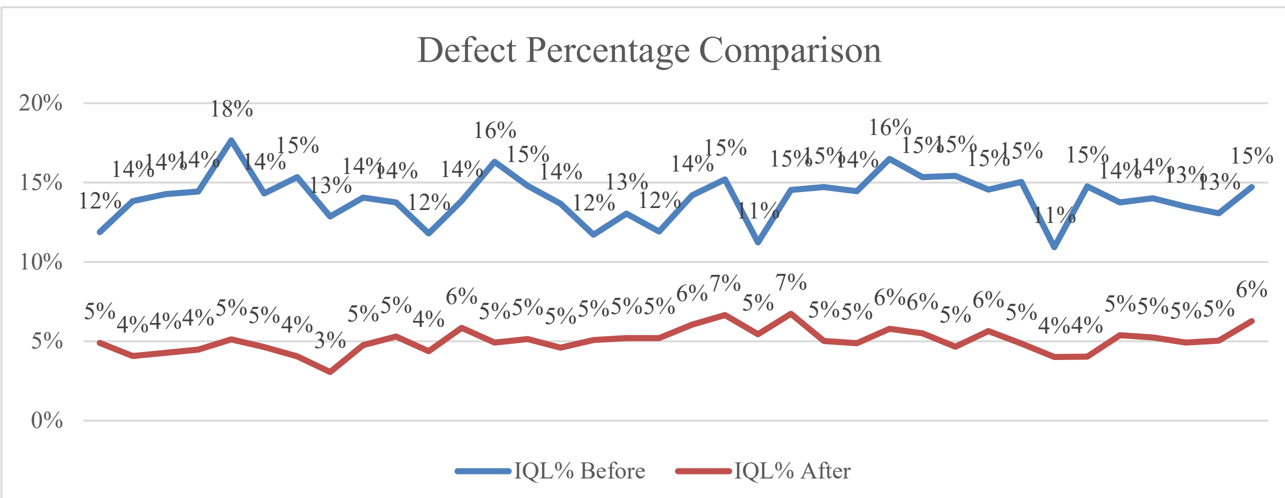


Figure 4.20 Inline defect percentage comparison pre and post solution implementation

In Figure 4.20, daily sewing defects in pillows, shams, flat sheet, and bed skirt are highlighted over 1.5 months. The study includes the evaluation of the proportion of defects that occur in lines, providing significant insights into how the implemented solution affects the overall quality. Figure 4.20 Before the implementation of the proposed solution, the proportion of defects occurring inline was 14%. After the implementation, there was a significant decrease, with the proportion of defects in the inline quality dropping to 5% over the next 1.5 months. The significant reduction of 9% in the proportion of defects occurring during the process indicates a notable enhancement in quality. This highlights the success of the deployed solution in identifying and resolving problems within the specific organizational setting. The graph in Figure 4.20 effectively illustrates this favorable pattern, supporting the numerical results and emphasizing the good influence of the suggested method in decreasing inline faults.

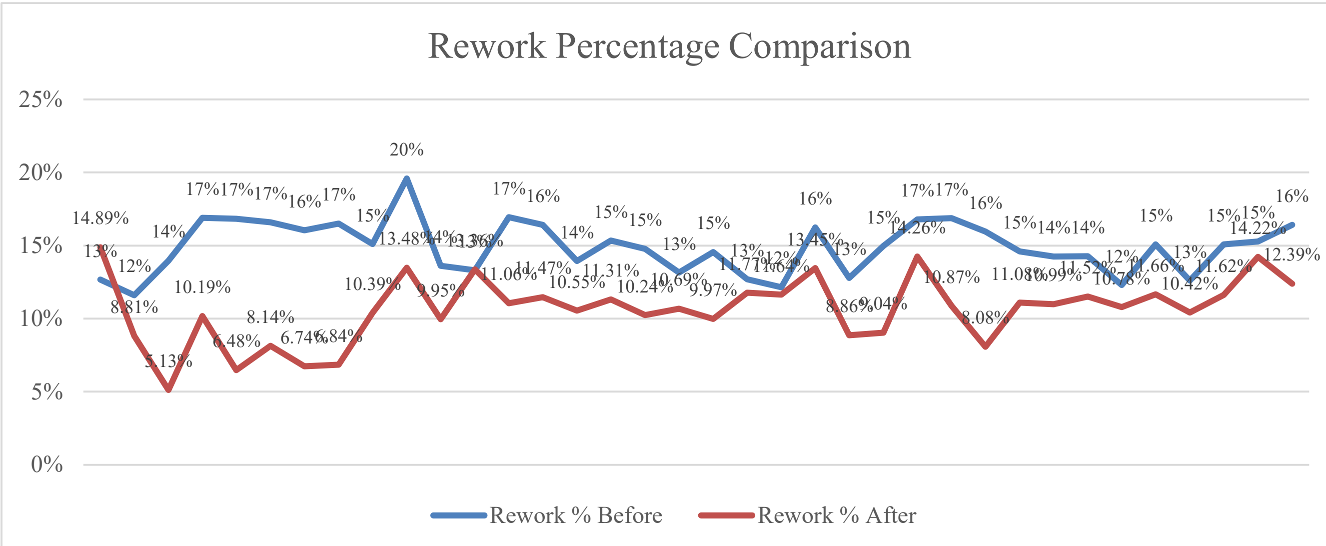


Figure 4.21 Rework percentage comparison pre and post solution implementation

The findings of the comparison study, depicted in Figure 4.21, emphasize the measurable influence of the suggested solution on the rates of rework within the examined organizational setting. Before implementing the proposed approach, we saw an average rework rate of 15% over a period of 1.5 months. After the implementation, there was a noticeable decrease, with the average proportion of rework being 10%. This results in a significant 5% reduction in rework within the initial 1.5 months following the implementation of the solution. The findings provide solid evidence that the implemented solution effectively improves operational efficiency and reduces instances of rework. These results are consistent with the solutions suggested by literature and expert advice.

4.2 Control Phase

The results from the solutions incorporated show that the formerly implemented DMAIC methodology will aid in enhancing the quality and quantity in the home textile sector of Pakistan where manual switching lines are currently operational. In the current circumstances characterized by a significant reduction in customer order volume, such models are beneficial to improve efficiency, reduce defects, and minimize rework and lost cost per minute.

CHAPTER 5: CONCLUSIONS, LIMITATION, AND FUTURE RECOMMENDATION

5.1 General

This chapter includes a concise overview of the investigation, including theoretical and practical contributions, and the research limitations. By offering remedies to overcome these constraints, it also offers prospective suggestions to researchers.

5.2 Conclusion

To summarize, this research highlights the effectiveness of a comprehensive strategy in tackling the complex issues related to the production processes in the home textile industry. This research has effectively identified and reduced risks by employing a thorough approach of integrating QFD, DMAIC and Monte Carlo simulation, resulting in a notable enhancement in prioritized risks to better satisfy client expectations.

By understanding the customer needs, the implementation of the House of Quality enabled the creation of a relation between technical requirements and customer expectations. Consequently, this process facilitated the recognition of crucial risks linked to certain departments of the industry like quality, production, EHS and maintenance, enabling a concentrated and strategic emphasis on sectors that exert the most influence on customer satisfaction.

The use of Monte Carlo Simulation enhanced the risk prioritization process by offering a strong mathematical foundation for identifying and managing the most significant risks. The following adoption of solutions suggested by experts of the field led to a noteworthy decrease in the proportion of defects occurring throughout the production process, dropping from 14% to 5%. Additionally, there was a considerable reduction in the percentage of rework, which decreased to 10% and the lost cost due to machine issues reduced by 59%. The visible benefits highlight the practicality and usefulness of the integrated technique in improving overall results.

5.3 Contribution to the study

This research significantly contributes to current literature by demonstrating the combined utilization of Quality Function Deployment (QFD), Monte Carlo Simulation, and expert-driven solution implementation. Moreover, this study addresses an important need in the existing body of literature, since there has been a lack of research focused on the home textile industry in comparison to the more widely examined garment and apparel sectors. The differentiation is especially important as number and type of operations, fabric properties, and specific fault patterns are inherent in the manufacture of home textile products. This research promotes the discovery and use of integrated approaches in many production fields by suggesting risk prioritization and its mitigation to bring improvement efficiently.

5.4 Limitations

A notable limitation of this research is the length of time for which the proposed quality improvement strategies are monitored after implementation. The outcomes were only monitored and examined during a little period of 1.5 months. Although this time yielded useful information to the immediate effects of an integrated strategy involving Voice of Customer, House of Quality, Monte Carlo Simulation, and quality improvement methods, a longer monitoring period could have uncovered longer-term trends, the sustainability of improvements, and potential emerging challenges. Therefore, the study's temporal limitation hinders a thorough comprehension of the long-lasting effects of the proposed techniques.

Furthermore, it is crucial to recognize that the study is focused on the home textile industry. This particularity provides a contextual constraint since the results and conclusion may not be immediately applicable to other textile industries or industrial areas. The suggested integrated strategy may be influenced by variations in processes, client needs, and operational dynamics across different industries, which might affect its application and efficacy.

5.5 Future Research

For future research, it is suggested to reproduce the present study across other textile industries and wider industrial environments. Expanding the study will not only improve the applicability of the results but also provide a more detailed comprehension of industry-specific intricacies in quality control. Conducting a comparison study across different sectors may help identify similarities and variations in how risks are prioritized. This can provide valuable insights into how well the integrated approach can be adapted and how successful it is in various industrial contexts.

Moreover, it is suggested to prolong the monitoring duration throughout the post-implementation phase to evaluate the durability and enduring effects of the quality enhancement methods. Increasing the duration of the period would provide researchers and practitioners with the ability to recognize developing trends, potential obstacles, and chances for ongoing improvement.

Furthermore, future studies might investigate the interrelationship between other categories of defects. Gaining insight into the relation between defects and their potential to affect one another can offer a comprehensive outlook on quality management. This inquiry has the potential to result in the creation of focused methods for tackling interrelated quality concerns, hence strengthening the overall effectiveness of the quality improvement framework. In summary, these future directions seek to improve and broaden the implementation of the integrated approach to identify and mitigate the risks associated with the processes suggested in this study.

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APPENDIX A: QUESTIONNAIRE FOR RISK EVALUATION

Respondent name: ____________________ Designation: ________________

Experience: ____________________ Gender: Male ☐ Female ☐

Industry Name: ____________________

Monte Carlo Risk Evaluation Form					
RQ=QUALITY RISKS; RP=PRODUCTION RISK; RES= EHS & COMPLIANCE RISKS; RM=MAINTENANCE RISKS					
Risk No.	**Risk ID**	**Description**	**Probability**	**Impact**	**Risk Exposure**
			1 2 3 4 5	**1 2 3 4 5**	**P * I= RE**
R1	R1Q1	Quality defects ratio is higher than 5% in the inline inspection, so the operator was stopped to check the issue			
R2	R2Q2	Defects of the operator were not caught in the line and articles was further stitched and unloaded from the switch track			
R3	R3Q3	Fabric defects were not detected at folding inspection and caught after stitching operations			
R4	R4Q4	More major defects than acceptance quality level was found in prefinal inspection resulting in failure of inspection			
R5	R5Q5	Found defects were not reworkable and the article gets rejected/B-grade			
R6	R6Q6	External auditor fails the external inspection due to major issues found in packed articles when checked.			
R7	R7Q7	There was no QC checked identification on the checked articles/cartons			

R8	R8P1	Produced pieces per day were falling behind the takt time & hourly target			
R9	R9P2	Due to greater rework ratio, production efficiency has dropped			
R10	R10P3	Bottlenecks in the line slowing down the production process			
R11	R11P4	Machine issues creating hurdles in meeting target efficiency			
R12	R12P5	Loss time due to changeover of the article reduced produced minutes			
R13	R13P6	Shipment target was lagging the shipment exit date			
R14	R14ES1	Production floor does not have operator SOP required by customer			
R15	R15ES2	Article defects cannot be traced back to the operator due to no identification sign of article			
R16	R16ES3	Packed cartons were not placed on the pallet			
R17	R17M1	Machine is leaking oil producing oil stains on the fabric			
R18	R18M2	Machine is breaking thread frequently resulting in defects and time loss			
R19	R19M3	Machine is not giving required quality on defined RPM and SPI (Stitches per inch)			
R20	R20M4	Machine overhaul is due and must be sent to workshop			
R21	R21Q8	Customer complains about some defects after the shipment receiving			
R22	R22Q9	Customer rejects whole shipment for not meeting required quality standards			
R23	R23P7	Stitching unit does not have the capacity of making the certain volume of order in specified time			

R24	R24P8	Manufacturing unit did not have the required machine resources for meeting product specification			
R25	R25ES4	They are no fire extinguishers or hose reels available in the manufacturing unit			
R26	R26ES5	Building does not meet the required safety standards			
R27	R27ES6	Safety/fire exit pathways are not specified in the unit			
R28	R28M5	Machine is breaking the needle causing extra needle loss and loss time			
R29	R29ES7	Needle guard and eye guard are not installed in the machine			
R30	R30P9	Fabric cutting was not received at the specified time.			
R31	R31ES7	Response time in case of hazard or accident is very high			

APPENDIX B: QUESTIONNAIRE RESULTS

Monte carlo Risk in home textile

Risk No.	Risk ID	Description	Probability	Impact	Risk Exposure	Probability	Impact	Risk Exposure
			1 2 3 4 5	1 2 3 4 5	P * I = RE			
R1	R1Q1	Quality defects ratio is higher than 5% in the inline inspection so the operator was stopped to check the issue	3	4	13	4	5	20
R2	R2Q2	Defects of the operator were not caught in the line and articles was further stitched and unloaded from the switch track	3	4	12	3	5	15
R3	R3Q3	Fabric defects were not detected at folding inspection and caught after stitching operations	2	3	7	3	5	15
R4	R4Q4	More major defects than acceptance quality level were found in prefinal inspection resulting in failure of inspection	2	3	6	1	4	4
R5	R5Q5	Found defects were not rework able and the article gets rejected/B-grade	2	4	8	2	5	10
R6	R6Q6	External auditor fails the external inspection due to major issues found in packed articles when checked.	1	4	6	2	5	10
R7	R7Q7	There was no QC checked identification on the checked articles/cartons	3	2	6	5	3	15
R8	R8P1	Produced pieces per day were falling behind the takt time & hourly target	3	3	8	3	4	12
R9	R9P2	Due to greater rework ratio, production efficiency has dropped	3	4	13	3	4	12
R10	R10P3	Bottlenecks in the line slowing down the production process	2	3	6	5	3	15
R11	R11P4	Machine issues creating hurdles in meeting target efficiency	3	4	11	3	4	12
R12	R12P5	Loss time due to changeover of the article reduced produced minutes	2	3	7	3	3	9
R13	R13P6	Shipment target was lagging behind the shipment exit date	1	4	6	1	5	5
R14	R14ES1	Production floor does not have operator SOP required by customer	2	2	6	4	1	4
R15	R15ES2	Article defects can not be traced back to the operator due to no identification sign of article	2	2	5	3	3	9
R16	R16ES3	Packed cartons were not placed on the pallet	2	2	4	2	4	8
R17	R17M1	Machine is leaking oil producing oil stains on the fabric	2	3	6	1	5	5
R18	R18M2	Machine is breaking thread frequently resulting in defects and time loss	3	3	9	4	5	20
R19	R19M3	Machine is not giving required quality on defined RPM and SPI (Stitches per inch)	2	4	9	2	4	8
R20	R20M4	Machine overhaul is due and must be sent to workshop	1	3	3	1	5	5
R21	R21Q8	Customer complains about some defects after the shipment receiving	1	5	7	2	5	10
R22	R22Q9	Customer rejects whole shipment for not meeting required quality standards	1	5	6	1	5	5
R23	R23P7	Stitching unit doesn't have the capacity of making the certain volume of order in specified time	1	3	4	1	5	5
R24	R24P8	Manufacturing unit didn't have the required machine resources for meeting product specification	2	3	4	2	3	6
R25	R25ES4	They are no fire extinguishers or hose reels available in the manufacturing unit	1	4	5	1	5	5
R26	R26ES5	Building doesn't meet the required safety standards	1	5	6	1	3	3
R27	R27ES6	Safety/fire exit pathways are not specified in the unit	2	3	5	2	2	4
R28	R28M5	Machine is breaking the needle causing extra needle loss and loss time	3	3	9	4	4	16
R29	R29ES7	Needle guard and eye guard are not installed in the machine	2	3	6	2	2	4
R30	R30P9	Fabric cutting was not recieved on the specified time.	2	3	6	1	4	4
R31	R31ES7	Response time in case of hazard or accident is very high	1	5	6	1	5	5

APPENDIX C: INLINE A REWORK REPORT (BEFORE)

Before							
Date	**LOT SIZE**	**CHECK PCS**	**FLAW**	**IQL (%)**	**T. AUDITS**	**REWORK**	**REWORK %**
4-Oct	5450	507	60	12%	169	21	13%
5-Oct	5950	564	76	14%	188	22	12%
6-Oct	5050	594	86	14%	195	28	14%
7-Oct	6150	408	55	14%	136	21	17%
8-Oct	5610	420	69	18%	140	23	17%
10-Oct	3650	333	48	14%	111	17	17%
11-Oct	3940	560	85	15%	186	27	16%
12-Oct	5070	399	53	13%	133	22	17%
13-Oct	3900	417	57	14%	139	21	15%
14-Oct	3335	345	45	14%	115	19	20%
16-Oct	4200	381	46	12%	127	18	14%
17-Oct	3660	427	56	14%	142	19	13%
18-Oct	3775	411	65	16%	137	22	17%
19-Oct	4000	393	56	15%	131	20	16%
20-Oct	3335	420	57	14%	140	19	14%
21-Oct	4970	704	73	12%	184	28	15%
23-Oct	3650	399	51	13%	133	19	15%
24-Oct	4075	567	71	12%	189	24	13%
25-Oct	5250	495	71	14%	165	23	15%
26-Oct	4450	459	68	15%	153	19	13%
27-Oct	4550	552	63	11%	184	22	12%
28-Oct	4700	513	72	15%	171	27	16%
30-Oct	7650	621	89	15%	207	28	13%
31-Oct	6210	566	81	14%	185	28	15%
1-Nov	5325	462	75	16%	154	26	17%
2-Nov	4185	453	70	15%	151	26	17%
3-Nov	4775	459	70	15%	153	24	16%
4-Nov	4350	508	71	15%	169	24	15%
6-Nov	7100	495	73	15%	165	23	14%
7-Nov	5735	528	50	11%	176	24	14%
8-Nov	6450	630	91	15%	210	26	12%
10-Nov	5290	447	61	14%	149	22	15%
11-Nov	6425	615	86	14%	205	26	13%
13-Nov	7425	594	74	13%	198	30	15%
14-Nov	5950	552	73	13%	184	29	15%

15-Nov	5950	525	76	15%	175	29	16%
		Average Inline %		**14%**	**Average rework %**		**15%**

APPENDIX D: INLINE A REWORK REPORT (AFTER)

After							
Date	LOT SIZE	CHECK PCS	FLAW	IQL (%)	T. AUDITS	REWORK	REWORK %
17-Nov	1000	143	7	5%	47	7	14.89%
18-Nov	5800	603	26	4%	203	20	8.81%
21-Nov	750	117	5	4%	39	2	5.13%
22-Nov	4650	563	25	4%	205	21	10.19%
23-Nov	3655	420	21	5%	140	9	6.48%
24-Nov	4570	574	26	5%	191	16	8.14%
25-Nov	4535	471	19	4%	182	12	6.74%
27-Nov	4400	400	12	3%	133	8	6.84%
28-Nov	6000	522	25	5%	173	18	10.39%
29-Nov	4700	485	26	5%	161	22	13.48%
30-Nov	5250	515	22	4%	171	16	9.95%
1-Dec	5300	524	30	6%	175	23	13.36%
2-Dec	5850	596	29	5%	199	22	11.06%
4-Dec	7880	848	43	5%	285	33	11.47%
5-Dec	7430	745	34	5%	249	26	10.55%
6-Dec	6780	730	37	5%	244	27	11.31%
7-Dec	6405	772	40	5%	258	26	10.24%
8-Dec	5050	687	37	5%	224	25	10.69%
9-Dec	4550	566	36	6%	187	20	9.97%
11-Dec	2665	392	25	7%	128	15	11.77%
12-Dec	4925	651	35	5%	217	26	11.64%
13-Dec	5950	767	50	7%	254	34	13.45%
14-Dec	5300	739	37	5%	245	22	8.86%
15-Dec	5350	743	36	5%	246	22	9.04%
16-Dec	3300	447	25	6%	148	21	14.26%
18-Dec	4405	657	35	6%	218	23	10.87%
19-Dec	4100	562	26	5%	186	15	8.08%
20-Dec	4300	583	33	6%	193	21	11.08%
21-Dec	4300	584	28	5%	194	22	10.99%
22-Dec	3550	483	19	4%	159	18	11.52%
23-Dec	3725	540	22	4%	180	19	10.78%
26-Dec	1200	246	13	5%	81	8	11.66%
27-Dec	1825	303	16	5%	101	10	10.42%
28-Dec	4250	549	27	5%	182	21	11.62%
29-Dec	2440	415	20	5%	138	18	14.22%
30-Dec	4740	650	34	6%	215	23	12.39%
		Average Inline %		**5%**			**10%**

APPENDIX E: MACHINES ISSUES

	Column Labels																	
	Count of Description								Sum of Total Time								Total Count of Descript	Total Sum of Total Time
Row Labels	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Thread Break	25	26	14	21	20	26	8	7	310	300	203	261	252	301	111	95	147	1833
Skip Stitch	21	19	25	16	19	23	7	5	255	245	304	195	233	298	86	55	135	1671
Graining Problem	16	20	16	17	22	22	7	7	195	225	195	198	271	283	109	61	127	1537
Top Stitch	13	16	12	10	16	18	5	2	160	210	148	118	228	204	72	15	92	1155
Puller Setting	14	15	18	25	11	10	7	9	170	185	185	286	145	120	95	115	109	1301
Bobbin Winder Problem	5			4	10	8		6	45			35	105	75		65	33	325
Feed Dog Setting	19	14	16	25	19	8	8	17	215	175	165	292	199	105	90	195	126	1436
Oil Stain			5	1	3	5	9				76	16	48	60	125		23	325
Safety Thread Break	2	1		4	5	4	2	1	25	10		55	72	56	28	10	19	256
Folder Problem						4		1						40		15	5	55
Pressure Foot Problem	2	3	2	6	2	3	3	7	25	35	10	60	30	35	35	85	28	315
Needle Problem			2	1	2	2	9				15	10	26	29	135		16	215
Thread Setting	8	6			4	2	5	5	80	60			45	25	45	65	30	320
Shuttle Timing Problem	13	4	9	8	5	1	5	10	145	45	110	90	60	15	55	85	55	605
Feed Dog Changed						1								10			1	10
Oil Pump Problem	1					1			10					15			2	25
Foot Problem						1								15			1	15
Feed Dog Problem					1	1	1						10	10	15		3	35
Gauge Set Changed						1								10			1	10
Looper Problem	1	1	2	2		1	2	10	10	10	20	25		10	25	125	19	225
Tension Post Problem				1		1		1				5		15		15	3	35
Cutter Problem	1	1	2	2	1		3	2	10	10	25	20	10		34	25	12	134
Knife Problem	1								5								1	5
Safety Skip	1		2	1					10		35	13					4	58
Folder Setting		1								10							1	10
Connecting Rod Problem	1								10								1	10
Looper Setting		1								15							1	15
Belt Problem				1								15					1	15
Button Problem					1								15				1	15
Shuttle Oil Problem	6	3	1	4					60	40	10	40					14	150
Button Setting		1								10							1	10
Link Pin Problem							1								10		1	10
Machine Jam Opened	1								45								1	45
Plate Needle Problem				1								10					1	10
Machine Replaced		1								45							1	45
Puller Problem		1	1		2					10	10		25				4	45
Main Shaft Problem		1								0							1	0
Reverse Problem	1								15								1	15
Stitch Problem			1				2				15				26		3	41
Bush Setting				1								15					1	15
Tension Post Setting	1								10								1	10
Shuttle Problem				3	1							39	10				4	49
Oil Adjustment					1								10				1	10
Bobbin Setting					1								15				1	15
Oil Problem			1	2	2		1				10	20	25		10		6	65
Folder Changed								3								35	3	35
Needle Bar Problem	3		1	1					25		10	15					5	50
Folder Change	6	1	2						80	5	20						9	105
Cam Problem				1	1		1					10	10		10		3	30
Looper Thread Break	2	1							25	10							3	35
Bearing Problem					1								20				1	20
Machine Jam	1								0								1	0