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Reducing Outgoing Quality Level (OQL) in Textile Manufacturing Through Six Sigma Methodology: A Case Study

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Article

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ABSTRACT

Globally, the textile industry plays a significant role in production but faces many challenges that affect its operation and sustainability. Product quality remains an essential concern despite technological advancements and quality control measures. Raw materials, production methods, and skills differ, resulting in customer dissatisfaction and damage to reputation. A quality management strategy is necessary to overcome these problems and promote quality improvement. This includes the implementation of the Lean Six Sigma approach. This article focuses on improving textile quality by developing the Six Sigma DMAIC method. An analysis of three months' data from a textile company shows that an increase in the Outgoing Quality Level (OQL) from 3% to 6% resulted in significant economic losses, amounting to PKR-240,000 due to rework, residual costs, customer returns, and lost sales time. By utilizing Six Sigma tools, the company reduced OQL from 6% to 4%, thus lowering product losses and increasing operational efficiency. As a result of these findings, the textile industry can improve quality and profitability through a Lean Six Sigma approach.

KEYWORDS

outgoing quality level, lean manufacturing, Six Sigma, DMAIC

INTRODUCTION

The textile sector in Pakistan is a cornerstone of the country's economy, playing a crucial role in its GDP and offering jobs to a large segment of the population. In the current epoch, the textile industry stands out as a significant sector within Pakistan's industrial landscape. The substantial impact of textile industries on the national economy cannot be overlooked [1-2]. The textile industry faces many challenges that significantly impact its operations and sustainability. One of the foremost challenges is the ever-evolving consumer demands and preferences, which necessitate rapid adjustments in production processes and product offerings. Additionally, the industry grapples with intensifying competition, both domestically and internationally, leading to pricing pressures and shrinking profit margins. Moreover, the textile sector is highly susceptible to economic fluctuations and geopolitical tensions, further complicating its operational landscape. However, one critical issue stands out amidst these overarching challenges: maintaining and ensuring product quality [3]. In discussing quality, Robert Jacobson emphasizes the need to consider feedback between quality and strategic factors and account for firm-specific influences to accurately assess quality's role [4]. The modern textile industry, driven by advanced technology, faces numerous competitive challenges. These include complex markets, short product life cycles, and growing demands for rapid response and just-in-time delivery. To succeed in this competitive landscape, textile companies must prioritize high-quality, innovative products and quick responses to customer needs [5]. Companies must implement continuous improvement procedures to meet the growing demands for quality assurance and process traceability. These efforts are essential for maintaining competitiveness and ensuring customer satisfaction with product quality [6]. Among the various tools and methodologies in quality management, Six Sigma has become increasingly popular over the last few decades. Six Sigma employs quality principles and techniques designed to minimize process defects [7]. Utilizing statistical analysis and process improvement methods, Six Sigma helps textile producers systematically detect and address quality concerns, boosting efficiency and customer satisfaction [8]. Moreover, Total Quality Management (TQM) is a widely adopted management philosophy across various sectors. Organizations implement TQM to gain a competitive edge in quality, productivity, customer satisfaction, and profitability. However, the literature provides mixed results regarding the positive impact of TQM on organizational performance [9].

In the realm of process quality evaluation, Nandakumar [10] and Pravin [11] proposed a comprehensive approach that integrates various methodologies such as DMAIC, SIPOC, VSM, ANOVA, and 5S techniques. Building on this, Barot et al. recommended amalgamating the Six Sigma methodology with the DMAIC cycle, emphasizing ongoing enhancements in process quality [12]. According to De Mast, one sustainable method for improving quality involves adopting a project-based approach utilizing the Six Sigma DMAIC methodology [13]. This strategy includes five steps: define, measure, analyze, improve, and control (DMAIC). Six Sigma's data-driven approach is designed to enhance the quality by refining existing procedures. It has proven effective in reducing costs, shortening process times, eliminating defects, increasing customer satisfaction, and significantly boosting productivity across various industries and organizations worldwide. Recently, Six Sigma methodologies have garnered widespread attention due to their demonstrated success in enhancing quality and generating substantial cost savings. Six Sigma primarily targets quality improvement by minimizing waste and assisting organizations in producing products and services more efficiently, swiftly, and economically [14]. The study by Kumar et al. underscored the efficacy of DMAIC Six Sigma in achieving cost reductions and enhancing quality, as exemplified through a case study of a prominent tool manufacturing company [15]. The results demonstrated the effectiveness of the DMAIC Six Sigma process in the machining and fabrication sectors, leading to improved process and product quality while ensuring profitability through lowered manufacturing expenses [16]. In the context of quality control in the garment industry, Souri and Somantri showcased the successful implementation of the Traffic Light System (TLS), resulting in significant improvements [17]. Similar to Tsarouha's investigation into Six Sigma methodologies within the manufacturing sector [18], this research focuses on optimizing the drained weight of olives in packaging. The goal is to enhance customer satisfaction and reduce costs. By applying the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) approach, this study identifies the root causes of weight variations and implements targeted improvements. These actions reduced the standard deviation of drained weight by 51.02%, cut defect rates by 99.97%, and improved production yield by 8.24%, resulting in annual savings of $ 228,000.

Building on these findings, this research explores the application of Six Sigma methodologies within the textile industry, seeking to identify opportunities for process improvement in textile manufacturing operations. To understand the impact of quality issues comprehensively, it is essential to incorporate data on economic losses resulting from increasing Outgoing Quality Levels (OQLs) for the company under study. The analysis will include data obtained over three months: November, December 2022, and January 2023. A significant increase in OQL from 3% to 6% occurred during these three months, resulting in a rise in defective products leaving the facility. This increase is estimated to result in substantial economic losses (Pakistan Rupees) PKR-50,000 per month due to rework and scrap costs. Additionally, customer returns and refunds accounted for an additional PKR-15,000 monthly. Within the last three months, the shipment delay and missed sales opportunities caused PKR-75,000 in revenue loss. The company lost PKR-240,000 due to the elevated OQL between November 2022 and January 2023. This data underscores the critical need for implementing robust quality improvement measures to mitigate these losses and enhance overall operational efficiency.

The primary objective of this paper is to enhance productivity and efficiency while minimizing defects and wastage. The paper employs the DMAIC approach, a methodology aimed at improving processes in the textile industry by mitigating process variation and reducing defects. Various tools are applied at different stages of the DMAIC approach, including SIPOC (Supply-Input-Process-Output-Customer) analysis, fishbone diagram, check sheet, Pareto analysis, and Critical to Quality (CTQ). These tools collectively contribute to the overarching goal of optimizing the textile production process. These tools collectively contribute to the overriding goal of optimizing the textile production process. In the context of quality, the Outgoing Quality Level (OQL) concept holds significance in quality management and is closely associated with Six Sigma and other quality improvement methodologies [19].

The primary objective of OQL is to minimize defects and product deviations that exit the organization. Doing so contributes to reducing the defective rate, enhancing customer satisfaction, lowering customer refunds and complaints, and upholding a positive market reputation. OQL represents the percentage of defects identified during an inspection. Mathematically, it is expressed as:

$$OQL\ \% = \frac{Number\ of\ Defects}{Sample\ Size} \text{ Or } OQL = \frac{Number\ of\ Defects}{Sample\ Size} \times 1 \tag{1}$$

In this context, the sample size depends on the Acceptance Quality Level (AQL), a statistical method used to evaluate a sample from a product batch. AQL, an international quality standard set by the International Organization for Standardization (ISO), determines the maximum allowable number of defects. To enhance business process capabilities by minimizing the likelihood of errors or defects, Six Sigma offers a comprehensive array of management tools and practices. This data-driven methodology employs statistical techniques to eliminate defects, reduce variations, and improve profitability. The primary objective of Six Sigma is to limit manufacturing defects to no more than 3.4 per million units or events while improving cycle times. Therefore, the Six Sigma process is implemented in this project to optimize the quality management framework. The OQL is a pivotal parameter associated with the quality standards that an industry aspires to attain for its products before their delivery to customers. This metric holds significant relevance in quality control and is intricately linked with the intricacies of manufacturing and production processes. The OQL establishes a benchmark for quality and incorporates a target for continual process improvement, aiming to reduce defects and enhance overall quality. Within the Textile industry, it has been observed that the typical OQL hovers around 5%. However, the maximum permissible OQL is capped at 1.5%. This discrepancy has resulted in a high defect rate, leading to unsuccessful inspections. The high Outgoing Quality Level (OQL) has significantly impacted productivity, quality standards, and delivery timelines and has led to considerable resource wastage, including fabric, utilities, labour hours, and costs. Notably, 21% of production planning losses are due to rework and rejection associated with this elevated OQL, highlighting the critical need for corrective measures.

METHODOLOGY

The methodology implemented in this study involves a comprehensive utilization of diverse data sources, encompassing both primary and secondary data. Primary data acquisition focuses on identifying the root causes of defects through visual observation, with particular attention to the curtain stitching production line. Simultaneously, secondary data is drawn from monthly production rates and defect records related to curtain manufacturing. In Figure 1, the flowchart illustrates the research methodology. The research flowchart of this initiative unfolds across three distinctive phases. In the initial phase, the project is initiated, and foundational knowledge is acquired through an exhaustive literature review. Progressing to the second phase, data is systematically gathered from the textile industry, specifically the segment dedicated to curtain stitching. Following the meticulous collection of data, the Six Sigma DMAIC approach is strategically applied to elevate the overall quality of the manufactured product. The third and final phase thoroughly analyzes outcomes derived from the amassed data and implemented interventions. These outcomes undergo rigorous validation, ultimately marking the conclusive phase of the project.

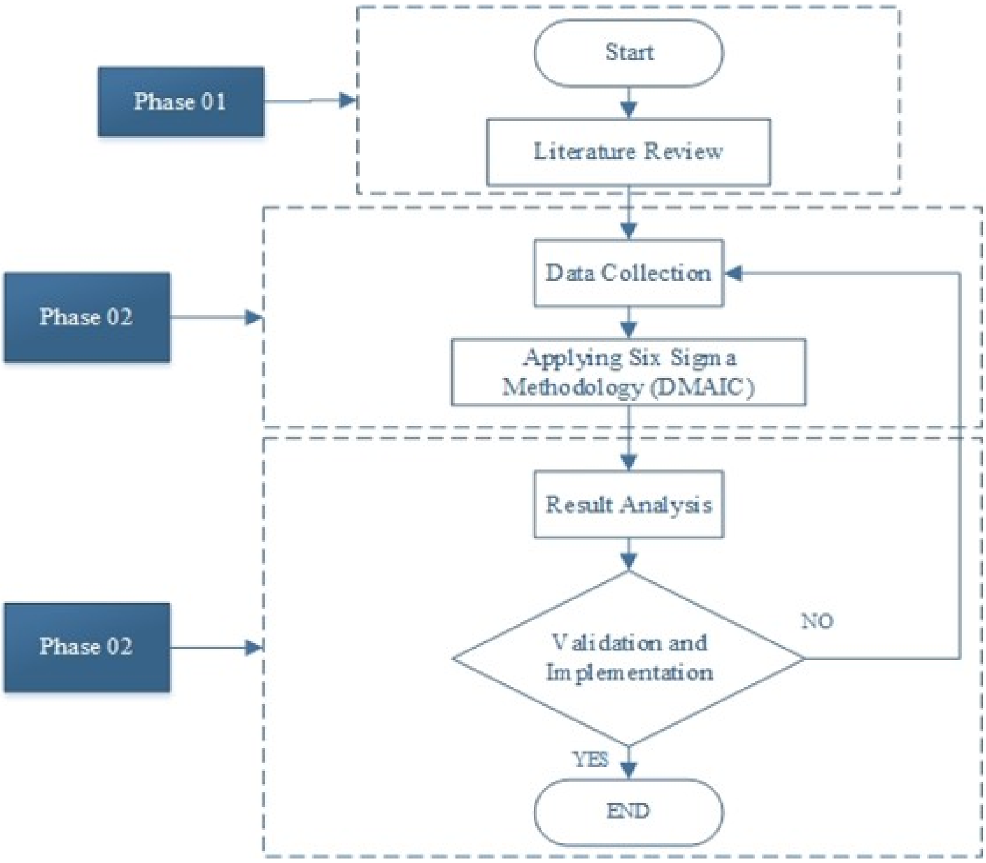

Figure 1. Research Methodology Flowchart

DMAIC Approach

The DMAIC approach is a problem-solving methodology within the Six Sigma framework and process improvement initiatives. DMAIC, an acronym for Define, Measure, Analyze, Improve, and Control, provides a systematic approach to problem-solving, facilitating the identification and resolution of issues in a structured manner, as mentioned in Figure 2. This study is oriented towards enhancing the quality of the stitching process by reducing the incidence of defective products.

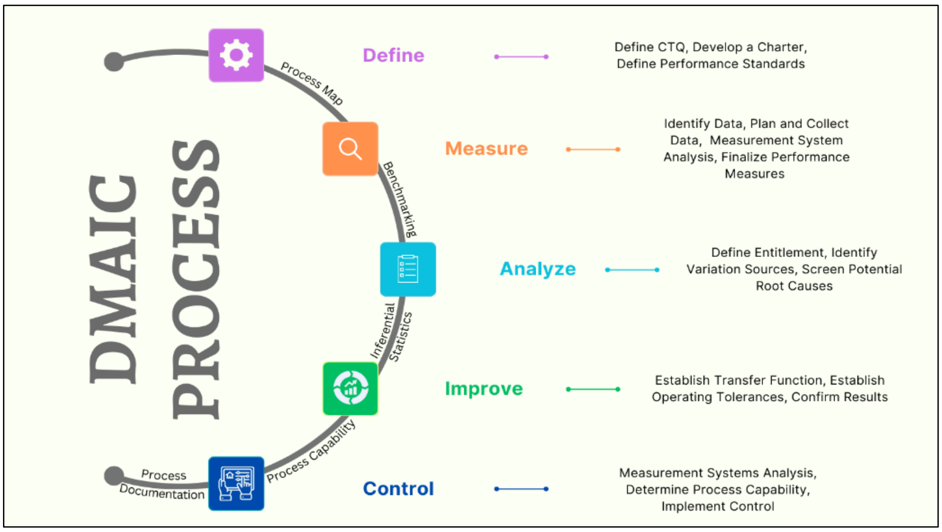

Figure 2. DMAIC Process

RESULTS AND DISCUSSION

Various tools and techniques are applied to scrutinize the outcomes of the implemented method and the collected project data. The results stemming from the implementation of the DMAIC approach are as follows:

Define phase

The Define phase encompasses a precise outline of the project's scope, goals, and objectives, aiming to identify opportunities for process improvement. Initially, a SIPOC analysis was conducted to gain a thorough understanding of the process and its stakeholders. Critical to Quality (CTQ) factors were identified, which are key parameters affecting customer satisfaction. Furthermore, a Pareto analysis was performed to prioritize and focus on the most significant issues contributing to process variation. The steps undertaken in this phase are detailed below:

SIPOC Analysis: SIPOC, which stands for Suppliers, Inputs, Process, Outputs, and Customers, is a tool for enhancing processes by applying Six Sigma techniques to provide deep insights. This analysis helps identify the critical components of the process. Figure 3 illustrates the elements of SIPOC.

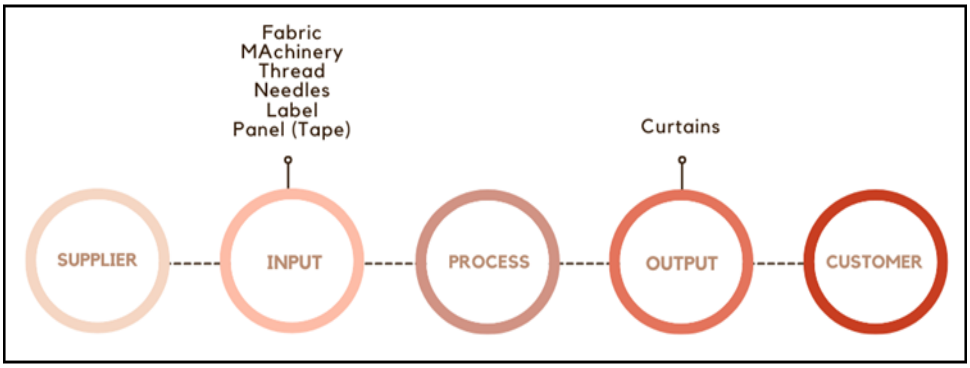

Figure 3. SIPOC Elements

Supplier: Suppliers play a critical role by providing the necessary inputs for the manufacturing process. These suppliers can be external or internal entities that furnish materials, knowledge, or resources to initiate the process.

Input: The input stage marks the commencement of the process and significantly influences its outcomes. This phase encompasses the materials, information, fabrics, and resources the supplier provides. Essentially, it involves utilizing raw materials for the process.

Process: The curtain stitching process involves transforming fabric into a finished curtain. Figure 4 depicts the outline of the curtain stitching process.

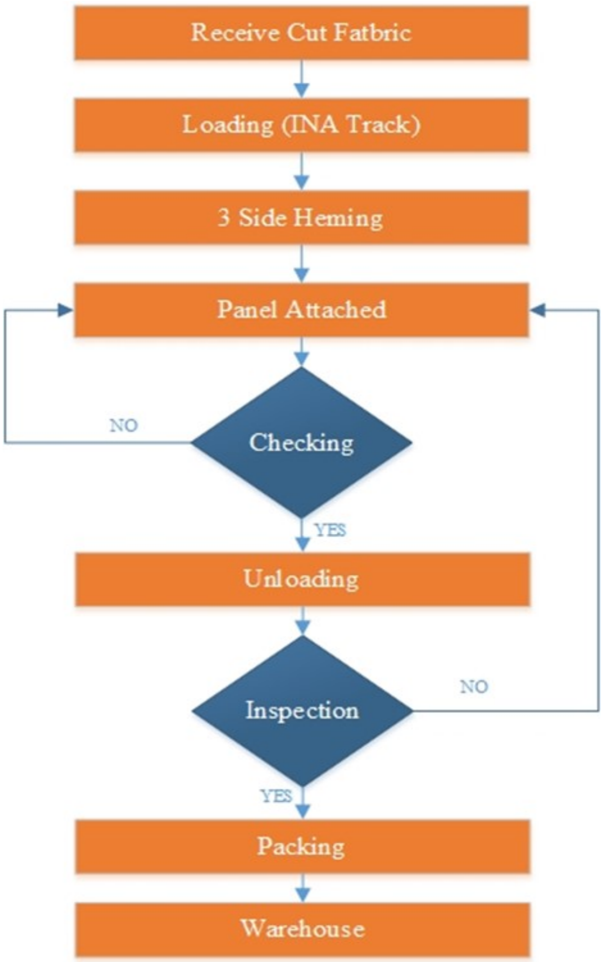

Figure 4. Steps for the Curtain stitching process

Output: Outputs represent the products received and evaluated by the customer. In the curtain stitching process, the final product is the finished curtains, which are ready for delivery to the customer. Outputs encapsulate the ultimate results of the product produced through the process.

Customer: The product's end users can be internal or external to the organization. In this case, IKEA is the customer for the product. Understanding the customer's needs and demands is essential for improving the production process.

Pareto Analysis: The Pareto analysis technique is essential for identifying and prioritizing issues within a specific context [20-21]. Particularly in enhancing product quality and the efficiency of the stitching process, Pareto analysis proves to be highly advantageous. Figure 5 presents a Pareto analysis explicitly outlining the common problems affecting product quality and the effectiveness of the stitching process. The Pareto analysis uncovers a notable discovery: 20% of the identified defects contribute to 80% of the total issues. These crucial defects comprise uncut thread, wash mark, bowing/skew, loose thread, bad stitch, Alternate tap attached, fly yarn, uneven stitch, and open hem. Recognizing and resolving these issues is pivotal for significant enhancements in product quality and the efficiency of the stitching process.

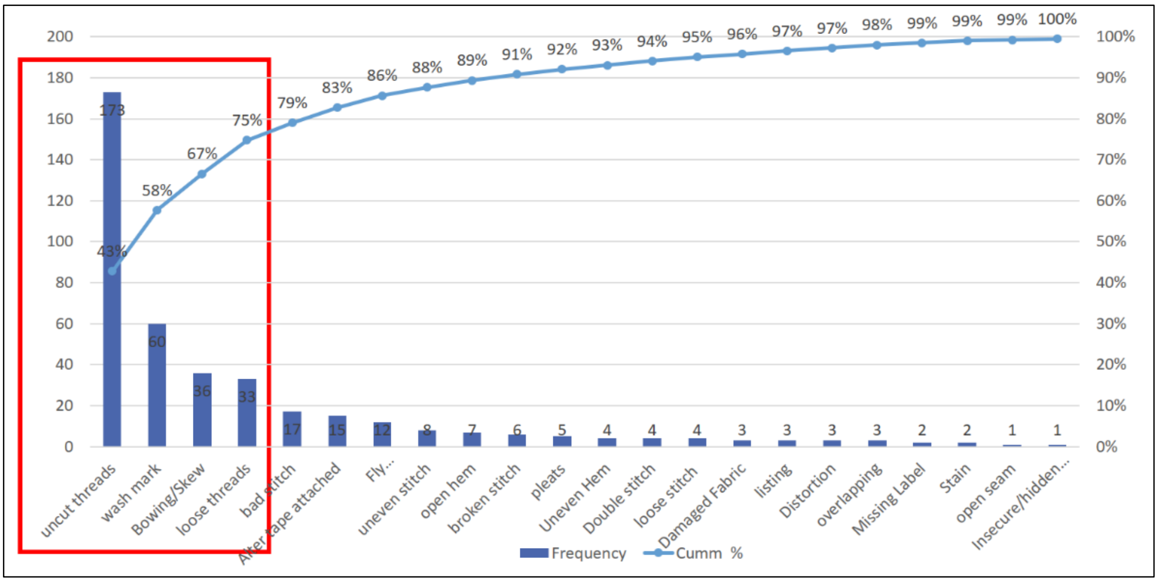

Figure 5. Three months' defects report of curtains

Critical to Quality Analysis: Critical to quality (CTQ) is a pivotal tool in quality management and the enhancement of production processes [22]. CTQ significantly influences the quality of the end product, as it determines issues, evaluates, and controls processes to ensure alignment with customer requirements and desired standards. CTQ factors encompass sample size, defects, and significant defects. In Figure 6, a visual representation accompanies the detailed analysis of the three months, presenting key quality control metrics observed during November, December, and January. The graphical illustration reinforces the insights derived from the provided table, outlining the sample sizes, significant defects, total defects, defect percentages, and out-of-specification limits (OQL) percentages for each respective month.

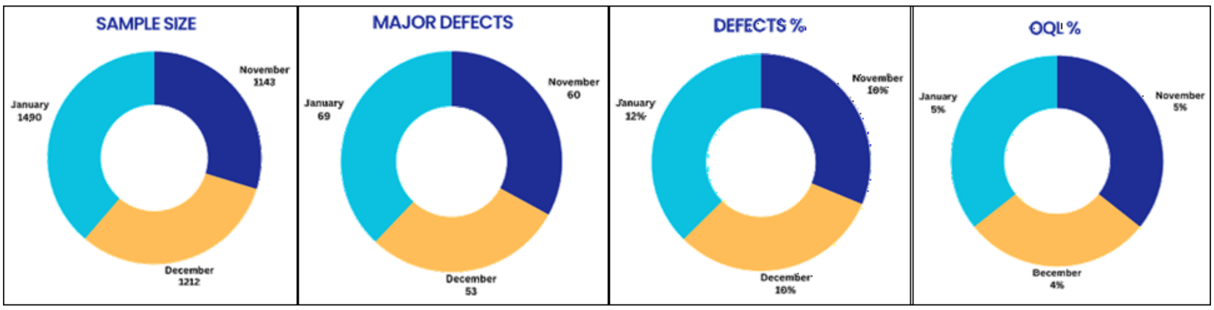

Figure 6. Quality Control Metrics Overview

By incorporating this visual aid, the presentation aims to enhance comprehension and facilitate a more nuanced understanding of the variations and trends in product quality across the specified timeframe. This combination of textual and graphical data provides stakeholders with a comprehensive view, enabling them to assess the effectiveness of quality control measures and pinpoint potential areas for improvement.

Impact on Production Planning: The evaluation of manufacturing efficiency necessitates careful consideration of the effect on production planning. Throughout the specified period, the overall production capacity reached 168,230 units. However, the planned production fell short, totalling 138,322 units, leading to an achieved production of 99,592 units. Consequently, the production planning loss for this period amounted to 38,730 units, resulting in a loss percentage of 21%. Delving into the monthly breakdown, in November, the production capacity of 168,230 units was planned to yield 138,322 units, yet only 99,592 units were achieved, reflecting a 28% loss. December revealed a production capacity of 76,164 units, with planned production at 63,326 units, and achieved production of 51,376 units, resulting in a 19% loss. January exhibited a production capacity of 156,436 units, a planned production of 126,957 units, and an achieved production of 109,741 units, reflecting a 15% loss. The total production planning loss for the three months stood at 21%, as shown in Figure 7. These figures underscore the imperative for comprehensively examining production planning strategies to minimize losses and optimize overall efficiency.

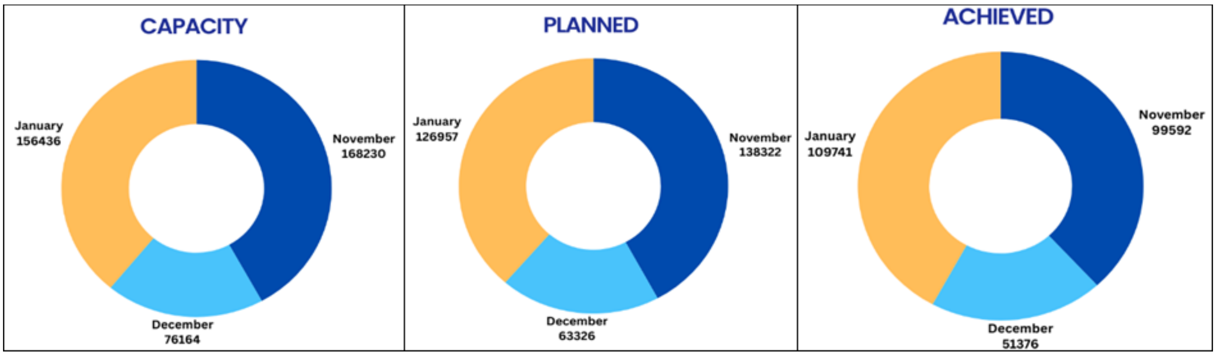

Figure 7. Impact on Production Planning

MEASURE PHASE

The Measurement phase of our research is dedicated to assessing and quantifying the fundamental performance and efficiency of the production process while identifying key performance indicators. This phase is instrumental in determining the current state of the production process and lays the groundwork for subsequent quality improvement initiatives and manufacturing process enhancements. In this Measure phase, our primary focus was on calculating the current sigma level of the production process. The sigma level is a critical metric for evaluating process performance by indicating its capability to generate defect-free outputs. The quantification of the sigma level enables us to comprehensively understand the existing state of the process, providing a baseline for improvement efforts.

Current Sigma Level Calculation: Calculating the current sigma level involves assessing the capacity and performance of the manufacturing process, shedding light on the level of defects and process variation. A higher sigma level signifies superior process performance with minimal defect occurrence. To illustrate the Current Sigma Level calculation, Figure 8 showcases the application of the relevant Sigma Level.

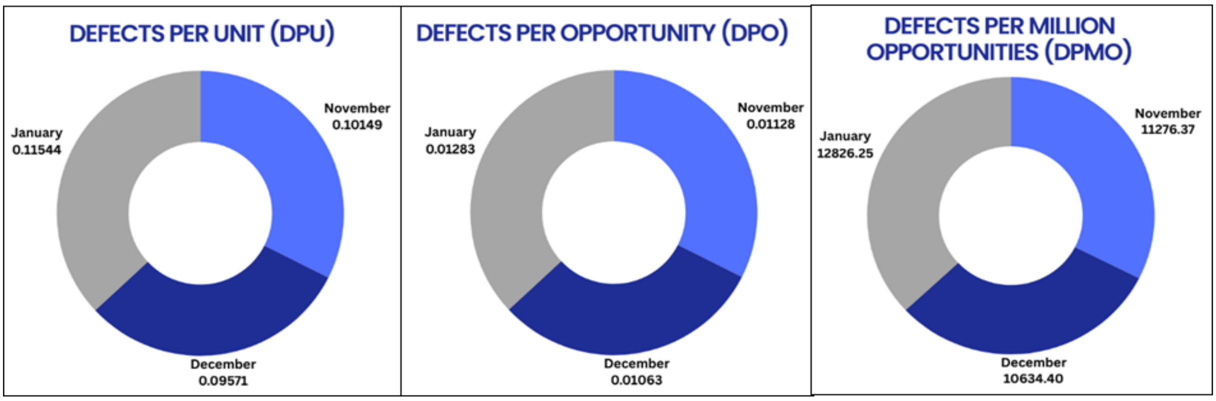

Figure 8. Current sigma level calculation

ANALYZE PHASE

During the analysis phase, our research employs statistical tools to scrutinize and analyze the measured data, aiming to identify defects and variations within the production process that significantly influence product quality. This phase concentrates on pinpointing the root causes of problems while identifying opportunities for improvement. To achieve this, a strategic focus is placed on utilizing fishbone analysis, a visual screening tool, to discern issues and defects contributing to elevated Out-of-Specification Limits (OQL). Figure 9 depicts the Fishbone Analysis of Uncut Thread, a critical defect impacting production planning and product quality. This defect is a significant contributor to a high outgoing quality level. Through the fishbone analysis, we systematically identify the causes of defects related to the uncut thread, examining factors attributable to human intervention, machinery, and procedural methods. This in-depth analysis facilitates a targeted approach to address the root causes of uncut thread defects, providing valuable insights for process improvement and quality enhancement.

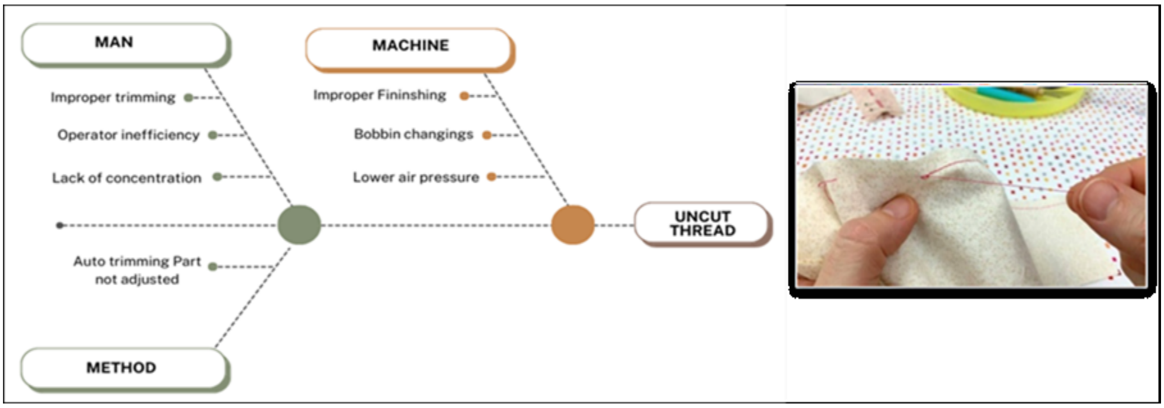

Figure 9. Root Cause of Uncut Thread

Fish Bone Analysis of Wash Mark: The Fishbone Analysis of Wash Mark unveils a significant defect affecting production planning and the outgoing quality level. Figure 10, titled "Root Causes of Wash Mark," visually captures the systematic examination of factors related to human involvement, machinery, methods, and materials contributing to wash mark defects. This analytical approach aims to identify and understand the problems associated with wash marks, offering a detailed insight into the root causes of these defects. Figure 10 serves as a visual aid to enhance the comprehension of the Fishbone Analysis, providing a comprehensive representation of the multifaceted factors influencing the occurrence of wash mark defects in the manufacturing process. The insights derived from this analysis enable targeted interventions to minimize wash mark defects and improve overall product quality.

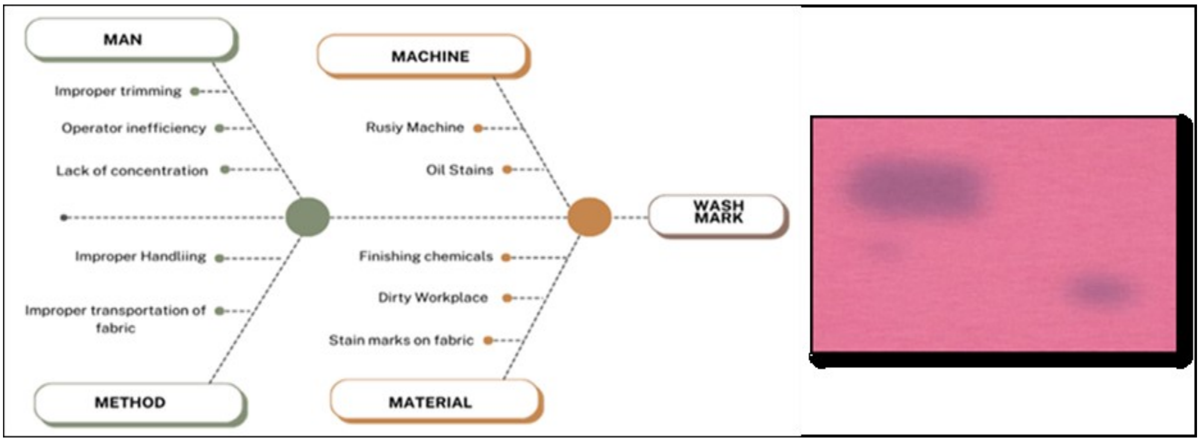

Figure 10. The root cause of wash mark

Fish Bone Analysis of Bowing / Skew: The Fishbone Analysis of Bowing/Skew delves into the significant defect of bowing, characterized by fabric distortion or an outward curve, and skew, denoting straightness deviation or misalignment in fabric. This defect holds prominence in the stitching process of curtains, posing challenges to product quality and contributing to a high outgoing quality level. As depicted in Figure 11, the comprehensive analysis systematically identifies issues and root causes related to human involvement, machinery, methods, and materials contributing to bowing or skew defects. That visual aid enhances the understanding of the multifaceted factors influencing the occurrence of these defects, facilitating targeted interventions for quality improvement in the curtain manufacturing process.

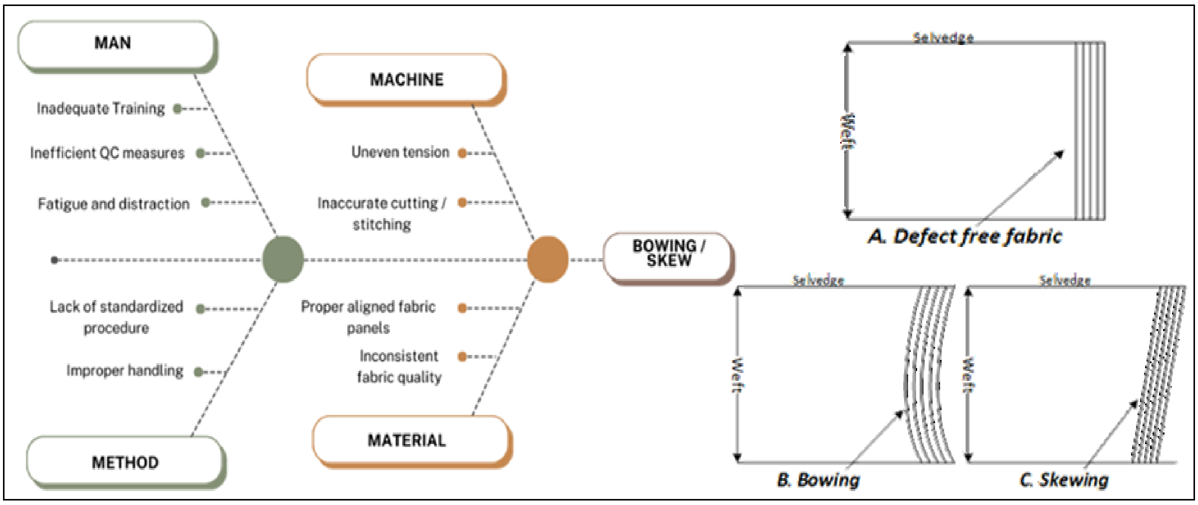

Figure 11. The root cause of bowing/skew

Fish Bone Analysis of Skip Stitch: On addressing the stitching problem characterized by the omission of stitches in a fixed pattern. This issue, known as skip stitch, poses challenges in maintaining the intended stitching pattern and contributes to a high outgoing quality level. Figure 12 visually represents the systematic identification of causes related to human involvement, machinery, materials, and methods contributing to skip stitch defects. Through this comprehensive analysis, we aim to discern the multifaceted factors impacting the quality of the product. The insights gleaned from the comprehensive Fishbone Analysis of Skip Stitch guide the implementation of targeted interventions to address skip stitch defects and improve the overall product quality within the stitching process.

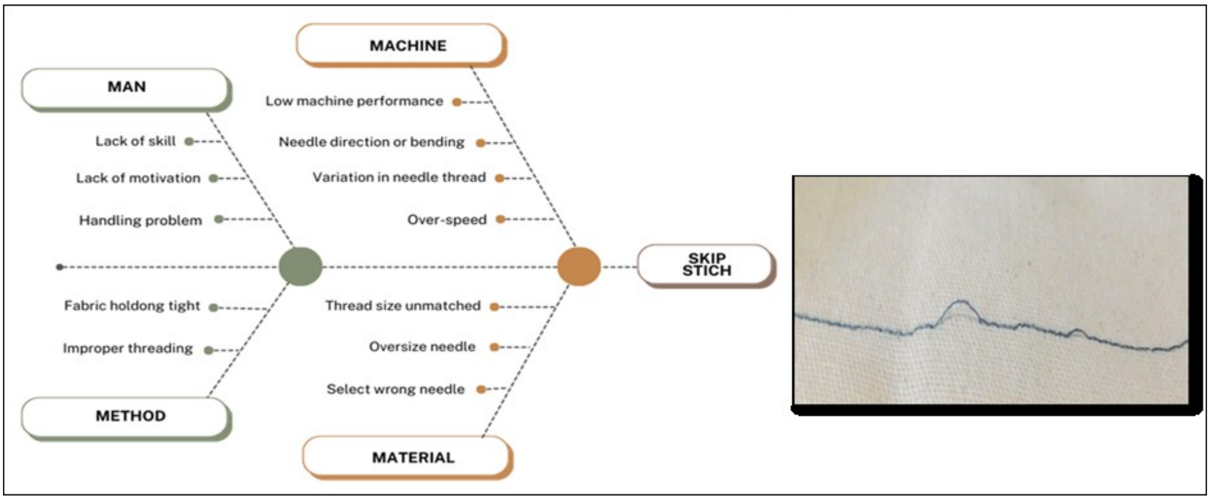

Figure 12. The root cause of skip-stitch

IMPROVE PHASE

Through Pareto analysis, recurring issues have been identified that contribute to 80% of defects in the improvement phase. The focus extended beyond recognizing these prevalent challenges to uncovering their root causes. Once these underlying issues had been identified, a strategic approach was taken, allowing them to be minimized or eliminated.

The measures are being implemented from February to April 2023, during which targeted interventions are applied to resolve the primary problems. The countermeasures included adjusting processes, training workers, and introducing new quality control procedures. Tables 1 - 4 provide a comprehensive overview of the interventions taken to improve the manufacturing process. This timeline and approach effectively integrated the countermeasures into the production process, improving quality and operational efficiency.

Table 1. Counter Measure of Uncut Thread

Causes	Action taken
Machine	Essential practices include consistently calibrating and maintaining machines, replacing worn-out cutting tools, executing meticulous machine setups, conducting regular inspections for malfunctions, and incorporating machine monitoring systems.
Operator	It is imperative to guarantee adequate operator training, institute quality control checks, deliver explicit work instructions, promote regular breaks to mitigate fatigue, and maintain focus on the task.
Method	Provide comprehensive training to operators on appropriate threading techniques, carefully choose cutting tools tailored to the material and thread type, recommend cutting speeds and feeds, ensure compliance with exact thread dimension specifications, and conduct routine process audits.

Measurement	Procure materials from trustworthy suppliers, conduct quality assurance testing on materials, maintain adequate lubrication during machining processes, and employ suitable tools and techniques for cutting materials of different hardness levels.

Table 2. Counter Measure of Uncut Thread

Causes	Action taken
Man	Before commencing work, operators should wash their hands and maintain personal hygiene. Additionally, material handling equipment (such as trolleys) should be utilized to transfer fabric and reduce direct contact.
Machine	Ensure machines are clean before the operation. Then, comprehensive training procedures must be followed for operators to maintain machine upkeep diligently.
Method	Develop detailed Standard Operating Procedures (SOPs) to regulate the production process, incorporating comprehensive guidelines for efficient material handling. Emphasize preventive maintenance and improve machine oil control systems utilizing the 5S technique. This involves thoroughly cleaning machine elements like needle teeth, bars, and covers. All components are methodically tightened and cleaned, proactively ensuring garments are correctly positioned on centre tables, avoiding placement on the floor. This systematic strategy has effectively diminished work-in-progress (WIP) levels.
Material	Before initiating any processes, notify the fabric supplier to be mindful of any spots on the fabric being transported via trolley or pallet.

Table 3. Counter Measure of Skip Stitch

Causes	Action taken
Man	Offering suitable training to operators and creating a stress-free environment where they can find satisfaction in their work.
Machine	Repair the damaged machine components and reduce the gap between the presser foot and the needle plate hole.
Method	Ensuring meticulous compliance with seam instructions has improved material handling and enhanced threading practices.
Material	Utilize needles engineered for loop formation, meticulously adjust needle height, conduct pre-bulk sewing assessments, and ensure precise needle mounting with eye positioning on the sewing machines. Furthermore, choose sewing thread compatible with the needle size, prioritizing high-quality thread devoid of flaws.

Table 4. Counter Measure of Bowing / Skew

Causes	Action taken
Machine	Utilized automated trimming machinery to cut fabric accurately.
Operator	Improve the operator's skill set, promote attentive focus during operations, utilize a cutter for raw edges, and ensure meticulous operator handling.
Method	Formulate precise operational specifications and uphold optimal allowances during hemming processes.
Measurement	Verify measurements sourced from the cutting section and employ the appropriate measurement folder.

COUNTERMEASURE OF OTHER DEFECTS

Open Seam: Open Seam occurs when gaps or missing stitches occur during the joining process. Corrective actions have been taken to rectify this, including ensuring proper alignment of the two parts, avoiding gaps in the lower part during joining, conducting routine checks, and strictly adhering to market guidelines.

Puckering/Sharing/Loose: his defect involves fabric appearing loose, showing shrinkage, gathering, or unevenness during joining. Comprehensive measures have been implemented to address this, such as providing thorough operator training, controlling work and revolution speeds, precisely aligning fabric parts, following designated cut marks, and avoiding pulling the fabric during sleeve joining.

Broken Stitch: Broken Stitch indicates loose or inaccurately formed stitches. Measures include using high-quality thread, ensuring smooth thread movement, precise thread placement, and consistent tension bar flow.

Pleats: Achieve consistent pleats by accurately and uniformly folding fabric before stitching. Use appropriate stitching techniques, such as backstitching, to secure pleats. Select fabrics conducive to pleats and consider using starch or interfacing for better retention: Mark folding and stitching points. Use steam iron or press post-stitching to set and shape pleats for a flat, uniform appearance.

IMPLEMENTING A TRAFFIC LIGHT SYSTEM

Introducing a traffic light system is an effective visual strategy for defect management and quality enhancement in curtain stitching. Leveraging this system with lean tools presents a practical approach to addressing issues such as uncut thread, broken stitches, and open hems.

1. **Defect Classification Criteria:** Clearly outline criteria for each defect category (uncut thread, broken stitch, open hem) to facilitate easy identification by workers.
2. **Traffic Light Color Assignment:**
    - Green: Indicates no defects.
    - Yellow: Signifies minor defects (e.g., one uncut thread, small open hem).

- Red: Flags major defects (e.g., multiple uncut threads, significant open hem, broken stitch).

3. **Visual Displays Placement:**
    - Install visible boards or signs at each workstation, displaying designated traffic light colours.
    - Position the boards strategically to ensure workers can quickly view them without disrupting their workflow.
4. **Worker Inspection Responsibilities:**
    - Train workers to inspect their work at specific stitching checkpoints.
    - In the presence of defects, workers place a coloured card (green, yellow, or red) on the corresponding board.
5. **Immediate Action Protocol:**
    - Yellow: Workers promptly address minor defects before proceeding with stitching.
    - Red: Workers cease stitching; the supervisor or quality control personnel inspect the piece and determine whether it requires rework or correction.
6. **Data Collection Process:**
    - Maintain records of the number of yellow and red cards placed on the boards.
    - Utilize the collected data to identify patterns, pinpoint improvement areas, and assess the system's effectiveness.
7. **Continuous Improvement Initiatives:**
    - Conduct regular meetings to deliberate on the accumulated data.
    - Brainstorm and implement strategies to diminish the occurrence of yellow and red cards over time.
    - Encourage worker participation in suggesting improvements and implementing solutions.
8. **Feedback Loop Establishment:**
    - Institute a feedback loop wherein workers can contribute suggestions for enhancing the traffic light system.
    - Continuously refine the system based on worker input and observed outcomes.

Incorporating the traffic light system provides a visual and efficient approach to tackling defects while minimizing disruptions to workflow. This system fosters a proactive approach to defect detection and cultivates a culture of quality consciousness among employees. A decrease in the occurrence of yellow and red cards over time indicates improvements in the stitching process's quality and efficiency.

The outcomes have proven highly favourable after applying Six Sigma techniques, specifically utilizing tools like the Pareto Chart and Cause & Effect analysis, coupled with addressing the underlying factors to enhance quality. The collaborative teamwork approach has been pivotal in achieving effective problem resolution. Implementing the lean Six Sigma DMAIC approach significantly improved the outgoing quality level, decreasing from 3% to 2%. Notably, the production planning loss, which initially stood at 21%, has seen a remarkable reduction of 6%, as mentioned in Table 5.

Moreover, incorporating the traffic light system has shown promising results in reducing the defective rate in production and enhancing overall product quality. Implementing Six Sigma techniques has also strengthened operational teamwork, fostering a robust and cohesive collaborative environment. This holistic approach, combining data-driven methodologies with systematic problem-solving and collaborative efforts, underscores a continuous commitment to refining and optimizing the production process for sustained quality improvements.

Table 5. Impact of Six Sigma Techniques on Quality and Production Metrics

S#	Matrix	Before	After	Achievements	Economic impact
1.	OQL (Sewing section)	5%	3%	2%	Reduced rework and scrap costs
2.	Reject/Scrap % (Sewing section)	0.21	0.15	6%	Lower production losses
3	Teamwork	Not strong	Stronger than previous	Improved	Improved efficiency and morale
4	Reward system	No	Yes	Improved	Reduced turnover
5	Six Sigma knowledge of workers	No	Yes	Improved	Increased productivity and quality

CONCLUSION

Lean Six Sigma DMAIC methodology has become a pivotal strategy in elevating quality standards in the textile industry, primarily by reducing the outgoing quality level. Guided by the DMAIC framework—Define, Measure, Analyze, Improve, and Control—this project has provided a structured and systematic approach to addressing critical issues impacting product quality. In the Define phase, SIPOC, CTQ, and Pareto analyses were used to identify critical issues contributing to the high outgoing quality level. Subsequent phases involved comprehensive root-cause analysis and targeted countermeasures implemented during the Improve phase, specifically addressing defects like uncut threads, oil stains/wash marks, skip stitches, and bowing/skew. Further, preventive measures aimed at reducing future defects ensure a sustained improvement in product quality. The tangible outcomes of this quality enhancement initiative are noteworthy. By applying lean methodologies throughout DMAIC, the outgoing quality level was reduced from 6% to 4%, consolidating the effectiveness of the lean methodology. As a result of this reduction, production losses dipped by 5%, highlighting the positive impact of this reduction on operational efficiency.

Traffic light systems were incorporated during the Control phase to monitor and regulate the production process. As a result of this systematic approach, defects are minimized, and rework is minimized, enhancing the overall quality of the product. These favourable outcomes reaffirm the efficacy of the DMAIC methodology in identifying, addressing, and rectifying process inefficiencies, ultimately leading to significant improvements in product quality and performance. Improve processes, reduce waste, and increase efficiency. At the management level, Six Sigma fosters a culture of continuous improvement and data-driven decision-making. Future research could explore the application of Six Sigma in other areas of the textile industry or the integration of different quality control tools for process improvement.

Author Contributions

Shuaib Kaka conceptualized the study, developed the methodology, and supervised the project. Muttahira Maryam curated the data, prepared the original manuscript draft, and contributed to its writing. Rano Khan Wassan and Ali Akbar reviewed and edited the manuscript. Umair Sarwar and Jansher Ansari visualized the data. All authors contributed to the project administration.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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REFERENCES

[1] Abou-Okeil A, Hakeim OA. Effect of metal ion binding of chitosan on the printability of pretreated wool fabric. Coloration Technology. 2005; 121(1):41-4. https://doi.org/10.1111/j.1478-4408.2005.tb00247.x

[2] Shah W, Warraich UA, Kazi AK. Challenges faced by textile industry of Pakistan: Suggested solutions. KASBIT Business Journal. 2012; 5:33-9.

[3] Pazilov GA, Ivashchenko NP, Bimendiyeva LA, Aitymbetova AN. Textile industry: issues of managing the growth of innovative activity in enterprises. Polish journal of management studies. 2020; 21(1):297-315. https://doi.org/10.17512/pjms.2020.21.1.22

[4] Jacobson R, Aaker DA. The strategic role of product quality. Journal of marketing. 1987; 51(4):31-44. https://doi.org/10.2307/1251246

[5] Das A. Testing and statistical quality control in textile manufacturing. Process control in textile manufacturing: Elsevier; 2013. p. 41-78.

[6] Neves P, Silva F, Ferreira LP, Pereira T, Gouveia A, Pimentel C. Implementing lean tools in the manufacturing process of trimmings products. Procedia Manufacturing. 2018; 17:696-704. https://doi.org/10.1016/j.promfg.2018.10.119

[7] Graafmans T, Turetken O, Poppelaars H, Fahland D. Process mining for six sigma: a guideline and tool support. Business & Information Systems Engineering. 2021; 63:277-300. https://doi.org/10.1007/s12599-020-00649-w

[8] Yame AA, Al-Werfalli D. Applications of lean methodologies and quality improvement in textile industry. 2016.

[9] Shafiq M, Lasrado F, Hafeez K. The effect of TQM on organisational performance: empirical evidence from the textile sector of a developing country using SEM. Total Quality Management & Business Excellence. 2019; 30(1-2):31-52. https://doi.org/10.1080/14783363.2017.1283211

[10] Nandakumar N, Saleeshya P, Harikumar P. Bottleneck identification and process improvement by lean six sigma DMAIC methodology. Materials Today: Proceedings. 2020; 24:1217-24. https://doi.org/10.1016/j.matpr.2020.04.436

[11] Pravin T, Somu C, Rajavel R, Subramanian M, Reynold PP. Integrated Taguchi cum grey relational experimental analysis technique (GREAT) for optimization and material characterization of FSP surface composites on AA6061 aluminium alloys. Materials Today: Proceedings. 2020; 33:5156-61. https://doi.org/10.1016/j.matpr.2020.02.863

[12] Barot R, Patel J, Sharma B, Rathod B, Solanki H, Patel Y. Lean six sigma feasibility and implementation aspect in cast iron foundry. Materials Today: Proceedings. 2020; 28:1084-91. https://doi.org/10.1016/j.matpr.2020.01.087

[13] De Mast J, Lokkerbol J. An analysis of the Six Sigma DMAIC method from the perspective of problem solving. International Journal of Production Economics. 2012; 139(2):604-14. https://doi.org/10.1016/j.ijpe.2012.05.035

[14] Kaushik P, Khanduja D. Application of Six Sigma DMAIC methodology in thermal power plants: A case study. Total Quality Management. 2009; 20(2):197-207. https://doi.org/10.1080/14783360802622995

[15] Kumar S, Wolfe AD, Wolfe KA. Using Six Sigma DMAIC to improve credit initiation process in a financial services operation. International Journal of Productivity and Performance Management. 2008; 57(8):659-76. https://doi.org/10.1108/17410400810916071

[16] Kumar SA, Suresh N. Production and operations management: New Age International; 2006.

[17] Souri S, Somantri K, editors. The Application of Traffic Light System on CVX. Proceeding Book of Proceeding Indonesian Textile Conference: textile 40 clothing and beyond (international conference); 2019: Penerbit Politeknik STTT Bandung.

[18] Tsarouhas P, Sidiropoulou N. Application of Six Sigma methodology using DMAIC approach for a packaging olives production system: a case study. International Journal of Lean Six Sigma. 2024; 15(2):247-73. https://doi.org/10.1108/IJLSS-06-2022-0140

[19] Cochran J, Erol R. Performance modelling of serial production lines with inspection/repair stations. International Journal of Production Research. 2001; 39(8):1707-20. https://doi.org/10.1080/00207540010022331

[20] Karuppusami G, Gandhinathan R. Pareto analysis of critical success factors of total quality management: A literature review and analysis. The TQM magazine. 2006; 18(4):372-85. https://doi.org/10.1108/09544780610671048

[21] Kaka S, Hussin H, Khan R, Akbar A, Sarwar U, Ansari J. Fuzzy logic-based quantitative risk assessment model for hse in oil and gas industry. Journal of Tianjin University Science and Technology. 2022; 55(06). https://doi.org/10.17605/OSF.IO/WVG2H

[22] Fleacă B, Corocăescu M. Critical To Quality (CTQ) Tree Technique To Improve Teaching And Learning Process–The Case Of Higher Education. Proceedings of AC 2019 in Prague. 2019: 130.