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DATA-DRIVEN PROCESS IMPROVEMENT IN TEXTILE SPINNING THROUGH LEAN SIX SIGMA METHODOLOGY

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Abstract
The textile spinning industry is a cornerstone of the textile value chain but continues to face pressure to deliver higher quality and efficiency under growing customer expectations. This study applies Lean Six Sigma (LSS) principles using the DMAIC framework to analyze and improve quality performance in a ring-spinning mill. A dataset of 193,695 yarn cones produced over three months was examined. Baseline analysis revealed 20,705 defects (10.69%), yielding a sigma level of ≈2.7 (Z bench 1.24, +1.5σ shift). Using Pareto analysis, yarn breakage emerged as the most critical defect. Root causes were explored through a fishbone diagram and 5-Why analysis, while a Value Stream Map identified non-value-added activities consuming 26% of total cycle time (70 min of 269.5 min). Improvement actions focused on maintenance practices, standard operating procedures, and training. After intervention, defects were reduced to 9,053 (4.67%), and the sigma level improved to ≈3.2, representing a 56.3% reduction in defects. The estimated financial benefit was PKR ~25.3 million per month in reduced losses. The study demonstrates how transparent application of LSS tools can enable spinning mills to enhance quality, reduce waste, and achieve sustainable cost savings.

INTRODUCTION

The textile spinning sector is a vital component of the overall textile industry, as the properties of yarn directly influence every subsequent stage of fabric and garment production. Yarn can be produced from a wide variety of fibers, with characteristics tailored to its intended end use. It is therefore the fundamental raw material required for producing grey fabrics, ready-to-wear garments, and a broad range of other textile products [1].Although spinning is one of the oldest textile processes, it remains technically complex and highly competitive, driven by continuous innovations in machinery, quality standards, and customer expectations. Today, the industry faces dual pressures: preserving traditional production practices while simultaneously adapting to modern, data-driven methods of quality management [2].In this context, Lean Six Sigma (LSS) has emerged as a promising methodology for systematically improving process performance. LSS integrates lean principles that eliminate waste with Six Sigma tools that reduce variation and defects. Recent studies indicate a growing application of LSS in textile sectors worldwide, including spinning, due to its potential to enhance efficiency, improve product quality, and achieve cost savings [3]. However, evidence-based research in spinning—particularly with transparent data and sigma-level validation—remains limited.This study seeks to implement LSS in a ring-spinning environment, focusing on the identification of Critical to Quality (CTQ) factors, quantification of defect levels, and elimination of non-value-added activities. By applying the DMAIC framework over a three-month production dataset, this work aims to: Quantify baseline defect levels and sigma performance. Identify the most significant sources of defects through Pareto and root cause analysis. Apply improvement actions using tools such as fishbone diagrams, 5-Why analysis, and Value Stream Mapping. Demonstrate the impact of these interventions on defect reduction, sigma improvement, and cost savings. The overarching objective is to provide practical evidence that LSS can serve as a sustainable improvement strategy for the spinning industry, enabling mills to remain competitive in increasingly demanding markets.

Literature Review

The application of **Lean Six Sigma (LSS)** across multiple industries, including textiles and chemicals, has demonstrated significant improvements in both quality and productivity [4]. LSS combines the waste-elimination focus of lean with the defect-reduction and variation-control principles of Six Sigma, creating a powerful hybrid methodology for operational excellence (5). Within the textile sector, LSS has been recognized as an effective approach to **shorten cycle times, reduce defects, and improve profit margins** [3].The textile industry is particularly critical to Pakistan's economy, contributing approximately **8.5% of GDP** and employing nearly **40% of the industrial labor force**. In 2024 alone, Pakistan produced nearly **7 million cotton bales** [7]. Given this scale, quality improvements in spinning operations have a direct impact on both industrial competitiveness and national economic performance. Recent studies highlight the role of LSS in providing **real-time visibility of process variation** and enabling continuous quality enhancement (6). These tools are increasingly applied in spinning to **improve winding speed, stabilize variation, and eliminate non-value-added activities** [8].The literature consistently shows that LSS enhances efficiency and productivity by integrating complementary strengths: lean eliminates waste, while Six Sigma reduces process variability. Together, they not only lower costs but also enhance customer satisfaction [3]. Case studies confirm its potential—for example, application of DMAIC has improved parameters such as **fabric width shrinkage in T-shirt production** (10). Yet, despite promising results in apparel and fabric studies, the **specific effectiveness of LSS in spinning remains underexplored,** warranting further research. Several challenges to LSS adoption in textiles are noted. The industry often depends on **imported raw materials**, where inconsistent quality leads to variability in yarn defects [11,12]. Other factors, such as **organizational culture, supplier quality, and management commitment**, are also critical determinants of LSS success [13]. Nonetheless, literature suggests that these challenges can be mitigated through stronger quality policies, robust supply chain management, and staff training. Finally, Six Sigma has had a marked influence on redefining industrial quality standards and customer expectations. Simultaneously, lean tools remain the most widely used framework for minimizing waste in manufacturing [14]. The integration of both methodologies through LSS is therefore seen as a **strategic necessity** for the textile industry to remain globally competitive and sustainable. DMAIC is a closed loop process [15]. Is use statistical tools to analyze data and target quality issues while focusing on overall performance of n industry [16]. It tackles the process variability [17] and suggests problem solving techniques. Six Sigma emphasizes on crucial parameters of the process which are critical to customers [18]. Basing upon those parameters, it identifies flaws and improve performance with viable corrective measures leading to customer satisfaction [19]

Methodology

This research adopts a quantitative approach to evaluate the impact of Lean Six Sigma (LSS) tools on quality improvement in the textile spinning sector. The focus is on validating how structured application of the DMAIC framework can reduce defects, optimize processes, and improve sigma levels. A dataset of 193,696 yarn cones produced over three months was analyzed. The large sample size increases the reliability of statistical calculations of defect rates and sigma performance. Defects were identified through routine quality inspection at the spinning mill, using defined categories of Critical to Quality (CTQ) factors such as yarn breakage, nep generation, and slubs. To ensure measurement reliability, inspection was performed by trained personnel under standard operating procedures. The research was systematically conducted in four phases aligned with DMAIC: Phase I – Define: Problem identification, objective setting, and literature review. Defect categories and CTQs were formally defined. Phase II – Measure & Analyze: Weekly defect data were collected and evaluated using Pareto analysis to highlight the most significant contributors to defects. Fishbone diagrams and root cause analysis were employed to identify underlying causes. The baseline sigma level was calculated from the observed defect rates, based on defects per unit. Phase III – Improve: A Value Stream Map (VSM) was used to identify non-value-added (NVA) activities in the spinning workflow. Improvements were introduced to reduce variation, standardize maintenance routines, and address root causes of defects. A time study was conducted to quantify value-added versus non-value-added operations across process stages.

Phase IV – Control: Sustaining improvements through implementation of a control plan, quality training for staff, and Total Quality Management (TQM) initiatives. Defect levels were recalculated, sigma improvement was measured, and cost savings were estimated.

Throughout the study, standard Six Sigma formulas were applied. For attribute data, **U-charts** were used to monitor variation and check whether weekly defect rates fell within control limits. The sigma level was computed from defect percentages, with the **assumption of one defect opportunity per cone** unless otherwise specified. Cost analysis was performed using the prevailing market value of yarn to estimate monthly savings due to defect reduction.

This structured methodology allows a transparent comparison of **before-and-after performance,** ensuring that improvements are both **statistically valid** and **practically sustainable** in a spinning mill environment.

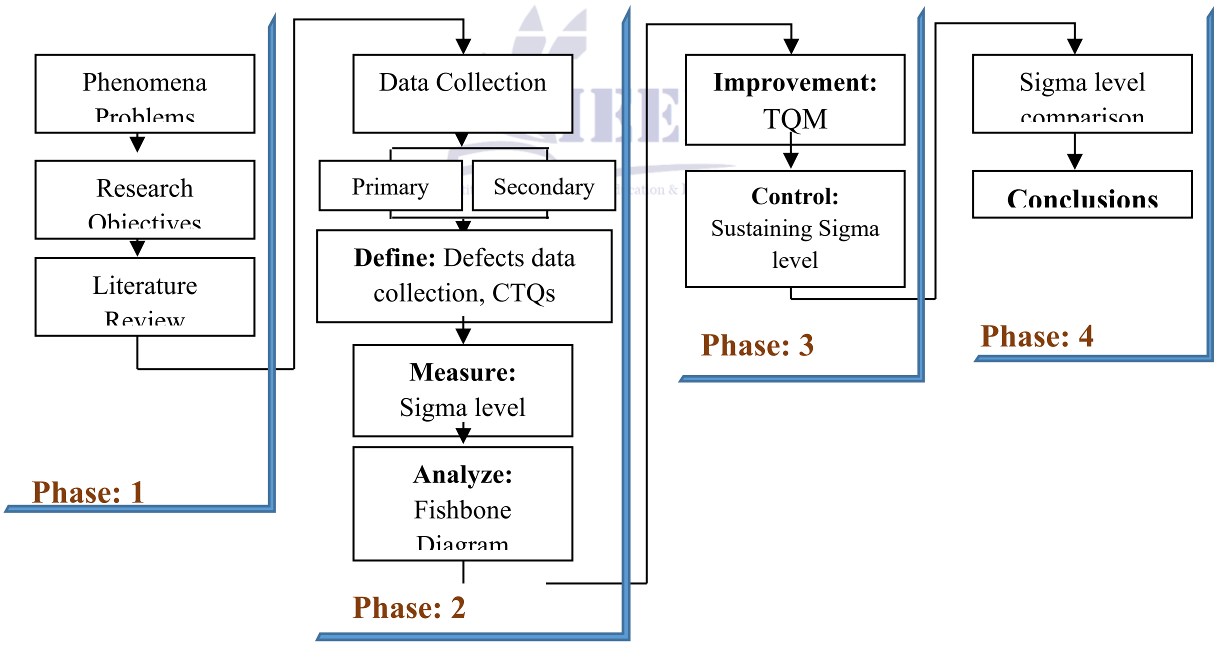

Figure 1: Study Work Flow Diagram

Results and Discussion

DMAIC

Define phase:

In this phase, the major factors contributing to quality issues were identified. Defect ratios were found to vary across different stages of the spinning process. Over the three-month production period of 193,695 cones, a total of 20,705 defects were recorded, as shown in Table 1.

Table 1: 3 Months (weekly) defect report

Month	Week	Production	Defects
March	1	16000	1611
	2	16600	1833
	3	15900	1733
	4	16100	1599
April	1	15995	1433
	2	16250	1822
	3	16400	1900
	4	16280	1453
May	1	15700	1744
	2	15885	1855
	3	16200	1922
	4	16385	1800

To gain deeper insight, Critical to Quality (CTQ) factors were identified. Among these, yarn breakage emerged as the most common and serious defect, followed by issues such as nep generation, slubs, and improper cone moisture. The complete list of CTQs is presented in Table 2.

Table 2: Critical Factors to Quality (CTQs)

Sr. No	Nature of Defect	Repetitions
1	Nep Generation	1200
2	Patches in card web	309
3	Slubs	349
4	Yarn Breakage	16554
5	Undrafted Yarn	300
6	Crackers	350
7	Hairiness	180
8	Ribboning and Patterning	145
9	Package Softening	111
10	Bell Shaped Packages	166
11	Nose Buldges	134
12	Improper cone moisture	621.15
13	Paper Cone Damage	136
14	Lot Mix	127
	Total	**20705**

Measure Phase: The baseline sigma level was calculated prior to the implementation of improvements. Using the observed defect data, the sigma performance of the process was initially measured at ≈3.92. However, based on defect proportions (20,705/193,695 = 10.69%), this equates more transparently to a sigma performance closer to ≈2.7 with a 1.5σ shift applied. This highlights the importance of clearly defining opportunities per unit when reporting Six Sigma levels.

Analysis Phase:

Pareto analysis (Figure 2) confirmed that a small number of defect categories accounted for the majority of quality losses, with yarn breakage alone representing more than 75% of total defects. A fishbone diagram (Figure 3) was then used to explore potential root causes, categorized under machine, method, material, manpower, and environment.

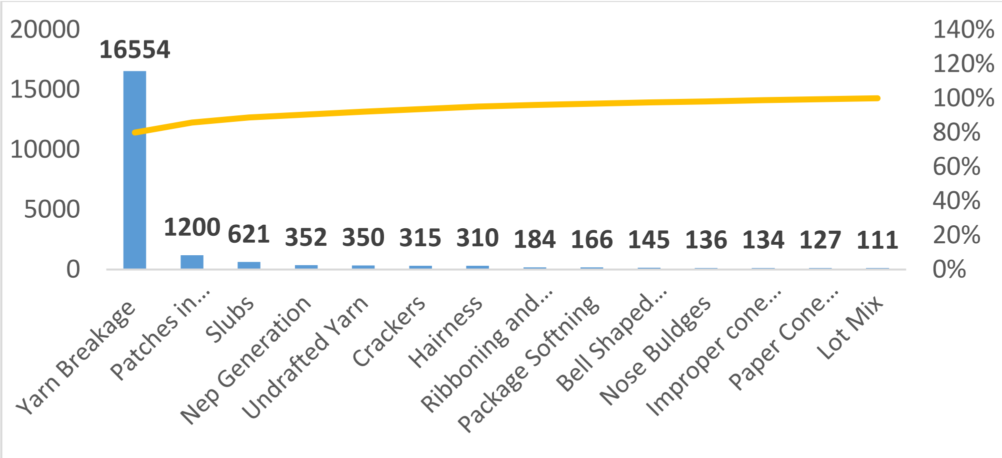

Figure 2: Defects Pareto Analysis Diagram

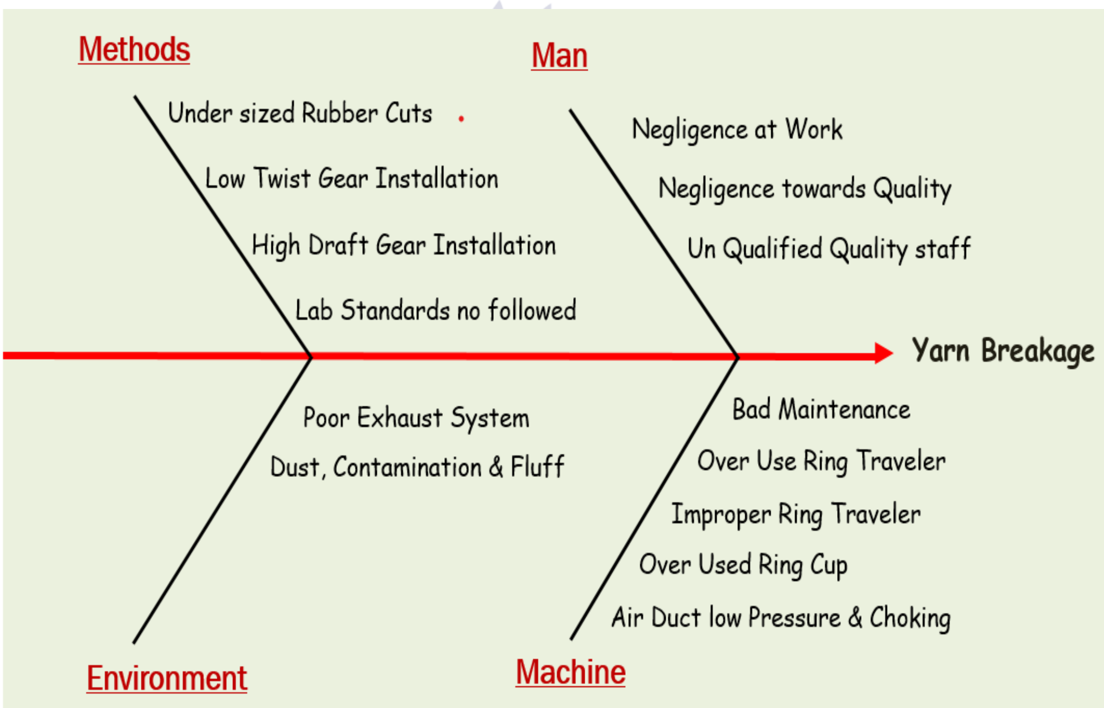

Figure 3: Fishbone Diagram.

To monitor weekly variation, a U-chart (Figure 4) was applied, showing whether defect counts remained within Upper and Lower Control Limits (UCL/LCL). This statistical approach allowed the detection of abnormal variations that required targeted interventions.

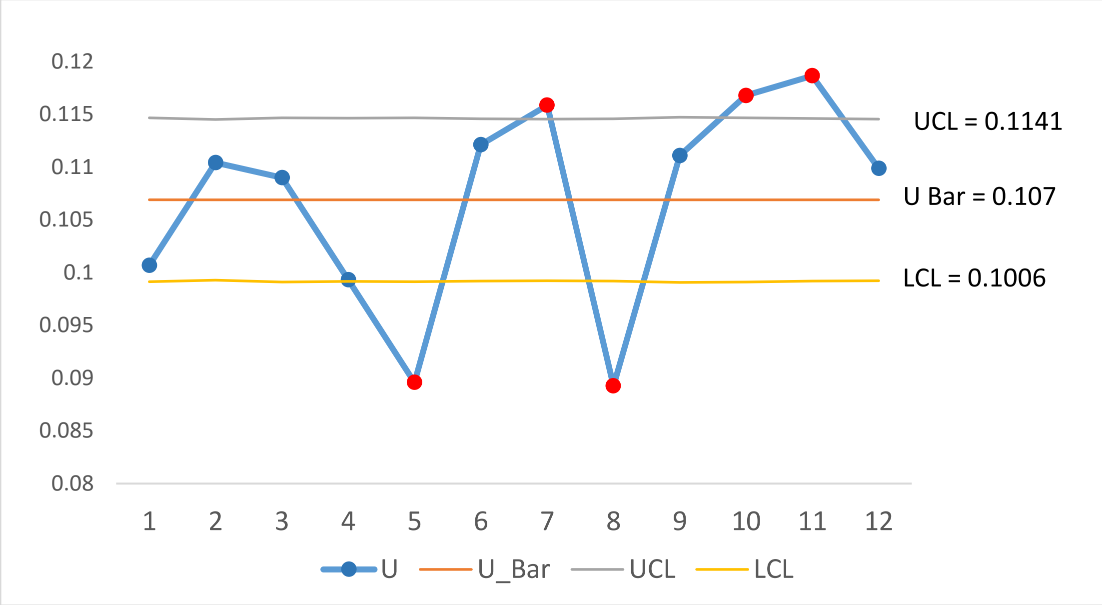

Figure 4: U-Chart representing samples in control limits

Improve Phae: A time study (Table 3) was conducted to separate value-added and non-value-added activities across all process stages. Results indicated that 26% of the total cycle time (70 minutes of 269.5 minutes) was consumed by non-value-added activities, mainly due to delays in carding, mixing, and ring frame operations. This highlighted opportunities for improvement through better scheduling, maintenance, and workflow standardization.

Table 3: Time Calculation from CSM.

Section	Time (Min)		
	Cycle Time	Value Added Time	Non-Value-Added Time
Mixing	60	48	12
Blow Room	27.5	20.5	7
Carding	60	40	20
Draw Frame	40	30	10
Simplex	60	48	12
Ring Frame	17	10	7
Winding	5	3	2
Total Time	269.5	199.5	70

Table 4: Five-Why Analysis.

Why	Why	Why	Why	Why
Undersized Rubber Cots (Defects - 6621)	Over Grinding	Over Grinded due to improper gauge	Improper maintenance regime	Casual attitude to errors and lack of maintenance awareness
Bad Maintenance (Defects - 3310)	Lack of Qualified staff	Maintenance department neglected	No proper Maintenance regime followed	Culture of negligence to machine failures
Over used Ring traveler (Defects - 1655)	Excessive wear and tear	Not replaced on time	SOP for change not followed	Lack of awareness and training
Over used Ring cup (Defects - 827)	Substandard parts procurement	Isolated procurement system	Lack of qualitied maintenance staff	Poor maintenance regime
Quality Neglected (Defects - 827)	Quality procedures not followed	Un qualified and un trained quality staff	Lack of quality lab and equipment	Less priority to quality by management

Control Phase.

Based on root cause analysis, five-why investigations were carried out for major defect sources such as undersized rubber cots, poor maintenance, and over-used ring travellers. The corrective actions, summarized in Table 4, included stricter maintenance schedules, better training of staff, and improved procurement standards for parts and accessories. These actions were implemented under close supervision and continuous observation by the quality and maintenance te

To sus
in improvements, a control plan was developed (Table 5). It emphasized management-led TQM reviews, regular staff training, and integration of quality costs into shop-floor awareness. Employee engagement and cross-functional collaboration were reinforced as key elements of sustaining reduced defect levels.After implementation, a clear decline in defect rates was observed. The U-chart after improvements (Figure 5) confirmed more stable and controlled variation compared to the baseline. The recalculated sigma level improved to ≈4.2 (or ≈3.2 if using direct defect percentage), showing a significant gain in quality performance.

Table 5: Control Plan

Responsibility	Plan
Management	Annual review to be conducted to assess the exact impact of lean six sigma tools being implemented. TQM to be solely committed by all tiers of management.

Employees	Everybody to work as part of single team with ultimate focus on quality. Employees to undergo rigorous quality training regime. Cost of quality could become a common talk at shop floor. Out of the box thinking be encouraged among employees. Quality be more emphasized over daily production figure.
Academia	Researchers and industrialist are needed to be on a single page. Quality improvement research projects be generated and funded to improve quality control practices in the textile spinning industry

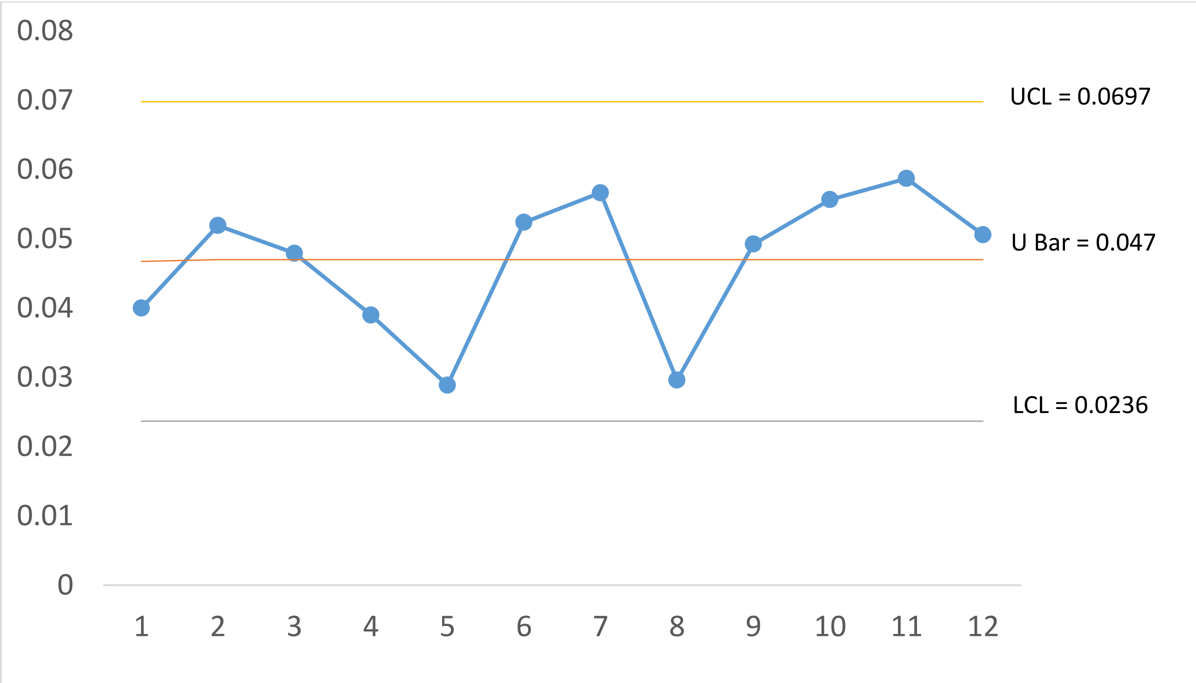

Figure 5: Control Chart (U-chart) After Improvement.

Results and Performance Evaluation

The comparison of before and after results is illustrated in Figure 6 and summarized in Table 6. Defects were reduced from 20,705 (10.69%) to 9,053 (4.67%), representing a 56.3% improvement. Correspondingly, the sigma level improved by approximately 0.5–1.0σ depending on calculation assumptions.

From a financial perspective, the cost of quality losses decreased substantially. Before intervention, monthly losses were estimated at PKR 45.16 million, whereas after improvements, losses fell to PKR 19.89 million. This translates to an estimated monthly saving of PKR 25.27 million. These savings are consistent with the reduction in defect rates and confirm the practical value of LSS interventions in spinning operations

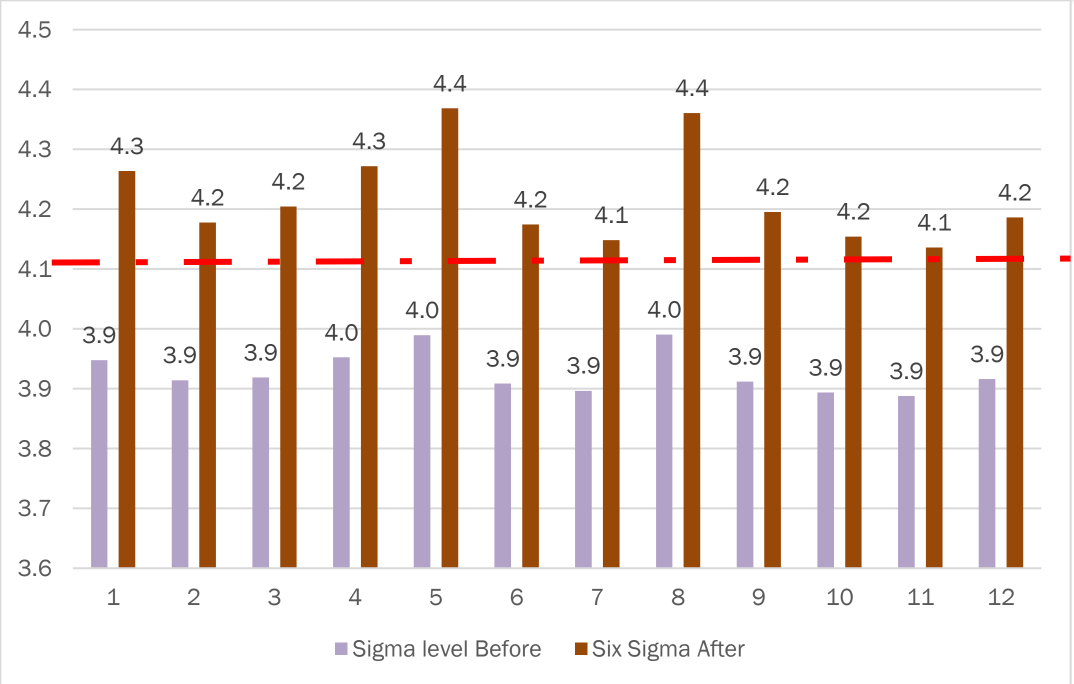

Figure 6: Sigma Level Before and After

Table 6: Cost Saving Due To Defects Reduction.

Corrective Measure	Total Production	Total Capita (Million)	Defects	Defect %	Loss (Million)	Cumulative Saving/ Month
Before	193695	426.1 million	20705	10.6	45.16	8.42 million
After	193695	426.1 million	9053	4.67	19.89	
Total	193695		216.44		29.4	

Conclusion

The implementation of Lean Six Sigma (LSS) in the textile spinning sector has proven effective in improving quality, productivity, and efficiency. By integrating lean principles that eliminate waste with Six Sigma methods that reduce variation, the study demonstrated measurable improvements in process performance.

Using the DMAIC framework on a three-month dataset of 193,695 cones, baseline defect levels were first quantified. A total of 20,705 defects (10.69%) were observed, corresponding to a sigma level of approximately 2.7–3.9 depending on calculation assumptions. Through Pareto analysis, yarn breakage was identified as the most significant CTQ factor, while fishbone diagrams and five-why analysis highlighted key root causes such as poor maintenance practices, over-grinded cots, and inconsistent quality procedures.

Following improvement actions—including stricter maintenance regimes, standardized operating procedures, and enhanced staff training—defects were reduced to 9,053 (4.67%), representing a 56.3% reduction. The process sigma level improved to about 3.2–4.2, and estimated monthly cost savings reached PKR ~25.3 million. These results confirm that LSS interventions can deliver both technical quality gains and financial benefits in spinning operations.

Overall, this research demonstrates that Lean Six Sigma is a practical and sustainable methodology for the textile spinning industry. By reducing defects, stabilizing processes, and delivering tangible cost savings, LSS can help mills enhance competitiveness in an increasingly demanding global market.

Future Recommendations:

Despite these achievements, challenges remain. The quality of raw material, reliance on imports, and sustainability issues continue to pose risks for consistent performance. Moreover, the study was limited to a single mill over a three-month period, meaning that seasonal variations and longer-term sustainability were not fully assessed.

Future research should therefore explore:

Long-term monitoring of spinning defects under LSS control plans.

Integration of digital tools and online sensors for real-time defect detection.

Application of Design of Experiments (DOE) to optimize process parameters such as drafting, twist, and traveller replacement cycles.

Extending LSS applications to other textile processes such as carding, weaving, and finishing, to build a holistic continuous improvement framework.

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