Process improvement and quality management in the textile industry using Lean Six Sigma methodologies and tools

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ABSTRACT – REZUMAT

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An important part of global manufacturing is the textile industry, which produces a wide range of products. In this research, 3 primary textile hubs in Tamil Nadu were selected for data collection: Karur, Tiruppur, and Coimbatore. This study investigates the optimisation of production processes in industry by incorporating the Lean Six Sigma (LSS) methodology. It also examined 5 key theories that addressed crucial issues such as production, defect rates, process inefficiencies, and cycle times. This research also used statistical tools such as Microsoft Excel and Minitab to conduct capacity assessment and process-control defect-rate analysis. This study also used Value Stream Mapping (VSM) and Measurement System Analysis (MSA) for rectifying the above defects. The Lean Six Sigma (LSS) techniques improved productivity in the textile industry by reducing cycle time from 62.5 to 53.1 minutes (15% improvement), lowering defect rates from 19.43% to 12.38% (36.3% improvement), and increasing the sigma level from –3.36 to 0.41 (3.77-unit improvement). The outcomes showed that, when supported by advanced statistical analysis and process mapping, LSS can dramatically boost productivity, product quality, and process reliability in the textile sector.

Keywords: *Lean Six Sigma, textile industry, DMAIC framework, cycle time, defect rate, process optimisation, quality improvement*

Îmbunătățirea proceselor și managementul calității în industria textilă utilizând metodologii și instrumente Lean Six Sigma

O parte importantă a producției globale la nivel mondial este industria textilă, care realizează o gamă largă de produse. În cadrul acestei cercetări, au fost selectate cele trei centre textile principale din Tamil Nadu pentru colectarea datelor, și anume Karur, Tiruppur și Coimbatore. Acest studiu investighează optimizarea proceselor de producție din industrie prin încorporarea metodologiei Lean Six Sigma (LSS). De asemenea, au fost analizate 5 teorii importante care abordează aspecte cruciale precum producția, ratele defectelor, ineficiențele proceselor și duratele ciclurilor. Această cercetare a utilizat, de asemenea, instrumente statistice precum Microsoft Excel și Minitab pentru a determina evaluarea capacității și analiza ratei de defectare a controlului proceselor. Acest studiu a utilizat, de asemenea, Cartografierea Fluxului de Valoare (VSM) și Analiza Sistemului de Măsurare (MSA) pentru remedierea defectelor menționate mai sus. Tehnicile Lean Six Sigma (LSS) au îmbunătățit productivitatea în industria textilă prin reducerea duratei ciclului de la 62,5 la 53,1 minute (îmbunătățire de 15%), scăderea ratelor defectelor de la 19,43% la 12,38% (îmbunătățire de 36,3%) și creșterea nivelului sigma de la –3,36 la 0,41 (îmbunătățire de 3,77 unități). Rezultatele au examinat modul în care, atunci când este susținut de analize statistice avansate și cartografierea proceselor, LSS poate crește semnificativ productivitatea, calitatea produselor și fiabilitatea proceselor în sectorul textil.

***Cuvinte-cheie**: Lean Six Sigma, industria textilă, cadrul DMAIC, durata ciclului, rata defectelor, optimizarea proceselor, îmbunătățirea calității*

INTRODUCTION

The goal of lean manufacturing in the textile sector is to maximise customer value by reducing waste and increasing productivity at every stage of production. By implementing Lean principles, textile manufacturers hope to reduce excess inventory, streamline processes, and eliminate non-value-added activities. This led to faster delivery, lower costs, and better quality. Kaizen, Just-in-Time (JIT), Total Productive Maintenance (TPM), and Value Stream Mapping (VSM) are among the primary Lean tools used in the textile industry. Businesses can use value stream mapping to see the entire production process, from acquiring raw materials to shipping the finished product, and identify inefficiencies such as lengthy wait times and transportation bottlenecks. Just-in-time (JIT) production methods ensure materials and products are produced only when needed by preventing overproduction and reducing the need for large inventories. A more responsive production environment results in lower storage costs and better cash flow.

In the textile industry, where delivery schedules and notable variations in product demand are commonplace, lean manufacturing has become increasingly important. Lean emphasises employee involvement and continuous improvement to foster a culture of problem-solving and waste reduction at all organisational levels. One of the main advantages of lean manufacturing is its capacity to increase product quality while reducing production costs. In lean approaches, tools such as Total Quality Management (TQM) and Six Sigma are frequently used to improve defect prevention and reduce process variability. Furthermore, lean manufacturing gives textile companies greater flexibility, allowing them to respond more skillfully to shifting market trends and consumer preferences. At last, implementing lean techniques makes the textile sector more competitive in a fast-moving global marketplace, enhances customer satisfaction, and builds more sustainable operations. Figure 1 depicts the types of apparel.

Fig. 1. Apparel types

In the textile industry, lean manufacturing is increasingly used to increase productivity, reduce waste, and improve efficiency. Its adoption can be facilitated by a structured framework that helps textile manufacturers improve operational performance and product quality while systematically eliminating non-value-added activities. Understanding the different lean tools and practices, such as value stream mapping, 5S, and continuous improvement, is a major challenge. All organisational levels must be committed to the implementation for it to be successful, with a focus on staff training and involvement. Manufacturers can improve their competitiveness, streamline operations, and reduce operating costs by focusing on waste reduction and workflow optimisation. This will result in long-term success and sustainable growth in the textile industry [1]. To promote a more sustainable production process, green lean production in the textile sector seeks to combine lean manufacturing concepts with environmental sustainability. To assess the effectiveness of green lean production, a hybrid fuzzy decision-making framework that accounts for both environmental and economic factors has been developed. In addition to increasing operational efficiency, this strategy helps textile companies identify and implement eco-friendly practices such as waste minimisation, water conservation, and energy conservation. Fuzzy logic is utilised in the decision-making process to account for environmental uncertainty, providing a framework that is adaptable and flexible enough to be customised for various organisational contexts. This framework's implementation promotes the development of an eco-friendly, sustainable, and productive production environment in the textile sector, supporting the sector's overall environmental responsibility [2].

Several obstacles could prevent the textile industry from successfully implementing lean principles. Organisational culture, inadequate training, change aversion and the difficulty of integrating lean practices with current procedures are frequently the causes of these challenges. Adopting lean strategies is further complicated by the textile industry's reliance on manual labour and antiquated technologies. Overcoming these obstacles requires an all-encompassing strategy that aligns lean practices with business goals, fosters strong leadership, and engages employees. To successfully implement lean, which eventually boosts output quality and customer satisfaction in the textile industry, these obstacles must be recognised and removed [3]. The apparel industry in Bangladesh has been greatly impacted by lean manufacturing, which has been used to improve operational performance. The adoption of lean methods, such as cutting waste, shortening lead times, and improving process flow, has improved resource utilisation and reduced costs. Research in the clothing industry shows that businesses that use lean manufacturing report higher profitability, productivity, and efficiency. Additionally, because the emphasis on collaboration and ongoing improvement fosters a positive corporate culture, lean practices have been linked to higher employee satisfaction. However, to ensure the long-term viability of lean initiatives in the apparel industry, issues such as supply chain disruptions and fluctuating demand need to be carefully managed [4].

Six Sigma techniques have been successfully applied in the textile industry to improve productivity and quality. A case study illustrated how operational processes were significantly improved by fusing the lean concepts with Six Sigma's emphasis on minimising variation. This strategy reduces errors and increases customer satisfaction by addressing both product quality consistency and production process efficiency. Organisations can streamline processes, improve efficiency, and produce high-quality goods at competitive prices by implementing Lean Six Sigma, which emphasises data-driven decision-making and strict process control [5]. Using lean manufacturing techniques has greatly improved the textile industry's operational performance. Waste reduction, production process optimisation, and continuous improvement are examples of lean practices that have been shown to lower costs and boost overall productivity in textile manufacturing operations. Industry data indicate that businesses that use lean manufacturing experience improvements in key performance metrics, including lead time, production costs, and product quality. Furthermore, the emphasis on employee empowerment and engagement in lean manufacturing fosters an innovative, problem-solving culture that supports textile companies' long-term competitiveness and success [6]. One of the main goals in enhancing operational effectiveness and environmental sustainability in the textile sector has been to develop a waste-reduction model based on lean manufacturing principles. Businesses can significantly lower their operational costs and environmental impact by implementing lean strategies, such as reducing material waste, using less energy, and streamlining production processes. This strategy not only increases output but also fits in with the textile industry's growing focus on sustainability.

Businesses that use lean manufacturing to reduce waste are better positioned to meet consumer demand for eco-friendly products and regulatory requirements, resulting in a more sustainable and lucrative future [7].

With a focus on the sewing sector, a lean manufacturing model based on production management has been suggested for small textile businesses to increase efficiency and reduce waste. By focusing on the sewing department, which frequently encounters bottlenecks in small textile businesses, the model seeks to improve productivity, reduce operating expenses, and streamline processes. By putting this lean model into practice, small textile businesses could become much more profitable and competitive, helping them compete in a fast-moving market [8]. Changes in consumer demand, workforce management and supply chain disruptions are just a few of the major issues the COVID-19 pandemic has brought about for the textile sector. An integrated approach to examining the obstacles to lean manufacturing in this setting emphasises the necessity of a flexible and robust supply chain, the importance of preserving worker safety, and the role technology plays in facilitating remote work and production processes. The importance of sustainability in manufacturing has been highlighted by the pandemic, which has led textile companies to prioritise both long-term environmental responsibility and operational efficiency. By addressing these issues, textile companies can overcome obstacles to lean implementation and emerge stronger in the post-COVID world. One important element in enhancing operational agility during the COVID-19 era in the textile industry has been the combination of lean practices and quick-response manufacturing. Textile companies have been better equipped to adapt to shifting demand patterns and pandemic-driven supply chain disruptions by combining the flexibility and speed of quick-response manufacturing with the waste-reduction principles of lean manufacturing. This strategy gives businesses a competitive edge in a rapidly changing market by enabling them to shorten lead times, manage inventory more effectively, and increase overall production efficiency. However, to prevent potential problems such as overproduction or more complex production systems, combining these practices requires careful planning and coordination [9].

In the textile industry, lean layout design is essential for increasing the productivity of production processes. A textile manufacturing facility's layout was redesigned in a case study using lean principles, with an emphasis on increasing worker productivity, reducing movement waste, and optimising material flow. The company shortened lead times, increased operational efficiency, and improved overall product quality by rearranging the layout to facilitate a steady, uninterrupted flow of materials. The lean layout design enhances operational and employee well-being by promoting a safer, more ergonomic workplace and increasing production efficiency [10]. Estimates of the effectiveness and growth of lean production in textile companies indicate substantial advantages, including lower costs, higher quality, and increased output. By reducing waste, optimising workflows, and increasing resource utilisation, applying lean principles streamlines operations.

Additionally, the emphasis on employee involvement and ongoing improvement fosters an innovative and efficient culture in textile businesses. The predicted effects of lean production underscore its potential to enable more profitable, efficient, and sustainable manufacturing processes as the sector further develops, positioning textile companies for long-term success [11].

In fact, textile companies can achieve greater efficiency, customer satisfaction, and competitive advantage in a demanding global market by using this integrated approach [12]. A model focusing on optimising waste-reduction processes and standardising work practices is proposed to enhance productivity in the textile industry by applying lean manufacturing techniques. The model highlights the importance of aligning lean concepts with the specific requirements and features of the textile sector to ensure that implemented practices are suited to the challenges faced by textile producers. Lower production costs, higher-quality products, and increased operational efficiency are the anticipated results of implementing this model. Textile companies can greatly increase their productivity and profitability in the market by strategically implementing lean techniques [13]. Productivity and layout design in the sewing portion of the apparel industry have been significantly impacted by lean manufacturing. An analysis of the effects of lean methods in this field emphasises the significance of resource efficiency, waste reduction, and process optimisation. Redesigning the layout and implementing lean techniques such as value stream mapping and standardised work can help clothing manufacturers reduce cycle times, improve quality, and increase overall productivity. In addition to improving operational performance, the adoption of lean manufacturing by the sewing sections promotes employee collaboration and a culture of continuous improvement, which boosts productivity and competitiveness over the long run [14].

METHODOLOGY

Data collection and demographic analysis

The three main textile manufacturing centres in Tamil Nadu were the focus of the study's extensive data collection strategy: Coimbatore, Tiruppur, and Karur. These areas were selected for their diverse operational profiles and significant contributions to the textile industry. Overall, 300 product quality evaluations focused on defect rates, production durations, and resource usage were included in the data, along with 500 process observations covering different production stages. An analysis of the manufacturing units' attributes, such as their size small, medium and large, the number of employees, product types such as apparel, home textiles and technical textiles, and yearly production volume was conducted using demographic profiling in table 1. The demographic data supplied important background information for interpreting differences in process performance and quality metrics.

Data analysis tool

In this study, Minitab and Microsoft Excel were essential for statistical analysis and process control in textile manufacturing. Minitab was used for advanced data analysis [15], including capacity assessment, sigma level estimation, and Statistical Process Control (SPC), employing control charts ($\bar{X}$-R, I-MR), capability histograms, and Pareto analysis to monitor defect rates and process variation. It also facilitated hypothesis testing (ANOVA, t-tests, chi-square) and regression analysis to identify inefficiencies. Microsoft Excel, on the other hand, was used for data aggregation, preprocessing, and visualisation through trend analysis, scatter plots, bar charts, and pivot tables. It computed statistical metrics such as mean, standard deviation, and correlation coefficients, and used conditional formatting to highlight defects and cycle-time variations.

The solver tool was applied for preliminary optimisation, improving efficiency by adjusting operational parameters. The integration of Minitab for statistical validation and Excel for data handling ensured a comprehensive, data-driven approach to process improvement, optimising quality and productivity in textile manufacturing. Utilising sophisticated instruments such as Value Stream Mapping (VSM), inefficiencies throughout the production process were identified [16, 17]. Key performance metrics such as cycle time, sigma levels, and defect percentages were validated, and data reliability was evaluated using measurement system analysis (MSA).

Proposed methodology

The suggested approach for applying Lean Six Sigma (LSS) in the textile industry, adhering to the DMAIC framework, is shown in figure 2.

Critical-to-quality (CTQ) factors, including cycle time, defect rates, and production efficiency, were the focus of stakeholder consultations and process mapping using SIPOC diagrams to establish project objectives during the Define phase. A total of 300 product quality evaluations and 500 process observations from textile units in Coimbatore, Tiruppur, and Karur were used to gather data for the Measure

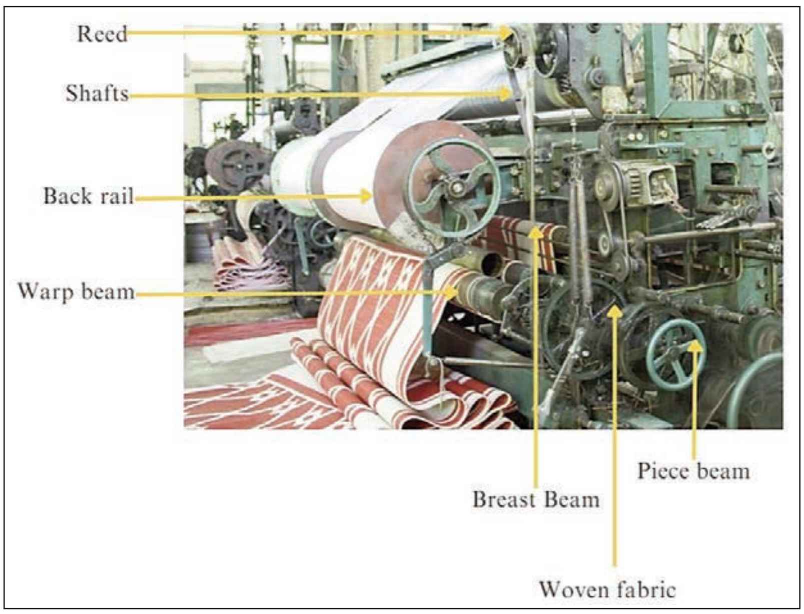

Fig. 2. LSS in the textile sector

Table 1

DEMOGRAPHIC PROFILES								
Region	**No. of units surveyed**	**Employee range**	**Annual output (tons)**	**Primary products**	**Process observa-tions**	**Product quality assessments**	**Product evaluated**	**Processes**
Coimbatore	10	50–200	1,200	apparel, yarn	200	100	cotton shirts	handling, weaving/knitting, dyeing, cutting, sewing, finishing, and packaging
Tiruppur	12	100–300	1,800	knitwear, hosiery	180	120	T-shirts, innerwear	
Karur	8	30–150	900	home textiles, fabrics	120	80	bedsheets, towels	

phase. When initial metrics were assessed, they showed a defect rate of 19.43%, a sigma level of –3.36, and an average cycle time of 62.5 minutes. The DMAIC architecture is shown in figure 3.

In the Improve phase, the improvement strategies centred on retraining staff on quality control standards, implementing preventive maintenance schedules for machinery, and optimising production layouts to reduce material transportation time. Before these changes were fully implemented, pilot projects and simulations were conducted to validate them. Ultimately, a systematic control plan was created during the Control phase, which included employee incentive programs, recurring audits, and real-time monitoring dashboards to ensure sustainability and sustain the gains. This comprehensive strategy guarantees a strong, scalable framework for increasing output and quality in the textile sector.

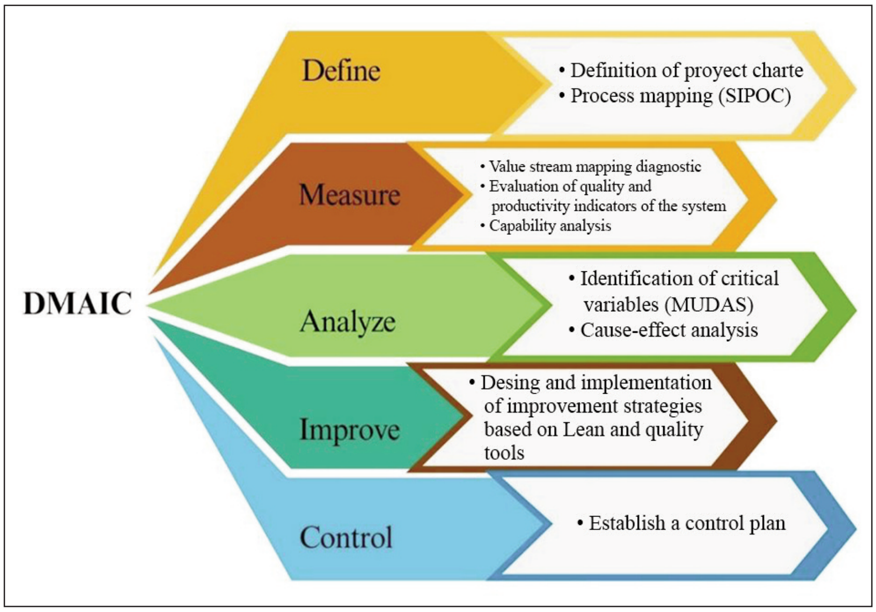

Fig. 3. DMAIC framework

Hypothesis testing

The study investigates key factors affecting manufacturing efficiency and product quality, focusing on defect rates, production cycle time, and process optimisation. Elevated defect rates indicate that product quality does not meet industry standards, which may result from inconsistencies in raw materials, inadequate process control, or equipment inefficiencies. Additionally, significant deviations in production cycle time suggest operational inefficiencies, potentially caused by bottlenecks, unoptimized workflows, or machine downtime. The presence of such inefficiencies, coupled with variations in raw materials, contributes to increased defect rates and overall production challenges. Implementing Lean Six Sigma methodologies can address these issues by identifying root causes, optimising workflows, and standardising processes, thereby reducing defects and improving cycle time. Furthermore, sustaining these improvements through robust control measures ensures long-term operational efficiency and consistent product quality, ultimately aligning manufacturing performance with industry benchmarks.

H_1: The defect rate exceeds industry standards, impacting product quality.

H_2: The production cycle time deviates significantly from the target, indicating inefficiencies.

H_3: Process inefficiencies and raw material variability drive high defect rates.

H_4: Lean Six Sigma tools will reduce cycle time and improve product quality.

H_5: Control measures will sustain improvements in efficiency and quality.

RESULTS AND DISCUSSION

Define phase

H_1: The defect rate exceeds industry standards, impacting product quality.

Figure 4 presents an integrated framework for the manufacturing process of sports sweaters, outlining the supply chain, inputs, processes, outputs, and customer segments. The supply section involves providers, supply chain management, maintenance management, human resources management, financial management, and marketing management to ensure seamless operations. In the input stage, essential resources such as workers, machinery, equipment, information systems, work orders, and textile materials are consolidated for efficient production. The process phase encompasses critical activities such as picking, cutting, assembly, and packing, all of which contribute to producing high-quality clothes of all types. The output stage delivers manufactured garments, along with release orders and bills of sale, to document and facilitate transactions. Lastly, the customer section focuses on distribution, financial management, customer service, and catering to corporate and individual clients, ensuring comprehensive service and satisfaction. This interconnected system ensures a streamlined and efficient manufacturing workflow, promoting quality and customer-centric outcomes.

Table 2 presents an analysis of the Define phase for Hypothesis 1, focusing on initial defect rates, cycle times, and observations across three regions: Coimbatore, Tiruppur, and Karur. This study identifies defects in textile products, including stitching issues (skipped stitches, seam puckering), colour inconsistencies (shade variation, fading), fabric flaws (holes, knots, wrinkles), and finishing problems (loose threads, uneven trims). Cycle time is the total duration of production, including raw material processing, cutting, sewing, dyeing, printing, and packaging.

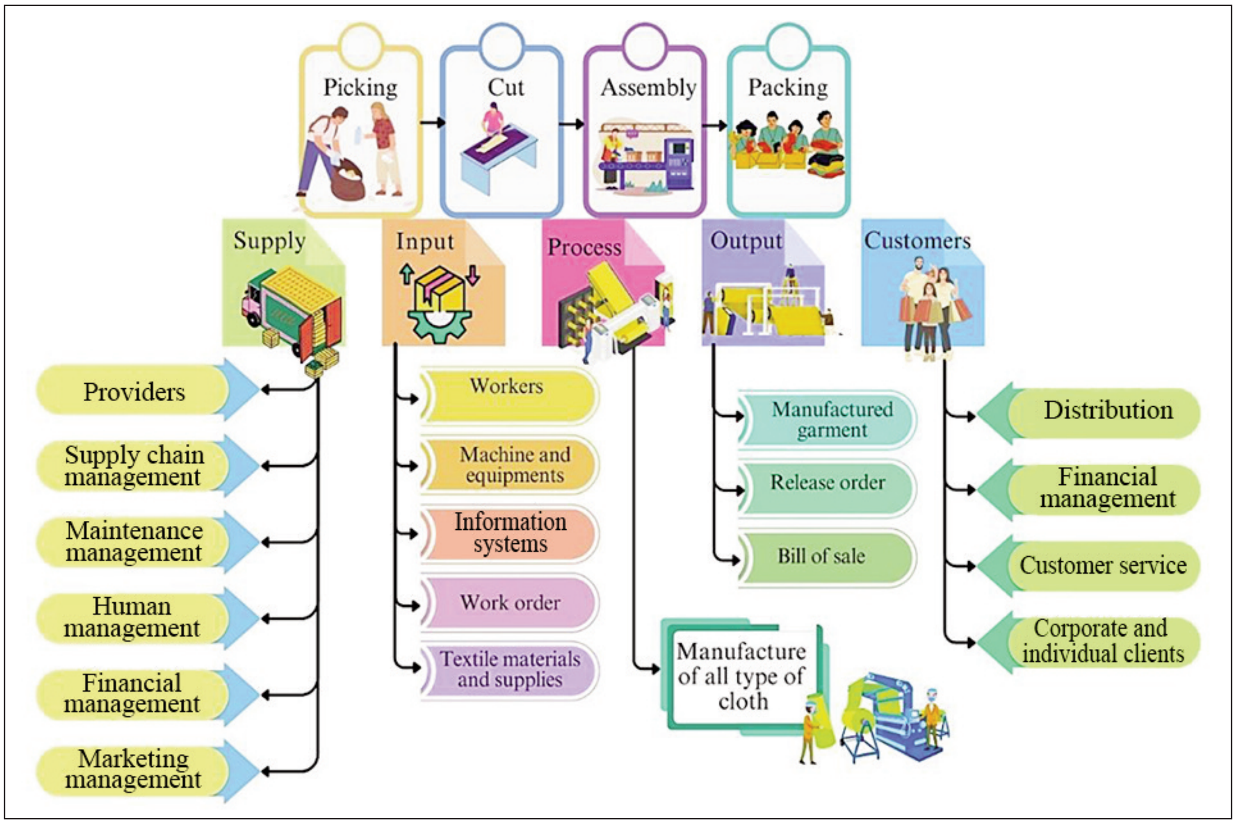

Fig. 4. SIPOC diagram for garment manufacturing in the textile industry

Table 2

ANALYSIS OF DEFINE PHASE (HYPOTHESIS 1)				
Parameter	**Region**	**Observation count**	**Defect rate (%)**	**Cycle time (minutes)**
Initial defect rate	Coimbatore	100	20.1	64.2
	Tiruppur	80	19.2	61.8
	Karur	70	18.6	60.4
Benchmark defect rate	-	-	10.0	50.0

Observations involve real-time monitoring of production lines to detect inefficiencies, bottlenecks, and quality variations.

Coimbatore recorded the highest observation count at 100, with an initial defect rate of 20.1% and a cycle time of 64.2 minutes. Tiruppur followed with 80 observations, a defect rate of 19.2%, and a cycle time of 61.8 minutes. Karur, with 70 observations, showed the lowest defect rate at 18.6% and the shortest cycle time of 60.4 minutes. These figures are compared against a benchmark defect rate of 10.0% and a cycle time of 50.0 minutes, highlighting the gap between current performance and the desired standard across all regions. This analysis underscores the need for process improvements to align with benchmark metrics.

Measure phase

H_2: The production cycle time deviates significantly from the target, indicating inefficiencies.

Figure 5 compares initial cycle time (CT) performance with the new process status after implementing improvements. The data is represented using a histogram overlaid with a probability density curve and trend line. This study applied Lean Six Sigma improvements, including process optimisation using Value Stream Mapping (VSM), preventive maintenance, employee training, defect reduction through Statistical Process Control (SPC), and workstation layout modifications. These strategies minimised downtime, reduced defects, streamlined workflows, and enhanced production efficiency. The initial performance shows greater variability and higher CT values, whereas the post-improvement results exhibit a more concentrated distribution around the optimised CT range. The probability density curve peaks near the target mean CT, signifying a significant reduction in deviation and enhanced consistency. This visual evidence confirms the effectiveness of process improvements in achieving streamlined, efficient operational performance.

Table 3 presents an analysis of the Measure phase for Hypothesis 2, evaluating cycle time and sigma

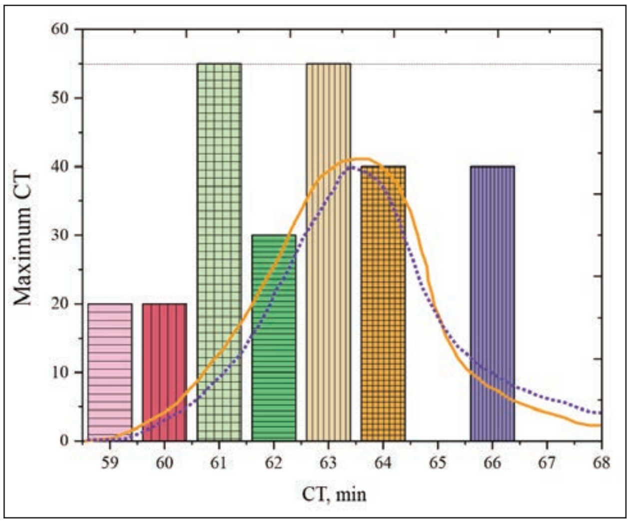

Fig. 5. Cutting accuracy and quality control measures

level across regions using statistical metrics. In Coimbatore, the mean cycle time was 64.2 minutes, with a standard deviation of 5.2, and a 95% confidence interval of 63.1 to 65.3 minutes. Tiruppur had a mean cycle time of 61.8 minutes and a standard deviation of 4.8, with a confidence interval of 60.7 to 62.9 minutes.

Karur recorded the shortest mean cycle time at 60.4 minutes, with a standard deviation of 5.1 and a confidence interval of 59.3–61.5 minutes, as illustrated in figure 6. All regions showed statistically significant results ($p < 0.05$). Additionally, the overall sigma level was measured at –3.36 with a standard deviation of 0.2 and a 95% confidence interval of –3.38 to –3.34, indicating a need for significant process improvements to reduce defects and enhance efficiency.

Table 3

ANALYSIS OF MEASURE PHASE (HYPOTHESIS 2)					
Metric	**Region**	**Mean value (Pre)**	**Standard deviation**	**P-value**	**Confidence interval (95%)**
Cycle time	Coimbatore	64.2 minutes	5.2	<0.05	63.1 – 65.3 minutes
	Tiruppur	61.8 minutes	4.8	<0.05	60.7 – 62.9 minutes
	Karur	60.4 minutes	5.1	<0.05	59.3 – 61.5 minutes
Sigma level	Overall	–3.36	0.2	<0.05	–3.38 – –3.34

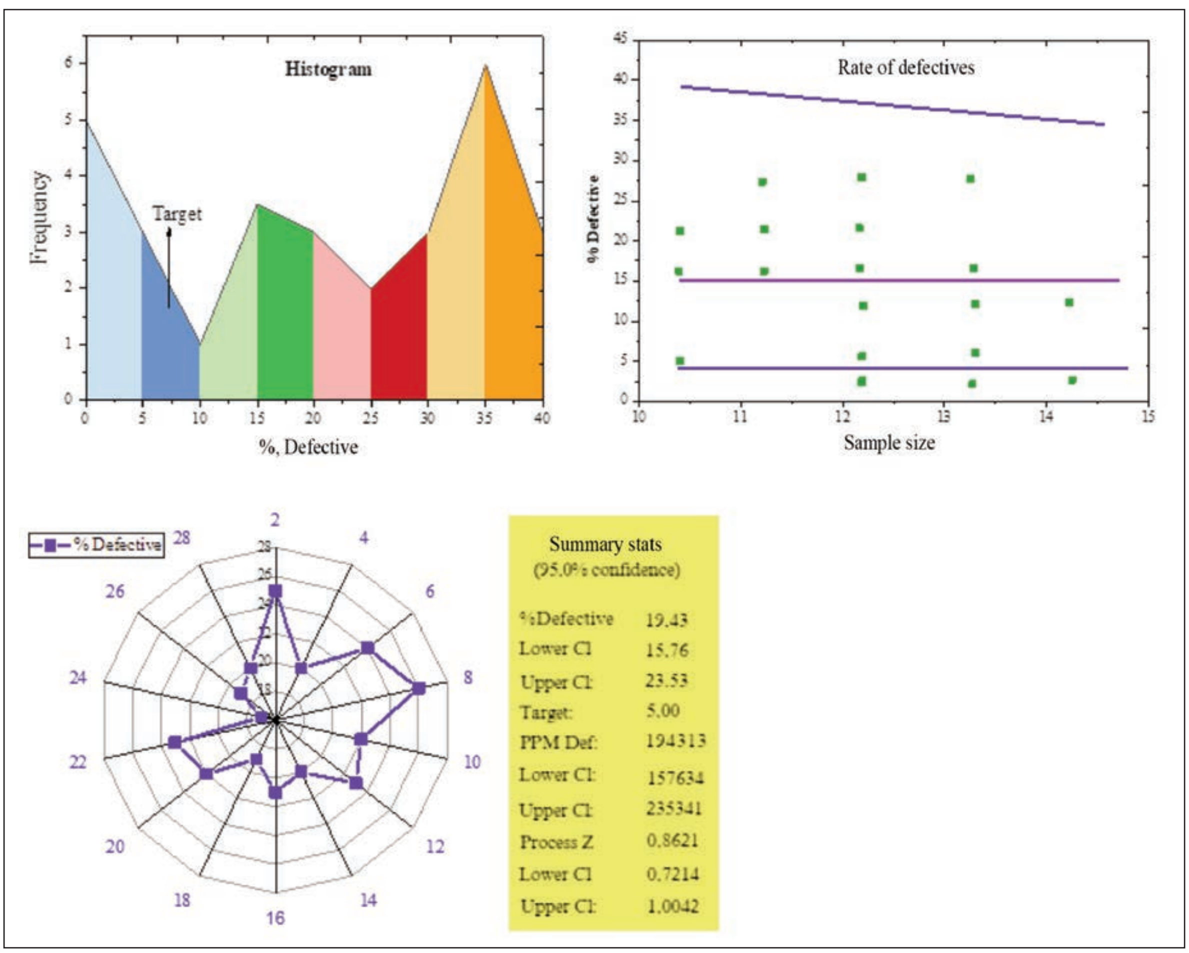

Fig. 6. Binomial process analysis of garment defects

Analyse phase

H_3: Process inefficiencies and raw material variability drive high defect rates.

Table 4 and figure 7 outline the evaluation of the Analyse phase for Hypothesis 3, identifying key root-cause categories, their frequencies, and their impact on defects. Variations in equipment performance, workforce experience, and automation levels led to differences in defect rates and process efficiency across textile companies in this phase. Workflow inefficiencies, including bottlenecks and poor workstation layouts, increased cycle times, while environmental factors like humidity affected fabric quality. Addressing these challenges through optimised scheduling, better maintenance, and controlled environmental conditions can enhance productivity and quality. Machinery issues were the most significant, occurring 120 times and contributing to 35.0% of defects, with a highly significant p-value (<0.01). Workforce errors accounted for 90 occurrences, representing 25.0% of defects, and were statistically significant (p-value < 0.01).

Material inconsistency, with a frequency of 80 and a 20.0% impact on defects, similarly had a significant p-value (<0.01). Workflow inefficiency was identified in 60 cases, accounting for 15.0% of defects, and was statistically significant (p-value < 0.05).

Environmental factors, though less frequent (40 cases) and contributing only 5.0%, were also statistically significant (p-value < 0.05). These findings emphasise the critical need to address machinery issues and workforce errors as primary areas for defect reduction.

Table 4

EVALUATION OF ANALYSE PHASE (HYPOTHESIS 3)			
Root cause category	**Frequency**	**Impact on defects (%)**	**P-value**
Machinery issues	120	35.0	<0.01
Workforce errors	90	25.0	<0.01
Material inconsistency	80	20.0	<0.01
Workflow inefficiency	60	15.0	<0.05
Environmental factors	40	5.0	<0.05

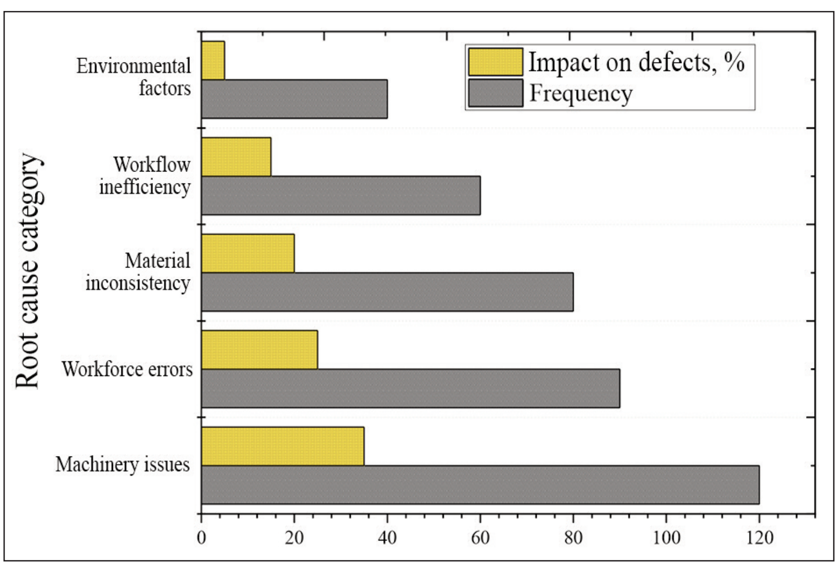

Fig. 7. Hypothesis 3 analysis

Improve phase

H_4: Lean Six Sigma tools will reduce cycle time and improve product quality.

The study applied Lean Six Sigma strategies, including Value Stream Mapping (VSM), preventive maintenance, employee training, Statistical Process Control (SPC), and workstation optimisation, to improve efficiency. Table 5 and figure 8 are based on real-time observations and statistical analysis, showing reductions in cycle time, defect rates, and process variability, validated through hypothesis testing and control charts. Figure 8 compares the initial cycle time (CT) performance with the new process status after improvement, focusing on the mean CT, deviation, and probabilities. The improved process has a mean CT of approximately 55 minutes, with a probability of 0.28 and a standard deviation of 0.1, highlighting its optimised performance. The probability decreases significantly at lower CT values (50 minutes: probability 0.15, deviation 0) and at higher CT values (60 minutes: probability 0.15, deviation 0.2). Extreme CT values, such as 45 and 70 minutes, are absent in the improved process, reflecting a significant reduction in variability. This analysis underscores the success of the improvements in stabilising CT and enhancing overall process efficiency.

The cycle time was reduced from 62.5 minutes to 53.1 minutes, reflecting a 15.0% improvement with a statistically significant p-value (<0.05), as shown in table 5.

The defect rate fell from 19.43% to 12.38%, representing a 36.3% improvement, with a significant p-value (<0.05). Additionally, the sigma level improved dramatically from –3.36 to 0.41, representing a 3.77-unit improvement with high statistical significance (p-value < 0.01). Figure 9 displays the VSM. These results demonstrate the effectiveness of the implemented measures in enhancing operational efficiency and quality control.

Control phase

H_5: Control measures will sustain improvements in efficiency and quality.

Table 6 presents the evaluation of the Control phase for Hypothesis 5, focusing on key metrics to assess stability and consistency after the improvement. The cycle time

Table 5

EVALUATION OF IMPROVED PHASE (HYPOTHESIS 4)				
Metric	**Pre-improvement value**	**Post-improvement value**	**Improvement (%)**	**P-value**
Cycle Time (minutes)	62.5	53.1	15.0	<0.05
Defect Rate (%)	19.43	12.38	36.3	<0.05
Sigma Level	–3.36	0.41	3.77	<0.01

increased slightly from 53.1 minutes to 53.4 minutes, with minimal variance (0.6%) and a statistically insignificant p-value (>0.05). Similarly, the defect rate increased by a negligible 0.3% from 12.38% to 12.42%, which is statistically insignificant (p-value > 0.05). The sigma level declined slightly from 0.41 to 0.40, with a variance of –0.2% and no statistical significance (p-value > 0.05). These findings suggest that the process improvements achieved in earlier phases have been effectively sustained, with only marginal variations in the evaluated metrics.

Figure 10 presents the I-MR P control chart used to monitor cycle time (CT) after the finalisation process, detailing both individual values and moving ranges across observations. The individual values show cycle times fluctuating between 50 and 55 minutes, with peaks at observations 7 (55 minutes) and 13 (55 minutes), and the lowest value at observation 11 (50 minutes). The moving range highlights variations in CT, ranging from 0 (observation 3) to a maximum of 4.5 (observation 11), reflecting significant process variability at certain points. Observations like 9 and 13 indicate

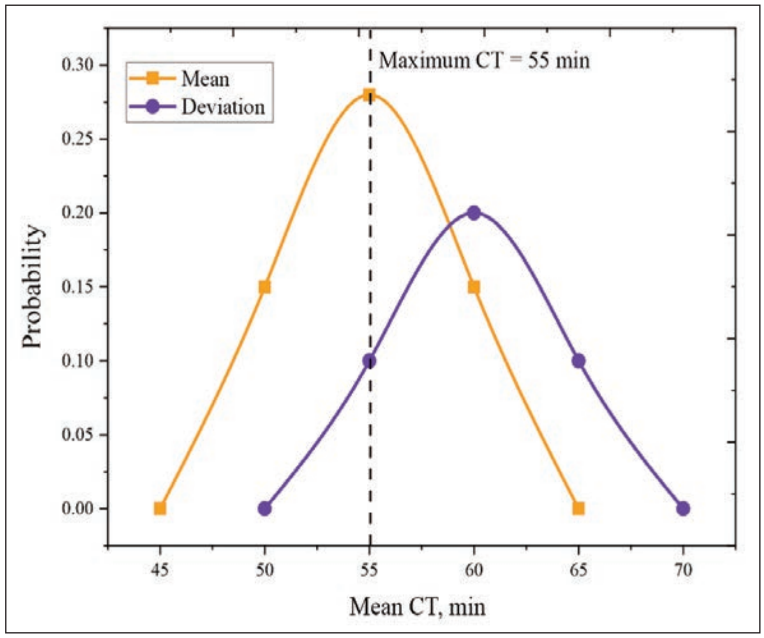

Fig. 8. Initial CT performance compared with the enhanced process

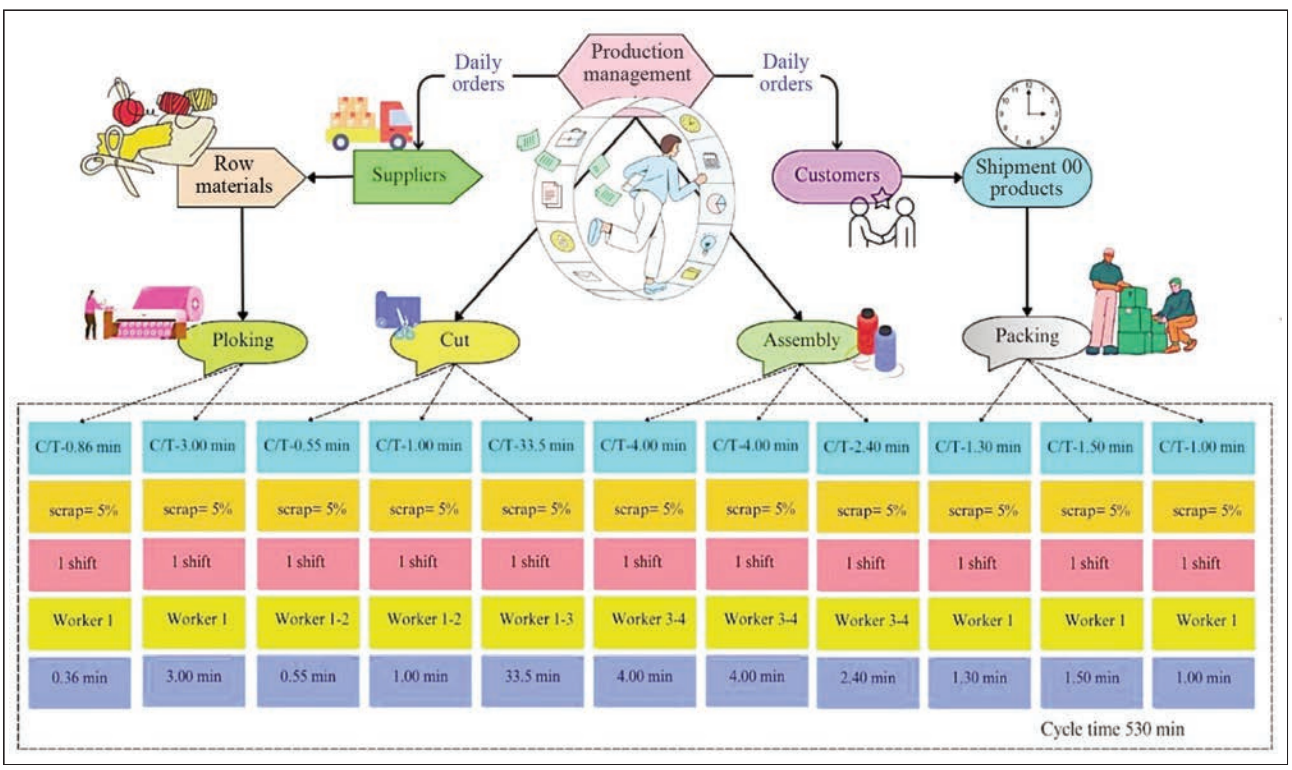

Fig. 9. Value stream mapping enhancements for textile manufacturing

Table 6

EVALUATION OF ANALYSE PHASE (HYPOTHESIS 5)				
Metric	**Baseline value**	**Post-control value**	**Variance (%)**	**P-value**
Cycle time (minutes)	53.1	53.4	0.6	>0.05
Defect rate (%)	12.38	12.42	0.3	>0.05
Sigma level	0.41	0.40	–0.2	>0.05

notable shifts, suggesting potential deviations that may require further analysis. This chart provides valuable insights into process stability and highlights areas for improving consistency in cycle time performance.

Figure 11 illustrates the P control chart used to monitor the proportion of non-conforming (NC) products after the finalisation process. The chart plots the proportion of NC products across 15 samples, highlighting variations in the production process. The proportions range from 0 (samples 4 and 20) to a peak of 0.4 (sample 14). Notable fluctuations include higher proportions in samples 2 (0.25), 10 (0.3), and 18 (0.25), while lower proportions are observed in samples 22 (0.05), 12 (0.12), and 28 (0.12). The data highlights significant variability in the NC product percentage, with some samples meeting acceptable quality standards (near zero) while others exceed typical control limits. This analysis emphasises the need for continuous monitoring and corrective actions to maintain consistent product quality.

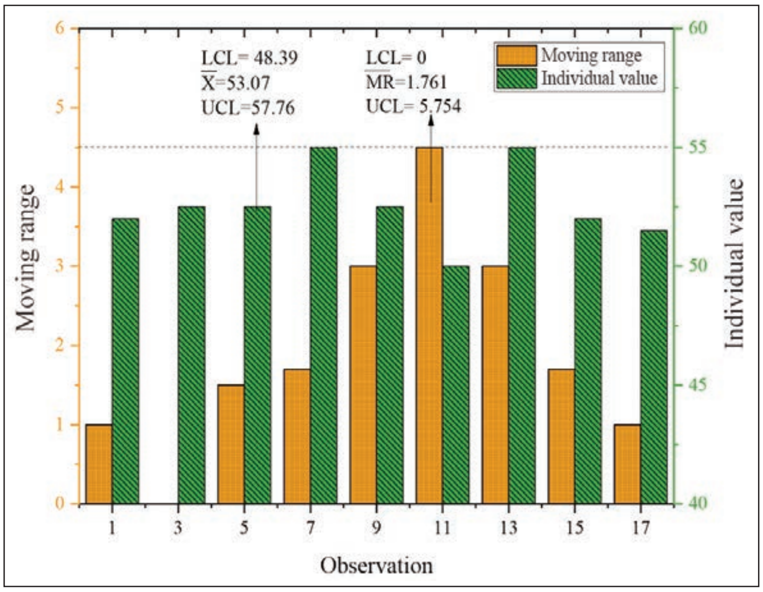

Fig. 10. Monitoring CT performance using the I-MR p chart

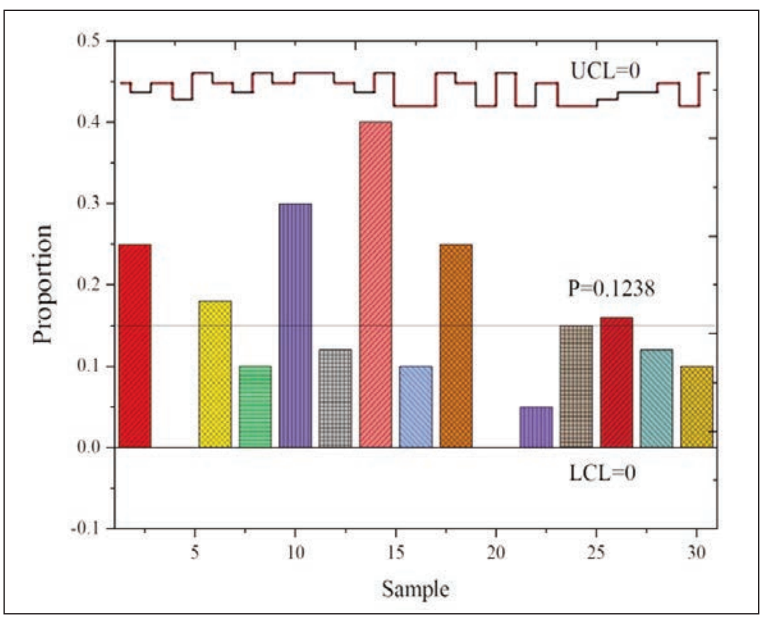

Fig. 11. Monitoring the NC product percentage with a P chart

DISCUSSION

This study outlines the specific improvements achieved through Lean Six Sigma. These include a 15% reduction in cycle time (from 62.5 to 53.1 minutes), a 36.3% decrease in defect rate (from 19.43% to 12.38%), and an improvement in the sigma level from –3.36 to 0.41. The impact of process changes – such as Value Stream Mapping (VSM), Statistical Process Control (SPC), and preventive maintenance – will be explicitly linked to these results to clarify the connection between interventions and outcomes.

CONCLUSION

The implementation of Lean Six Sigma in the Tamil Nadu textile sector has demonstrated significant improvements in both operational efficiency and product quality. The study addressed critical inefficiencies using a structured approach that included the DMAIC framework, resulting in a 15% reduction in cycle times and a 36.3% reduction in defects. Hypothesis testing was used to validate the data-driven improvements, and p-values verified that the changes were statistically significant. These findings demonstrate not only how well Lean Six Sigma streamlines textile production but also how it can raise textile companies' competitiveness.

Manufacturers can increase their market share, lower operating costs, and improve customer satisfaction by optimising production schedules and quality control. The results highlight the importance of incorporating Lean Six Sigma and other quality management systems into the daily operations of textile manufacturing facilities. The post-control phase shows that the gains are long-lasting, as the metrics remain steady and there are few deviations. The gains in cycle time and defect reduction will be maintained through ongoing monitoring and recurring audits, which will also enable the identification and implementation of any necessary additional improvements. Overall, the study shows how Lean Six Sigma can be scaled to address broader operational issues in the manufacturing sector and offers a roadmap for enhancing textile production processes. Businesses that adopt these approaches can build resilience and long-term growth in an increasingly competitive global market.

REFERENCES

[1] Begum, S., Akash, M.A.S., Khan, M.S., Bhuiyan, M.R., *A framework for lean manufacturing implementation in the textile industry: A research study*, In: International Journal of Science and Engineering, 2024, 1, 4, 17–31

[2] Vahabi Nejat, S., Avakh Darestani, S., Omidvari, M., Adibi, M.A., *Evaluation of green lean production in textile industry: A hybrid fuzzy decision-making framework*, In: Environmental Science and Pollution Research, 2021, 1–22

[3] Robertsone, G., Mezinska, I., Lapina, I., *Barriers for lean implementation in the textile industry*, In: International Journal of Lean Six Sigma, 2022, 13, 3, 648–670

[4] Bashar, A., Hasin, A.A., Adnan, Z.H., *Impact of lean manufacturing: Evidence from the apparel industry in Bangladesh,* In: International Journal of Lean Six Sigma, 2021, 12, 5, 923–943

[5] Jiménez-Delgado, G., Quintero-Ariza, I., Romero-Gómez, J., Montero-Bula, C., Rojas-Castro, E., Santos, G., Sá, J.C., Londoño-Lara, L., Hernández-Palma, H., Campis-Freyle, L., *Implementation of Lean Six Sigma to improve the quality and productivity in textile sector: A case study*, In: International Conference on Human-Computer Interaction, 2023, 395–412

[6] Naeem, M., Ahmad, N., Hussain, S., Nafees, B., Hamid, A., *Impact of lean manufacturing on the operational performance: Evidence from textile industry*, In: Humanities & Social Sciences Reviews, 2021, 9, 3, 951–961

[7] Torres-Luna, S., Valdivia-Ríos, J., Macassi-Jáuregui, I., Palomino, E.R., Viacava-Campos, G., León-Chavarri, C., *Waste reduction model design in textile industry: A lean manufacturing approach*, In: Brazilian Technology Symposium, 2020, 427–434

[8] Zamora-Gonzales, S., Galvez-Bazalar, J., Quiroz-Flores, J., *A production management-based lean manufacturing model for removing waste and increasing productivity in the sewing area of a small textile company*, In: Brazilian Technology Symposium, 2020, 435–442

[9] Salman, S., Ahmed, T., Taqi, H.M.M., Frederico, G.F., Dip, A.S., Ali, S.M., *An integrated approach to explore the barriers to lean manufacturing in the context of the COVID-19 pandemic: Implications for sustainability*, In: International Journal of Industrial Engineering and Operations Management, 2024, 6, 2, 165–184

[10] Afum, E., Agyabeng-Mensah, Y., Baah, C., Dacosta, E., *Consolidating lean practices with quick-response manufacturing: A boon or bane for the textiles industry during the era of COVID-19*, In: International Journal of Lean Six Sigma, 2024

[11] Lista, A.P., Tortorella, G.L., Bouzon, M., Mostafa, S., Romero, D., *Lean layout design: A case study applied to the textile industry*, In: Production, 2021, 31, e20210090

[12] Yaxyaeva, I., *Efficiency and development forecasts of implementation of the concept 'Lean Production' in textile enterprises,* In: International Journal of Early Childhood Special Education, 2022, 14, 5

[13] Kurnia, H., Tumanggor, O.S.P., Jaqin, C., *Lean Six Sigma: Literature review and implementation for textile and textile product (TTP) industries*. In: 3rd Mercu Buana Conference on Industrial Engineering, 2021, 3, 1

[14] Saravanan, S., Chakraborty, P.S., Nallusamy, S., Kumar, V., *A proposed model for productivity improvement by implementation of lean manufacturing techniques in a textile industry*, In: SSRG International Journal of Mechanical Engineering, 2023, 10, 8, 31–48

[15] Ajmera, R., Umarani, P., Valase, K.G., *Lean six sigma implementation in textile industry*, In: International Research Journal of Engineering and Technology, 2017, 4, 04, 1670

[16] Rahman, S.S., Baten, A., Hoque, M., Mahmud, M.I., *Impact of lean manufacturing on productivity and layout design in sewing section of a garment industry*, In: International Journal of Industrial Management, 2023, 17, 3, 152–161

[17] Pereira, A.M.H., Silva, M.R., Domingues, M.A.G., Sá, J.C., *Lean six sigma approach to improve the production process in the mould industry: A case study*, In: Quality Innovation Prosperity, 2019, 23, 3, 103–121

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