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Quality Improvement in Interlining Manufacturing Through the Six Sigma DMAIC Methodology: A Case Study

Mejora de la calidad en la fabricación de entretelas mediante la metodología Six Sigma DMAIC: un estudio de caso

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ABSTRACT

The Six Sigma DMAIC (Define, Measure, Analyze, Improve, and Control) methodology is widely used for quality improvement in manufacturing processes. This study presents a case study focused on improving quality in an interlining manufacturing process within a textile company. The objective was to identify the most frequent defects, analyze their root causes, and implement corrective and preventive actions to increase the process sigma level. Quality tools such as inspection sheets, Pareto analysis, p control charts, Ishikawa diagrams, and a PDCA-based action plan were applied. The results showed that stains, creases, and tears accounted for approximately 80% of total defects. After implementing improvement actions, sigma levels increased across all defect categories, with improvements of up to 0.6 in some cases. Although the target sigma level was not achieved for all defects within a single cycle, the findings demonstrate the effectiveness of DMAIC as a structured approach for quality improvement in interlining manufacturing and highlight the importance of continuous improvement strategies.

Keywords: DMAIC, six sigma, PDCA, quality, continuous improvement, Ishikawa

RESUMEN

La metodología Six Sigma DMAIC (Definir, Medir, Analizar, Mejorar y Controlar) es ampliamente utilizada para la mejora de la calidad en los procesos de manufactura. Este estudio presenta un caso de estudio enfocado en la mejora de la calidad en un proceso de fabricación de entretelas dentro de una empresa textil. El objetivo fue identificar los defectos más frecuentes, analizar sus causas raíz e implementar acciones correctivas y preventivas para incrementar el nivel sigma del proceso. Se aplicaron herramientas de calidad como hojas de inspección, análisis de Pareto, gráficos de control p, diagramas de Ishikawa y un plan de acción basado en el ciclo PDCA. Los resultados mostraron que las manchas, arrugas y desgarres representaron aproximadamente el 80 % del total de defectos. Tras la implementación de acciones de mejora, los niveles sigma aumentaron en todas las categorías de defectos, con mejoras de hasta 0,6 en algunos casos. Aunque el nivel sigma objetivo no se alcanzó para todos los defectos en un solo ciclo, los hallazgos demuestran la eficacia del DMAIC como un enfoque estructurado para la mejora de la calidad en la fabricación de entretelas y destacan la importancia de las estrategias de mejora continua.

Palabras clave: DMAIC, Six Sigma, PDCA, calidad, mejora continua, Ishikawa

INTRODUCTION

In the manufacturing sector, quality is considered a strategic indicator and one of the most crucial elements, as it directly impacts customer satisfaction, cost reduction, and market competitiveness (Evans, 2011). In the textile industry, ensuring product quality is essential, especially for intermediate products such as interlinings, which play a fundamental role in garment construction by providing structure, durability, and aesthetic appearance (Hayajneh, 2013). Any deviation in their quality may lead to rework, waste, and loss of customer confidence.

The Six Sigma methodology has been widely promoted and adopted by world-class manufacturing organizations due to its proven advantages in reducing waste, improving process efficiency, and eliminating activities that do not add value to the process (Rifqi, 2021; Ahmed, 2019; Smith, 2011). Its successful application relies on the correct identification of critical problems, the prioritization of improvement areas, and the implementation of structured actions aimed at minimizing defects, errors, and variability while maximizing organizational profitability (Coronado, 2002).

Among the different Six Sigma approaches, the DMAIC model (Define, Measure, Analyze, Improve, and Control) provides a systematic framework for problem-solving based on data-driven decision-making. This model enables a clear definition of the problem, the selection of appropriate measurement tools, an in-depth analysis of process performance, the implementation of improvement actions, and the establishment of control mechanisms to ensure long-term sustainability (Chavez, 2025; Lynch, 2003; Monday, 2022).

Although literature reports numerous applications of DMAIC in textile and manufacturing processes, most studies focus on final garment production or large-scale operations. Limited research has specifically addressed the application of DMAIC in interlining manufacturing processes, despite their critical role in garment quality. Therefore, this research aims to apply the DMAIC Six Sigma methodology to improve quality in an interlining manufacturing process, identifying the most frequent defects, analyzing their root causes, and proposing corrective and preventive actions to increase the process sigma level and ensure compliance with customer requirements.

It is important to highlight that a series of limitations may be presented by the application of DMAIC, mainly because each of the phases must be used with the lean thinking philosophy. Likewise, once the methodology is applied in an initial stage, a continuous improvement program that uses the PDCA model (Plan, Do, Check, Act) is to be designed by management, thus allowing of success of the improvement actions to be monitored and changes to be proposed based on the variations that are undergone by the process over time (De Mast, 2012; Mandal, 2012).

DMAIC Cycle

Within the continuous improvement of six sigma projects, the acronym DMAIC has been widely employed in conjunction with the PDCA cycle (Sokovic, 2010; Sin, 2015). Each of the letters that make up the DMAIC has a particular objective and is served as the basis for the following phase as shown below

- Define: Identify the need for change and the benefits from it.
- Measure: Quantify the actual state of the system by diagnostic and root causes
- Analyze: Compare the state of the system with the "ideal" state and determine corrective and preventive actions
- Improve: Follow the actions and measure the results.
- Control: Continue with the successful actions and modify what is needed.

Define

The objective of this stage is to verify the actions necessary to resolve problems that are considered critical for the organization and are directly related to the organization's available resources. A strategic vision must be established, with a focus on external factors that generate costs for the organization. This allows for the establishment of containment, correction, and prevention actions, and internal cost problems can subsequently be resolved (Rahman, 2018).

Measure

In this stage, all available information on the process to be studied is gathered by the organization, with a particular focus on information that will allow for a better understanding of how stakeholders' expectations are being met. Statistical tools are often utilized, as well as core tools such as failure mode and effect analysis (FMEA). Special care must be taken to include and select information in an appropriate format that is to be presented to management so that permanent containment actions can be established (Basios, 2017).

Analyze

In the analysis stage, different tools and methods are typically employed based on risk-based analysis. Clear evidence must be presented for the interpretation of the results obtained in the previous phase. For Sigma projects, the process capability is defined at the Sigma level, which will serve as a performance indicator so that, once the improvement plan actions (PDCA) have been implemented, the degree of impact of the Six Sigma project on the organization can be measured (Beyene, 2016).

Improve

Considered the most important stage of the Six Sigma methodology, the carrying out of all the management and execution actions necessary to improve the organization's functions, financial aspects, and customer requirements is deemed important (Kurnıa, 2021). It is suggested that the root causes of the problems must be resolved by the improvement plan (Nedra, 2019).

Control

The effectiveness of the measures established in the improvement plan is sought to be monitored by the control phase while the future state of the system is simultaneously monitored (avoiding the repetition of the same waste). The final stage of the original DMAIC cycle is represented by it, but at the same time, a guideline is served by it to ensure that the organization's objectives and goals are not deviated from (Adnan, 2010).

Literature review

The literature has widely reported the application of lean thinking and Six Sigma tools, from the service industry to manufacturing and processing.

The six-sigma methodology has been successfully applied in foundry projects, with a focus on customer complaints, an increase in process capability, a reduction in the defect rate, and a reduction in customer complaints (Kumar, 2007).

Six-sigma methodology has been successfully implemented in the design of a fixture that would reduce warp during the heating process of a heat treatment, achieving a new die design that not only eliminates costs due to rework but also increases the efficiency of the process, presenting significant savings (Kumar. 2009; Hernandez, 2025).

DMAIC applications are not limited to large companies with complex processes where based on an Ishikawa, the main causes of defects were clearly identified by a CNC machining company (Hiregoudar, 2011), leading to a reduction in manufacturing costs, an improvement in the process, and the development of a training plan, as well as the implementation of a 5'S model in small and medium-sized companies in India. It is worth noting that an increase in productivity in medium-sized companies has been through the application of continuous improvement tools such as the 5'S (Hernandez, 2025).

Researchers have emphasized the importance of integrating 4.0 technologies with the DMAIC methodology for automated processes, where Machine Learning (ML) technology serves as a tool to predict the weight of components based on prior statistical information, allowing for the prediction and control of the amount of scrap generated in the process, as well as more precise control of parameters (Martinez, 2025; Krauß, 2023).

Case Study: Background

This research project began with a meeting between the project team, senior management, and production managers to analyze the main problems related to the interlining manufacturing process. During the meeting, current procedures were reviewed, and a preliminary diagnosis of production conditions was conducted. As a result, several common nonconformities were identified that directly affect the quality of the final product, including stains, tears, and wrinkles in the interlinings.

These defects not only increase costs through rework and waste but also affect customer perception and compromise product functionality. The team prioritized a detailed analysis of the causes of these problems and proposed corrective and preventive actions to improve process efficiency and ensure compliance with quality standards. Management expressed its willingness to collaborate with the necessary resources, and key project stakeholders took specific responsibilities, committing to work under a continuous improvement approach aligned with the Six Sigma methodology.

Unlike previous studies, this research focuses on interlining manufacturing, a scarcely documented textile sub-process which increases novelty due to main authors emphasizing the use of lean tools in mostly automotive and aerospace industry. The objective of this research is to improve the sigma level of the interlining manufacturing process through the DMAIC methodology.

Interlinings, as intermediate products used primarily in the manufacture of collars, cuffs, and hems, must have specific technical standards met, such as strength, adhesiveness, and uniformity. The final appearance of garments and their functionality can be compromised by the presence of defects such as stains, creases, or tears, generating rework, waste, and loss of customer confidence (Montgomery, 2020).

METHODOLOGY

The first stage involved directly observing the production process, which included the warping, gumming, weaving, dyeing, and napping stages. The team used verification sheets to record the number and type of defects they identified in the interlinings produced during several work shifts. The researchers randomly selected production batches for the sample to ensure representative data.

For data analysis, we used an inspection sheet to record and classify the most frequently observed defects (stains, creases, tears, etc.). Using an attribute control chart (p-chart), we evaluated the proportion of defective products in 10 different batches, corresponding to 5 workdays with two shifts per day. We selected a batch size of 100 items by simple random sampling.

The team then organized and analyzed the information using a Pareto chart to visualize which defects accounted for the highest proportion of nonconformities. Following the 80/20 principle, they also determined the process's sigma level based on each defect. Once they quantified the defects, they used an Ishikawa diagram to identify their root causes, classifying them into categories such as materials, methods, machinery, labor, and environment, and ultimately establishing an action plan.

RESULTS AND DISCUSSION

Project Charter (Define)

The results obtained in this study demonstrate that the application of the DMAIC Six Sigma methodology is an effective approach for identifying, prioritizing, and reducing defects in the interlining manufacturing process. The analysis of 1,000 linear meters of interlinings revealed a defect rate of 10%, which is considerably higher than the scrap levels of approximately 5% reported in similar textile processes (Jiménez-Delgado, 2023; Mughal, 2021; González, 2023) This finding justified the need for a structured improvement project.

In the kick-off meeting of this six-sigma project, the team established a Project charter that defined and delimited the object of study. This tool serves as the basis for defining any improvement project. (Prashar, 2014; Srivastava, 2021) present the information corresponding to the definition phase in table 1.

Table 1

DMAIC Project Charter

Project title	Minimize defects in interlinings.
Business Case	A considerable number of errors were found during the fabric production process. A representative sample of 1,000 meters of interlinings was used to quantify these to establish an approximate production batch.
Goal	Increase the process sigma level to 4.5 for each defect.
Metrics (CTQ´s)	Primary Metric (sigma level) Cost of quality ($)
Project Scope	Management, project team, production department.

Checklist (Measure)

During the analysis carried out at the plant, the team inspected 10 production batches corresponding to one week of work, with a total of 1,000 linear meters of interlining inspected. The sample size was selected based on industrial inspection standards and resource availability, ensuring representativeness while minimizing production disruption. The team recorded the defects found in Table 2 using the verification sheet.

Table 2
Interlining presented defects

Defect type	Frequency
Stains	37
Creases	25
Tears	18
Lack of adhesiveness	10
Textile pollution	7
Frays	3
Total	**100**

The table 2 clearly shows that most defects corresponded to stains, folds, and breaks with 37, 25, and 18 defects respectively, while the lack of adhesiveness occurred a total of 10 times; finally, the exposure of textile contamination and fraying ranked as the least observed defects, so clear evidence exists of what type of defects the present improvement project should focus on.

Researchers have reported scrap levels of 5% in the literature for different stages of a textile process (Jiménez-Delgado, 2023) so that when they observe a total of 100 defects in 1000 meters of interlinings, they find that the value of 10% is considerably high compared to what other improvement projects have reported (Mughal, 2021; González, 2023).

Sigma Level (Measure)

Sigma level was calculated based on DPMO using standard Six Sigma conversion tables. According to what is shown in Table 2, the defects and their frequency were quantified based on the representative sample, and the sigma level of the process was also determined. As shown in Table 2, the sigma level for defects was reported as 3.3, 3.5, 3.6, 3.8, 3.7 and 4.3 for stains, folds, tears, lack of adhesiveness, textile contamination and fraying respectively. The management goal is set at 4.5, with no value being recorded above the established goal.

Table 3
Sigma Level of the Process

Defect type	Sigma Level	Sigma Level Goal
Stains	3.3	4.5
Tears	3.6	4.5
Lack of adhesiveness	3.8	4.5
Textile pollution	3.7	4.5
Frays	4.3	4.5

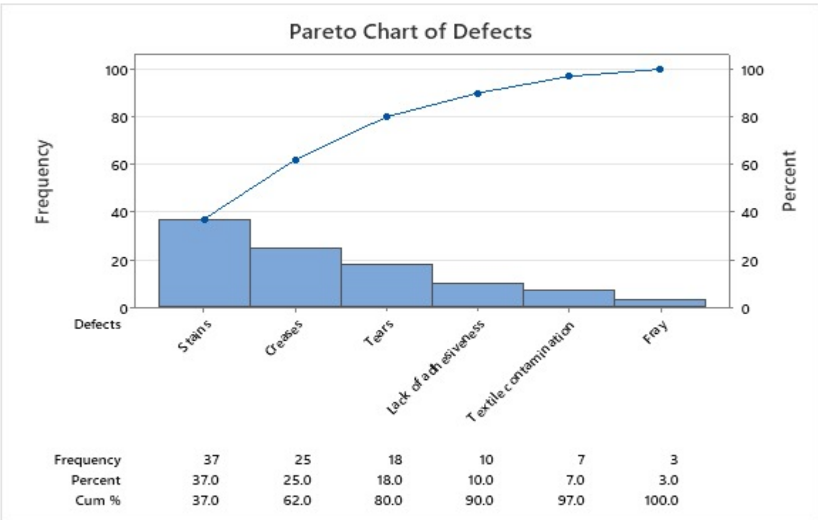
The importance of using the sigma level of a process as a key performance indicator to measure the current state of the system and to be able to monitor the effect of improvement actions on process optimization was highlighted previously (Patel, 2023). For the present research, it is stated that the sigma level is at least above 3 for each of the defects, with which it is aimed that this level is increased by a maximum of 1.5.

Pareto Diagram (Measure)

According to optimize the organization´s time and resources the team created a Pareto diagram corresponding to all detected defects. It clearly shows that the three most common defects are strains, creases and tears, representing 80% of the total defects, complying with the 80/20 principle. This indicates that by focusing on eliminating these three defects, the team could reduce the number of defects by 80%. The investigation did not prioritize three defects that accounted for 20% due to their low percentages, which were individually 10%, 7%, and 3%. The Pareto analysis showed that stains, creases, and tears accounted for approximately 80% of total defects, confirming the applicability of the 80/20 principle in this process. Similar patterns have been reported in previous textile related Six Sigma studies, where a small number of defect types were responsible for most nonconformities (Kumar. 2009; Hiregoudar, 2011), By focusing improvement efforts on these critical defects, the project optimized the use of organizational resources and maximized the potential impact of corrective actions.

Figure 1

Pareto Chart of Defects



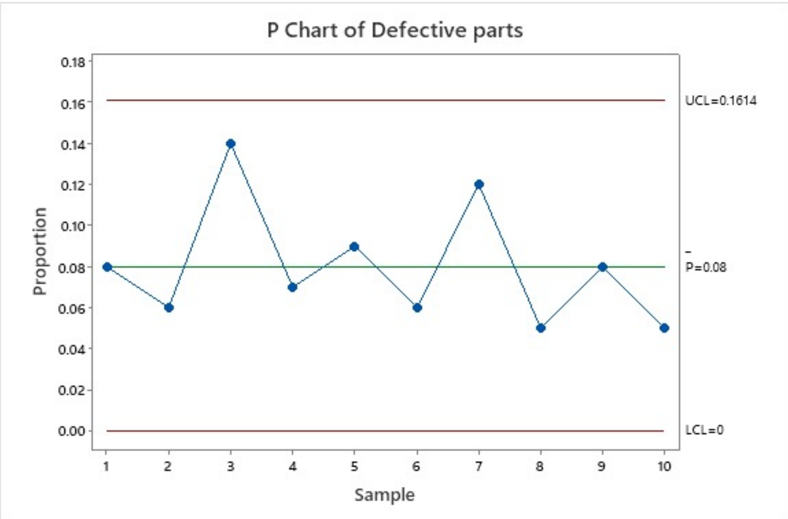
Control Chart-P (Measure)

The use of p control charts allowed for the identification of abnormal variability in two production batches, indicating the presence of special causes affecting process stability. This result is consistent with findings reported by other researchers, who highlight the effectiveness of attribute control charts in detecting process instability within Six Sigma projects [1–8]. The identification of out-of-control points provided valuable information for directing root cause analysis efforts. As shown in figure 2, which corresponds to a p control chart, we can see the proportion of defective units per production batch. Each point corresponds to the percentage of defects found in a batch of 100 randomly inspected units. The center line (CL) shows the process mean, while the upper (UL) and lower (UL) lines represent the statistically calculated control limits.

Based on the p chart, two batches out of 10 (20%) are out of control; batches 3 and 7 are above the LCL, 0.14 and 0.12 respectively, indicating abnormal variability at those points in the process. The goal is to verify whether this system's behavior is due to a special cause. A preliminary analysis suggests that the causes could be machine failures or human error, which should be investigated to prevent recurrences. Researchers have reported that using attribute control charts in Six Sigma projects is effective for measuring and, if that approach fails, taking process control measures (Evans, 2011; Hayajneh, 2013; Rifqi, 2021; Ahmed, 2019; Smith, 2011).

Figure 2

Initial Control Chart-P of defects



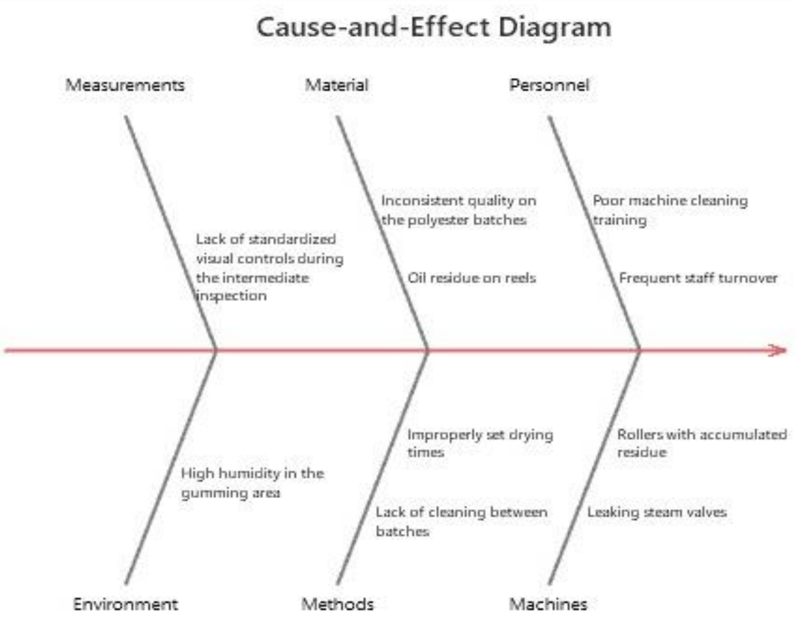
Ishikawa diagram (Analyze)

Root cause analysis using the Ishikawa diagram revealed that the main sources of defects were related to materials, methods, machinery, and personnel. In particular, inconsistent raw material quality, inadequate cleaning procedures, insufficient training, and poor environmental conditions were identified as critical contributors to staining defects. These results align with previous studies in textile manufacturing, which emphasize the influence of material handling, equipment cleanliness, and operator training on product quality (Nedra, 2019; Kumar, 2007). Figure 3 shows the Ishikawa diagram, developed to analyze the root causes of the most common defect: staining. Possible causes were identified, grouped into six classic categories: materials, methods, labor, machinery, environment, and measurement.

In the materials category, inconsistent quality in polyester batches and oil residue on the reels were considered; in the methods category, lack of cleaning between batches and improper adjustment of drying times; in the labor category, lack of training in the handling of the gumming system; in the machinery category, rollers with accumulated residue were detected; in the methods category, poor cleaning between batches; in the environment category, excess moisture in the gumming area; and in the measurement category, the lack of standardized controls during inspection (Kurma, 2021).

Figure 3

Fishbone Diagram



Action Plan (Improve)

For the action plan, management, along with those responsible for the project and production, developed a series of recommendations based on containment, correction, and prevention actions. Table 4 mentions these actions.

Table 4

Improvement actions for the problems detected

#	Problem	Action
1	Measure: Lack of standardized visual controls	Management, in conjunction with the production department, will develop a series of visual aids and controls to assist workers in their daily tasks. They will constantly monitor the system's status to make improvements if necessary.
2	Material: Inconsistent quality on polyester batches	The team developed a procedure that details the quality characteristics that the material must meet.

3	Material: Oil residue on reels	To eliminate dirt caused by oils and/or residues, an awareness campaign on industrial hygiene was carried out.
4	Personnel: Poor machine cleaning training	The maintenance department, in conjunction with quality, developed training in autonomous maintenance.
5	Personnel: Frequent staff turnover	The future plan proposes that the HR department conduct an analysis of the reasons for high staff turnover.
6	Environment: High humidity in the gumming area	Researchers will conduct a subsequent study to establish corrective actions.
7	Methods: Improperly set drying times	The methods department conducted a study to determine the ideal drying time.
8	Methods: Lack of cleaning between batches	Maintenance and Production established a cleaning procedure as part of autonomous maintenance.
9	Machines: Rollers with accumulated residue	As with cause number 8, both problems were corrected by the cleaning procedure.
10	Machines: Leaking steam valves	A preventive maintenance plan was developed to address this situation.

Control Chart-P (Control)

Once the improvement actions were implemented, a P control chart was created again to monitor the system status, as shown in Figure 4. The process variation was decreased because of the implementation of the improvement actions. P charts have been successfully used to measure process variation and to have a detailed control of the control of changes in a process (Jimenez, 2023; Patel, 2023),

Figure 4 Improve Control Chart-P of defects

Sigma Level (Control)

As a result of the implementation of improvement actions, the process sigma level index was increased from 3.3, 3.5, 3.6, 3.8, 3.7, and 4.3 to 3.5, 3.7, 3.9, 4.0, 4.2, and 4.5, respectively. Increases in quality and productivity in various areas have been led to by the implementation of DMAIC, resulting in the sigma level of the processes being increased.

Table 5

Sigma Level of the Process

Defect type	Sigma level before	Sigma level after
Stains	3.3	3.5
Creases	3.5	3.7
Tears	3.6	3.9

Lack of adhesiveness	3.8	4.0
Textile pollution	3.7	4.2

After implementing the proposed corrective and preventive actions, improvements were observed in the sigma levels of all defect categories. The sigma level increased by up to 0.6 in some cases, demonstrating the positive impact of the DMAIC methodology on process performance. However, the target sigma level of 4.5 was achieved only for one defect type (frays), indicating that while significant progress was made, further improvement cycles are required. Similar limitations have been reported in other DMAIC-based case studies, where incremental improvements are achieved through successive PDCA cycles rather than a single intervention (Krauß , 2023; Patel, 2023). Overall, the results confirm that integrating DMAIC with continuous monitoring tools such as PDCA and control charts provides a robust framework for quality improvement in textile manufacturing processes, particularly in intermediate products such as interlinings.

Although the DMAIC methodology proved effective in reducing defect rates and increasing sigma levels, the results indicate that achieving the target sigma level for all defect categories within a single improvement cycle is challenging in interlining manufacturing processes. Defects associated with raw material variability and environmental conditions showed slower improvement rates, suggesting the need for sustained corrective actions and stronger process controls. These findings emphasize that DMAIC should be complemented with continuous improvement mechanisms such as PDCA cycles, preventive maintenance programs, and operator training to ensure long-term process stability. Therefore, quality improvement in intermediate textile processes should be approached as an iterative and systematic effort rather than a one-time intervention.

CONCLUSIONS

This study applied the DMAIC Six Sigma methodology to improve quality in an interlining manufacturing process, enabling the systematic identification, analysis, and reduction of the most frequent defects affecting the final product. Through the use of statistical and quality tools, critical defects were prioritized, and their root causes were identified, allowing for the development of targeted corrective and preventive actions.

The implementation of the improvement actions led to a measurable increase in the process sigma level for all defect categories. Although the target sigma level of 4.5 was achieved only for one defect type, the overall improvement demonstrates the effectiveness of the DMAIC methodology as a structured approach for quality improvement in textile manufacturing processes.

It is important to emphasize that continuous monitoring of the implemented actions is required to ensure their long-term effectiveness. The integration of DMAIC with the PDCA cycle provides a continuous improvement framework that allows organizations to evaluate performance, detect deviations, and implement additional corrective actions as needed.

Future research should focus on conducting successive PDCA cycles to further increase the sigma level of the remaining defects, as well as on integrating advanced tools such as digital monitoring systems or Industry 4.0 technologies to enhance process control and predictive capabilities in interlining manufacturing.

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