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Six Sigma TQM Implementation for Defects Reduction & Sigma Level Improvement: A case study in Best Shirt Limited

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Abstract

The apparel industry faces strong global competition and firms must balance product quality with production efficiency. Defects such as misaligned seams, skipped stitches, and broken threads drive up waste, rework, and costs while weakening competitiveness. Researchers have used Six Sigma and Total Quality Management (TQM) to address these issues, and their studies show improvements in quality, cost, and. Yet no study, to the best of our knowledge, has combined Six Sigma and TQM in a single framework that both reduces garment defects and improves sigma performance. This study applies the DMAIC cycle with TQM tools including Pareto charts, Cause–effect diagrams, and Standard Operating Procedures (SOP) to reduce sewing defects at Best Shirt Limited. The framework reduced defect rates and raised the sigma level from 2.1592 to 2.5427. These results confirm that integrating Six Sigma and TQM provides a practical path to sustainable quality improvement in garment manufacturing.

Keywords
DMAIC, Six Sigma, TQM, Pareto Analysis, Cause-Effect Diagram, Sigma Level.

1. Introduction
Mesopotamia, Egypt, and Rome made the earliest example of shirt fabrication and still fabricating for thousands of years. Both men and women wore the tunic, which was a basic shirt-like clothing. By the Middle Ages, shirts had developed into linen undergarments, mostly worn by males. The production of shirts transitioned from rigid designs in the 18th and 19th centuries to widespread manufacturing methods in the early 20th century. The mid-20th century experienced advancements in mechanization, the introduction of synthetic fabrics, and the establishment of global supply chains.

In the 21st century, Lean Six Sigma methodologies enhance product quality & efficiency (Mridha et al., 2019; Kurnia et al., 2021). High-pressure situations in the clothing industry can result in sewing flaws like skipped stitches, open seams, and broken stitches. These are frequently brought on by machine malfunctions and human inefficiency. Expert assistance and routine maintenance aid in resolving these problems. Bangladesh's apparel exports are impacted by sewing flaws since they result in rework, rejections, increased expenses, and decreased competitiveness (Alie & Sarjono, 2022; Ahmed et al., 2022). In an era where global competition and consumer expectations are at an all-time high, the garments industry faces relentless pressure to deliver high-quality products while maintaining cost efficiency and production speed. Defects in garment manufacturing not only lead to increased waste and rework but also erode customer trust and brand reputation. Traditional quality management approaches often fall short in addressing the root causes of defects and optimizing production capacity, leaving manufacturers in search of more robust and sustainable solutions.

Entering Lean Six Sigma, synergistic methodology that combines the waste-reducing principles of Lean Manufacturing with the defect-minimizing rigor of Six Sigma. While Lean Six Sigma has been widely adopted in industries such as automotive, healthcare, and electronics, its application in the garments industry remains underexplored, particularly in the context of simultaneously reducing defects and enhancing production efficiency (Fibriani et al., 2024; Sjarifudin et al., 2022). This research paper seeks to bridge this gap by investigating the implementation of Lean Six Sigma in the garments industry, with a focus on its dual potential to mitigate defects and boost production efficiency. Unlike previous studies that have often treated defect reduction and capacity improvement as separate challenges, this research adopts a holistic approach, exploring how Lean Six Sigma tools and techniques can be tailored to address both objectives in tandem.

By leveraging methodologies such as DMAIC (Define, Measure, Analyze, Improve, Control), value stream mapping, and statistical process control, this study aims to uncover innovative strategies that can transform garment manufacturing processes. Furthermore, the research will delve into the cultural and operational challenges unique to the garments industry, offering practical insights into how organizations can overcome barriers to successful Lean Six Sigma adoption. The findings of this study are expected to provide garment manufacturers with an actionable framework for achieving operational excellence, reducing defects, and maximizing production capacity. In doing so, this research not only contributes to the academic discourse on Lean Six Sigma but also offers a fresh perspective on its application in an industry that is pivotal to the global economy yet often overlooked in the context of advanced quality management practices. As the garments industry continues to evolve, the integration of Lean Six Sigma could serve as a catalyst for sustainable growth, enabling manufacturers to meet the demands of a dynamic market while maintaining a competitive edge (Sjarifudin et al., 2022).

1.1 Objective
1. To determine the main defect categories and present rate of defects in the clothing production process.
2. To determine the underlying causes of failures by improving processes and reducing defects in the clothing manufacturing industry.
3. To suggest SOP for the stakeholders of RMG industries.

2. Literature Review

The integration of Six Sigma and TQM methods assists in solving challenges like defects and poor workflow in garment factories. The approach of Six Sigma involves a precise and data-driven process to identify and resolve quality problems, while TQM encourages the entire organization to work towards improvements. Garments usually follow the DMAIC steps (Define, Measure, Analyze, Improve, Control) to keep production focused and track real results. That approach proved effective in a real-world setting—a DMAIC project at a woven garments plant successfully reduced defect rates, lowered costs, and improved service speed (Kankariya & Valase, 2017). Using tools such as cause-and-effect diagrams and Pareto charts produced fewer defects and better on-time delivery (Nhu et al., 2023). Additionally, research shows production systems built on Six Sigma and TQM produce higher operational efficiency (Pacheco-Bonilla et al., 2020; Sutrisno, 2023). When these methods are applied correctly, firms tend to achieve better cost performance, higher productivity, and fewer defects (Akbar et al., 2024; Sanrio Putri & Agung Saryatmo, n.d.). Several research efforts focus on defect reduction and improved efficiency independently. The challenge presented here is that both objectives could be accomplished simultaneously by using the same set of tools that can improve both defect reduction and the utilization of what factories already have. The research fills that gap by combining Six Sigma and TQM methodologies to decrease defect instances and boost capacity. The paper is intended to offer more than just another theoretical concept by providing a step-by-step solution that can implement these principles on the factory floor. As the marketplace continues to shift and competition increases, integration of these principles provides factories with the opportunity to offer improved quality, capacity, and long-term efficiencies.

3. Methods

1. Collecting data on sewing defects that are occurring in the production line of a shirt.
2. Illustrating these with application of Pareto Chart & Sigma level table.
3. Finding the "Vital few" defects that have most impact by conducting a pareto analysis.
4. Making cause effect diagram for each of them to find their root causes.
5. Developing and implementing SOP to address the identified "vital few" defects.
6. Measuring the effectiveness of SOP in reducing rework rates and improving quality standards by Six sigma TQM.

DMAIC approach for reducing defects:

Define – This initial stage involves clearly outlining the project's purpose, scope, and objectives. It includes identifying the team's responsibilities, understanding customer needs and expectations, and setting specific goals for the project.

Measure – In this stage, key metrics are selected to assess current process performance. Data is collected to establish a baseline, which helps in evaluating the effectiveness of future improvements and monitoring progress.

Analyze – This phase focuses on identifying the root causes of defects or issues within the process. It involves analyzing data to understand why problems occur and prioritizing areas for improvement.

Improve – During this step, potential solutions are developed and tested using various techniques, including experimentation and statistical analysis. The goal is to implement changes that reduce defects and enhance process quality.

Control – is the last step, which makes sure that the gains are sustained over time. It includes standardizing the enhanced procedures to avoid regression, recording modifications, and keeping an eye on continuous performance.

Defects Rate Formula

Defects Rate (%)=(Total Defects/Total Checked Units)×100

DPMO (Defects Per Million Opportunities) Formula

DPMO=[(Total Defects×1,000,000)/(Total Checked Units×Opportunities per Unit)]

Sigma Level Formula

Sigma Level = $\Phi - 1(1 - \frac{DPMO}{1000000})$

4. **Data Collection:** We have collected data using Check Sheets for multiple defects from Best Shirt Limited within 18/01/2025 to 25/01/2025 (Table 1-Table 6).

Table1. Check Sheet for defects

Defects Name	D.Q. (18/01/2025)	D.Q. (19/01/2025)	D.Q. (22/01/2025)	D.Q. (24/01/2025)	D.Q. (25/01/2025)
Uneven	208	215	205	209	218
Broken Stitch	120	115	117	112	110
Skip Stitch	112	110	113	115	118
Slanted Stitch	160	165	162	168	166
Projection	56	54	53	58	163
Oil spot	152	155	160	158	162
Button ½ stitch	48	50	53	47	152
Irregular S.P.I.	40	42	44	46	38
Puckering	72	74	70	73	72
Reverse	64	60	66	68	70
Ropping	48	46	48	49	49
Button Displace	56	60	58	62	55
Uncut thread	32	30	34	35	38
Raw edge Out	48	48	54	47	49
Lob Show	56	54	60	62	54
Tension Loose	48	48	46	49	50

5. Result and Discussions:
5.1 Numerical Results:

Table 2. Sigma Level & DPMO Table

Sigma Level	**DPMO** (Defects Per Million Opportunities)
1 Sigma	690000
2 Sigma	308537
3 Sigma	66807
4 Sigma	6210
5 Sigma	233
6 Sigma	3.4

Table 3. Data of Sigma Level before implementing Six sigma TQM

Date	Total Checked Units	Total Defects	Defects Rate	DPMO	Sigma Level
18/01/2025	5200	1320	25.38%	2,53,846.15	2.1624
19/01/2025	5250	1326	25.26%	2,52,571.43	2.1664
22/01/2025	5310	1343	25.29%	2,52,919.02	2.1653
24/01/2025	5300	1358	25.62%	2,56,226.41	2.1550
25/01/2025	5270	1364	25.88%	2,58,823.53	2.1469
	Total=26330	Total=6711	Avg.=25.5%		Avg.=2.1592

Sample Calculation: For 18/01/2025, the calculation of Defects Rate, DPMO and Sigma Level are:
Defects Rate (%)=(Total Defects/Total Checked Units)×100
= (1320/5200)× 100
= 25.38%

DPMO=[(Total Defects×1,000,000)/(Total Checked Units×Opportunities per Unit)]
=[(1320×1,000,000)/(5200×1)]
= 2,53,846.15

Sigma Level = $\Phi{-1}(1-\frac{DPMO}{1000000})$

$= \Phi{-1}(1-\frac{253846.15}{1000000})$

= 0.662435+1.5

=2.1624

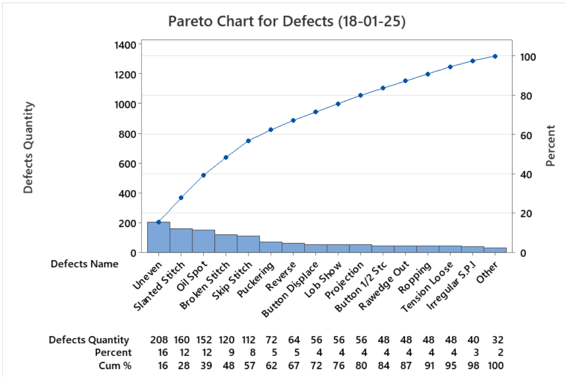
Table 4. Data of Sigma Level after implementing Six sigma TQM

Date	Total Checked Units	Total Defects	Defects Rate	DPMO	Sigma Level
20/02/2025	5000	810	16.2%	162000	2.4862
21/02/2025	4830	760	15.73%	157349.89	2.5054
22/02/2025	5100	790	15.49%	154901.96	2.5156
23/02/2025	4580	650	14.19%	141921.39	2.5717
24/02/2025	4670	599	12.83%	128265.52	2.6346
Average	Total=24180	Total=3609	Avg.=14.89%		Avg.=2.5427

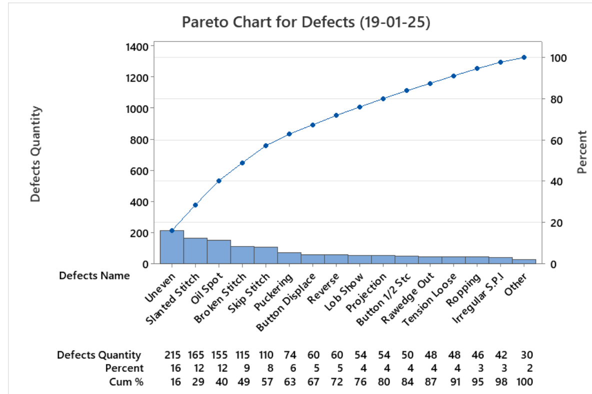
Six sigma TQM reduces significantly defects rate & increases sigma level.

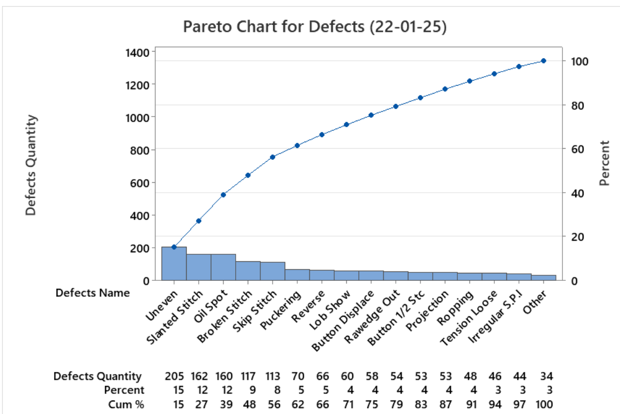
5.2 Graphical Results

Pareto Chart: A Pareto Chart is a bar graph that ranks problems or causes based on their frequency or impact, emphasizing the most critical issues (80/20 rule) within 20/02/2025 to 24/02/2025. The purpose of this analysis was to identify the important causes behind 80% of the problems in the sewing process. Focusing on these important 20% of causes can significantly cut down on waste and rework in the production line. Here, Figures 1 represent Pareto charts showing the distribution of major sewing defects across different production days. The analysis identifies uneven stitch, broken stitch, slanted stitch and oil spot as the most significant contributors to total defects. The cumulative percentage curves demonstrate that a small number of defect categories are responsible for nearly 80% of the observed quality problems, thereby confirming the applicability of the Pareto principle. The recurrence of similar defect patterns over multiple days indicates the existence of systematic process-related issues rather than random variation. Consequently, these defects were selected as the “vital few” for focused improvement within the Six Sigma TQM framework.

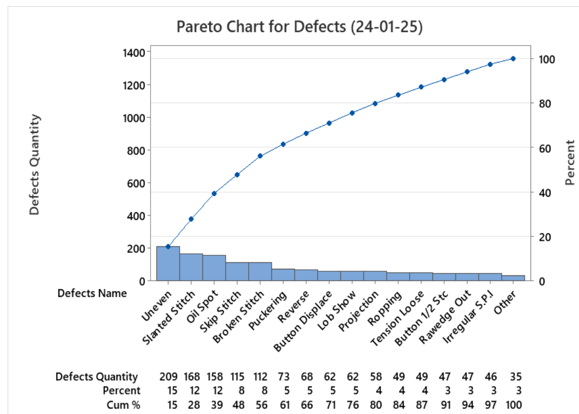


(a)





(c)



(d)

(e)

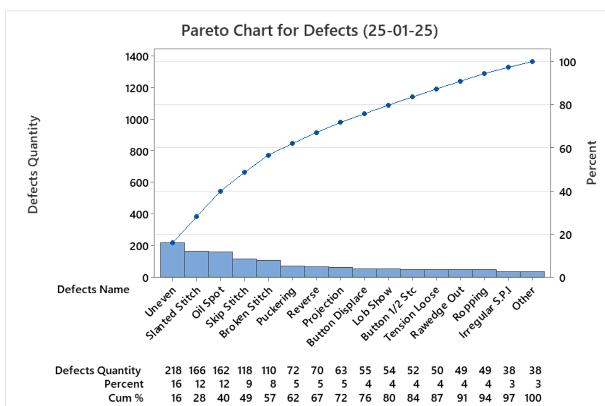


Figure 1. Major defects contributing to the overall defects on (a) 18-01-25, (b) 19-01-25, (c) 22-01-25, (d) 24-01-25, (e) 25-01-25.

5.3 Proposed Improvements:

Cause & Effect diagram: A Cause-Effect Diagram (Fishbone Diagram) identifies possible causes of a problem which needs to be addressed. It sorts issues into categories such as Man, Machine, Method, Material, Management, Measurement, Environment from which the center can then be analyzed, improving overall problem solving and process efficiency. This cause effect diagram assists to find out exact causes of 20% vital few' problems. Here, Figures

2 illustrate cause-effect (fishbone) diagrams developed for the identified critical defects including broken stitch, oil spot, skip stitch, slanted stitch, and uneven stitch. Root causes are classified into Man, Machine, Method, Material, Measurement and Management. The analysis indicates that improper machine settings, inadequate preventive maintenance, inappropriate needle and thread selection and limited operator skill or training are the primary factors causing defects. These diagrams provide a systematic understanding of the underlying causes and form the basis for developing targeted Standard Operating Procedures (SOPs) aimed at eliminating root causes and achieving sustainable quality improvement.

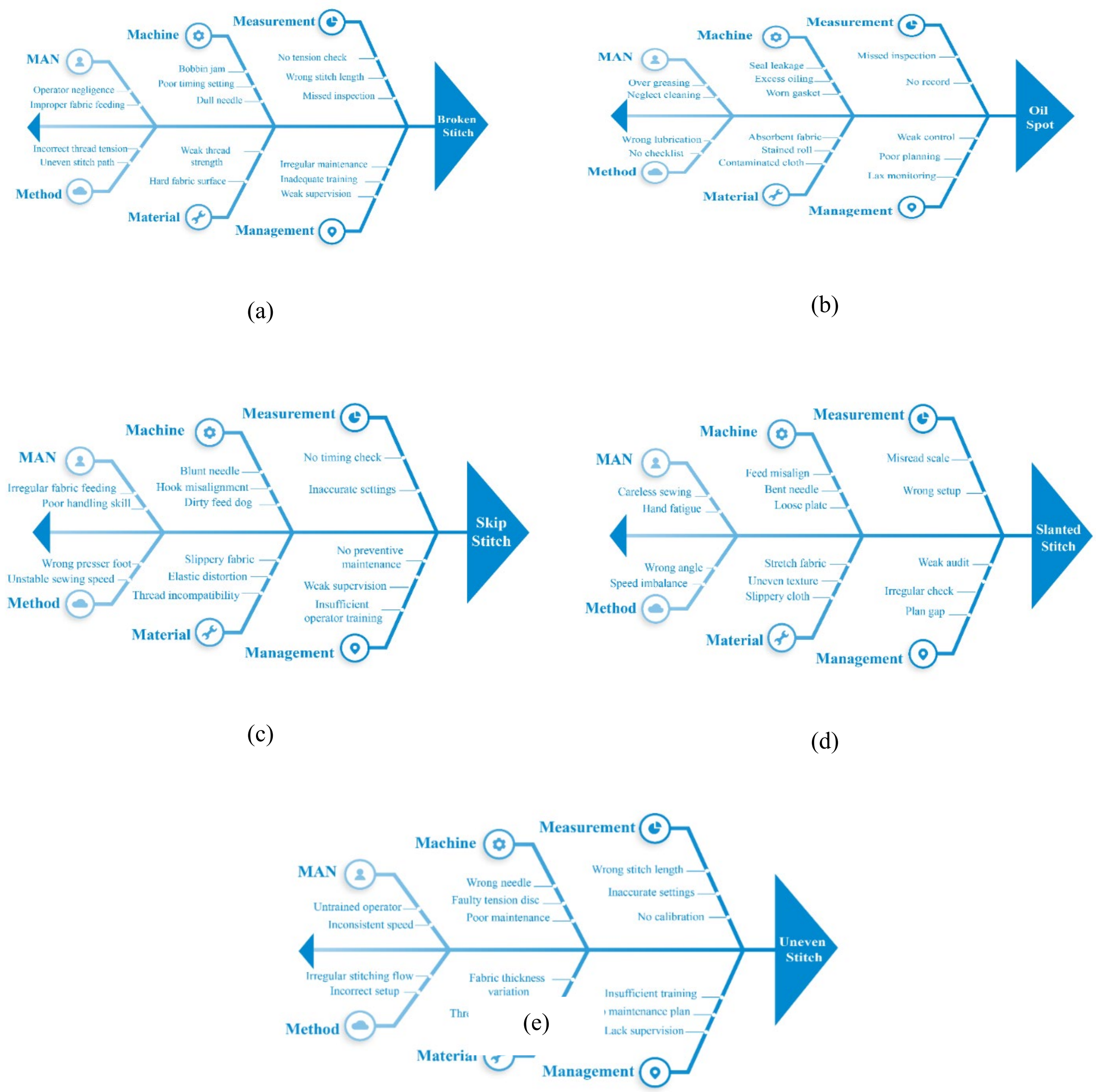


Figure 2. Fishbone diagram to identify root causes of (a) Broken Stitch, (b) Oil Spot, (c) Skip Stitch, (d) Slanted Stitch, (e) Uneven Stitch

Creating Standard Operating Procedures (SOP) for detected defects: A Standard Operating Procedure (SOP) is a written set of instructions that outlines the exact steps required to complete a specific task or operation. Organizations use SOPs to ensure that all processes are done consistently, safely, and in accordance with industry rules and company policies.

Table 5. Standard Operating Procedures (SOP) for detected defects

Defects	Solution
1. Uneven Stitch (Operation Manual Sewing Machine, 2000)	To avoid discrepancies, make sure the thread tension is accurate, use the right needle and presser foot, keep the machine settings in check, instruct personnel on how to handle cloth, and do routine machine maintenance.
2. Broken Stitch (Masum Alam, 2021)	For smoother sewing, use the appropriate needle and thread, maintain machine timing, clean the bobbin area, adjust thread tension appropriately, and instruct personnel on proper fabric handling.
3. Skip Stitch (Measure Your Sew-How Solving Common Sewing Machine Problems " ’164, n.d.)	For stable fabric movement while sewing, check the needle's sharpness, adjust the thread tension, make sure the needle and hook are timed correctly, clean the feed dogs, and use the appropriate presser foot.
4. Slanted Stitches (Binjie XIN et al., 2009)	To maintain straight and consistent stitches, make sure you feed the fabric correctly, use the appropriate presser foot, change the needle position, keep the thread tension level, and check the feed dog alignment.
5. Oil spot (Operation Manual Sewing Machine, 2000)	Avoid overlubricating, make sure the fabric doesn't come into contact with oily parts when sewing, use the right kind of oil, wipe extra oil off machine parts, and execute routine maintenance.
6. Button 1/2 Stitch (Operation Manual Sewing Machine, 2000)	Button 1/2 Stitch can be fixed by making sure the buttonhole is aligned correctly, adjusting machine settings, using the right stitch pattern, checking thread tension, and routinely checking attachments to hold buttons securely without leaving any stitching gaps.
7.Irregular S.P.I(Operation Manual Sewing Machine, 2000)	Stitch length settings should be adjusted appropriately, feed dog movement should be constant, fabric feeding should be even, thread tension should be checked, and machine speed should be calibrated for uniform stitch creation in order to address irregular S.P.I.
8.Puckering (Dunne, 2020)	Uneven fabric surfaces that result in wrinkles or distortions are known as puckering defects. An uneven texture is usually the result of tension variations in the cloth during manufacture.
9.Reverse (Operation Manual Sewing Machine, 2000)	When the inside side of the cloth is visible on the outside, it is known as the reverse fault. This frequently results from incorrect fabric orientation or stitching during garment manufacture, which detracts from both appearance and quality.
10. Ropping (Operation Manual Sewing Machine, 2000)	A weaving flaw known as "ropping" occurs when threads twist or bunch together, giving the appearance of rope. Usually, it results from uneven bobbin winding or incorrect yarn tension.
11. Button Displace (Roy & Prakash, n.d.)	Incorrectly sewed buttons can cause misalignment or detachment, which is known as button displacement. This flaw, which affects the operation and appearance of the clothing, might be caused by inadequate stitching, an incorrectly sized button, or stretch in the fabric.
12. Uneven threads(Operation Manual Sewing Machine, 2000)	Inconsistencies in fabric thickness, color, or texture are referred to as uneven flaws. These defects give a product a non-uniform look or feel and are caused by anomalies in the knitting, weaving, or finishing processes.
13. Projection (Masud, 2010)	Regular quality inspections, improved fitting procedures, and staff training on precise measurements are all necessary to address RMG projection flaws and guarantee that clothing efficiently satisfies design requirements.

14. Skip stitch (Operation Manual Sewing Machine, 2000)	A skip stitch fault occurs when the sewing machine fails to stitch in specific places, resulting in holes or gaps. Inaccurate machine settings, problems with the needle, or irregular fabric feeding can all cause this.
15. Tension Loose (Masud, 2010)	Make sure the tension settings are correct, look for worn belts or pulleys, and confirm motor alignment in order to address the RMG tension loose problem. To avoid slack and guarantee reliable performance, regularly inspect and maintain your machines.
16. Rawedge Out (Operation Manual Sewing Machine, 2000)	To address RMG raw edge out defects, ensure proper needle alignment, correct thread tension, and appropriate feed dog height. Regularly inspect and maintain the machine for optimal performance.

5.4 Validation

Table 6. Sigma level before and after implementing Six sigma TQM

Sigma Level (Before)	Sigma level (After)
2.1624	2.4862
2.1664	2.5054
2.1653	2.5156
2.1550	2.5717
2.1469	2.6346
Avg.=2.1592	Avg.=2.5427

6. Conclusion

The literature indicates that Six Sigma TQM is a powerful methodology for reducing defects and improving Six Sigma the garment industry. By systematically applying the DMAIC framework and utilizing various Six Sigma and TQM tools, garment manufacturers can achieve significant improvements in quality, productivity, and competitiveness. These studies collectively demonstrate the potential of Six Sigma TQM to transform garment production processes and meet the demands of a competitive market**.**

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