Defect Reduction in Automotive Seat Manufacturing: A Lean Six Sigma Approach

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Received: April 3, 2025 / Revised: May 19, 2025 / Accepted: May 19, 2025

Abstract— **This study investigates the issue of rear cushion wrinkling in a pickup truck seat production line using the Lean Six Sigma (LSS) methodology. By applying the DMAIC framework, we identified that excessive tension in the extruded listing fleece caused deformation, particularly in curved seat sections. To resolve this problem, we redesigned the fleece by incorporating rectangular slots (15 × 5 mm) spaced 80 mm apart. As a result, wrinkling defects were reduced by 60%, from 312 to 187 pieces, lowering the overall defect rate from 4.05% to 1.61% over six months. This exceeded our initial goal of reducing defects to less than 2.0%. Additionally, this improvement led to estimated cost savings of 852,500 THB, primarily due to a reduction in rework and material waste. Beyond cost benefits, the new design helped streamline the production process, cutting cycle time by 20% and improving customer satisfaction by a similar percentage. While these results demonstrate the effectiveness of Lean Six Sigma in quality improvement, certain limitations remain. Factors such as operator variability and material inconsistencies were not fully controlled in this study. Future research could explore real-time defect detection systems or adaptive tension control mechanisms to enhance process stability.**

***Index Terms*— Lean Six Sigma, DMAIC, Wrinkle Defects, Defect Reduction, Automotive Manufacturing**

I. Introduction

In the automotive manufacturing industry, balancing high product quality with efficient production processes is a constant challenge. To address inefficiencies and maintain competitiveness, we applied Lean Six Sigma (LSS), a methodology that combines Lean manufacturing's principles of waste reduction with Six Sigma's emphasis on reducing process variability. Using the DMAIC (Define, Measure, Analyze, Improve, and Control)

Framework, we systematically identified key process inefficiencies in our production line, particularly those affecting defect rates and cycle time. For instance, variations in material handling and assembly techniques contributed to inconsistent quality levels. By integrating data-driven analysis with Lean methodologies, we were able to pinpoint root causes and implement targeted improvements that enhanced overall production efficiency [1].

Previous studies have highlighted the effectiveness of LSS in automotive production, with studies reporting defect reductions of up to 50% and cost savings exceeding 40% in similar projects [2]. In this study, we applied the LSS DMAIC framework to address a critical quality issue—rear cushion wrinkling—in a specific production line at a sample company in the automotive industry, focusing on a seat model for a pickup truck. The wrinkling issue, primarily caused by excessive tension in the listing fleece at the seat's curved sections, not only compromised aesthetic quality but also increased rework costs and impacted customer satisfaction.

Our objective was to systematically investigate this issue, identify its root cause, and implement effective corrective actions. Several approaches were explored, including modifying the fleece design, refining sewing techniques, and utilizing Statistical Process Control (SPC) tools to monitor and maintain quality standards. We then tested these solutions to determine whether the defect rate could be reduced below 2.0% and whether defect-related costs could be decreased by at least 40%. It is important to note that this study focuses solely on a single production line and specifically on the wrinkling defect in pickup truck seats, without extending to other production lines or defect types.

II. Objective

The objective of this study is to reduce wrinkling defects in the MMTH 4P00 seat production line using Lean Six Sigma methodology.

III. Literature Review

A. Six Sigma Theory and Principles

The implementation of Lean Six Sigma in automotive manufacturing has been extensively studied to improve process efficiency, defect reduction, and quality control. George [3], Lean Six Sigma integrates Lean principles with Six Sigma's statistical tools to enhance production capabilities and eliminate non-value-added activities [2]. Further emphasized the impact of LSS in reducing operational costs and increasing process reliability in automotive component manufacturing [2].

B. DMAIC Methodology

The DMAIC (Define, Measure, Analyze, Improve, and Control) framework is widely used in automotive seat manufacturing to enhance production efficiency and minimize defects. It helps manufacturers systematically analyze issues such as fabric misalignment, stitching errors, and assembly inconsistencies. In practice, the Measure phase involves collecting defect data from seat cushion inspections, allowing engineers to identify common quality concerns. During the Analyze phase, they investigate root causes, such as uneven fabric tension contributing to wrinkles. Research has shown that integrating DMAIC into seat production can lead to measurable improvements, including reduced defect rates, greater process stability, and lower manufacturing costs [4].

C. Related Research Studies

Several studies have investigated improvements in car seat manufacturing quality across different contexts [4], [5]. For example, Tsou and Chen [4] proposed an integrated model combining the Economic Production Quantity (EPQ) framework with Six Sigma's DMAIC methodology. This model aimed to reduce production costs and defect rates in automobile seat assembly lines. In addition, Purba and Sunadi [5] carried out fine feature Quality Function Deployment (QFD) within the automobile seat industry, aligning production approaches with customer necessities to improve seat pleasant and personal pride.

Wrinkle reduction in cloth and leather packages Preceding research on wrinkle reduction in car seats has explored numerous techniques, specifically for leather substances, that are at risk of tension-associated wrinkling in the course of assembly. As an instance, adjusting material tension and applying warmth remedies were recognized as powerful strategies to minimize wrinkles while keeping the sturdiness and appearance of leather-based seats. These techniques informed our approach, guiding us to focus on structural modifications to deal with the wrinkling difficulty. Cloth amendment strategies in the Seat production

In the Thai manufacturing sector, research has focused on enhancing manufacturing performance within the automobile industry. Research like [6] displays how Statistical Procedure Control (SPC) tools, together with manage charts and technique mapping, can effectively reduce defects and hold fine consistency. Moreover, Thai researchers have explored how lean manufacturing concepts, paired with Value Engineering, can help streamline car seat manufacturing with the aid of boosting efficiency and reducing fabric waste [7].

IV. Research Methodology

A. Define Phase

The rear cushion wrinkling issue in the MMTH 4P00 production line, identified as a critical quality defect impacting both efficiency and customer satisfaction, prompted a Lean Six Sigma initiative following data analysis from April to June 2023. Out of 25,408 units produced, 1,028 exhibited wrinkles (4.05% defect rate), with Pareto analysis attributing 30.3% of total defects to this issue, primarily caused by excessive tension in the extruded fleece material, particularly in the seat's curved sections. To address the problem peaking in May 2023, the project aims to reduce defects by at least 50% (lowering the rate to below 2.0%) within six months through structural design modifications, standardized sewing/assembly processes, and tension protocol adjustments. Leveraging the DMAIC framework, the initiative also targets a 40% cost reduction by minimizing material waste and rework expenses, while enhancing product durability and customer satisfaction through improved aesthetics and consistency.

B. Measure Phase

The Measure phase established a defect baseline for the MMTH 4P00 production line, focusing on rear cushion wrinkling and other quality issues. Over three months (April-June 2023), data were systematically collected through visual inspections by trained QC teams using standardized checklists to identify defects such as wrinkles, scratches, and assembly errors. Defective units were tagged, recorded in the digital quality management system, and verified against production logs for accuracy. Based on manufacturing data, 1,028 defects were detected among 25,408 parts, yielding a defect rate of 4.05%. This baseline analysis provided a reference point for identifying critical problem areas and monitoring improvements throughout the production process.

Table I summarizes production and defect data from April to June 2023. In April, 7,745 units were produced with 319 defective units (4.12% defect rate). May saw increased output (9,601 units) but recorded the highest defects at 380 units (3.96% rate). June produced 8,062 units with 329 defects (4.08% rate). Fig. 1, a vertical bar chart, visualizes monthly defect counts (April: 319, May: 380, June: 329) and the cumulative 1,028 defective units. The chart underscores May's peak defect count, indicating potential fluctuations in production conditions or material quality during that period—a trend to be investigated in the Analyze phase [8].

To further analyze the defect profile, the 1,028 defective units were categorized into 22 distinct types during inspections. Fig. 2 presents a horizontal bar chart illustrating the ten most common defects observed in production. "Wrinkled Seat" dominated with 312 cases (30.3% of total defects), followed by "Scratches/Scrapes" (143 units, 13.9%), "Foam Debris Inside" (74 units, 7.2%), "Unusual Testing Noise" (72 units, 7.0%), and "Headrest with Vaseline Stains" (67 units, 6.5%). Additional defects ranked in the top ten were "Incorrect Foam Coverage" (51 units), "Incomplete Label" (47 units), "Loose Wiring" (41 units), "Stain Marks" (38 units), and "Visible Needle Holes" (34 units). Together, these defects accounted for 65% of all reported issues, highlighting 'Wrinkled Seat' as the primary concern requiring corrective action. This analysis provided key benchmarks for identifying root causes and monitoring improvement efforts in subsequent project phases.

TABLE I
PRODUCTION AND DEFECT DATA FOR MMTH 4P00 PRODUCTION LINE (APRIL-JUNE 2023)

Month	Total Production	Defective Units	Defect Rate (%)
April	7,745	319	4.12
May	9,601	380	3.96
June	8,062	329	4.08
Total	25,408	1,028	12.00

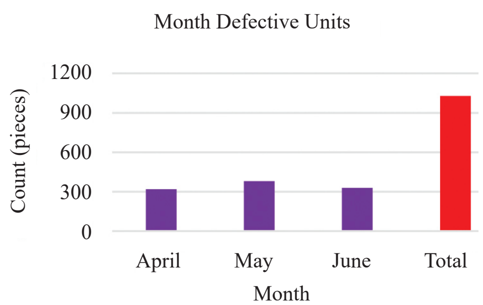

Fig. 1. Vertical bar chart depicting monthly defect counts in the MMTH 4P00 production line (April-June 2023, Total: 1,028 pieces), with May showing the highest defect count at 380 units.

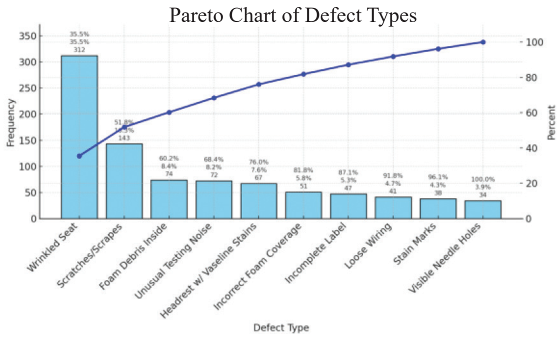

Fig. 2. Pareto Chart of the Top 10 Defect Types in the MMTH 4P00 Production Line (April-June 2023).

C. Analyze Phase

Environmental factors, particularly humidity and fabric tension, have been shown to critically influence material behavior during automotive seat production [9].

To better understand the root causes of rear cushion wrinkling in the MMTH 4P00 production line, we applied Lean Six Sigma tools, including the Fishbone Diagram (Cause-and-Effect Diagram) and the 5 Whys method. Data from the Measure phase indicated that "Wrinkled Seat" was the most frequent defect, with 312 recorded cases, accounting for 30.3% of total issues. The Fishbone Diagram (Fig. 3) categorized potential causes into six key areas: Material, Process, Equipment, Environment, People, and Measurement, and a team of production operators, quality control personnel, and process engineers collaboratively examined factors such as material tension inconsistencies, deviations in sewing procedures, and ergonomic difficulties during assembly. By identifying these factors, the team was able to prioritize corrective actions that directly targeted the primary defect. The findings helped develop standardized sewing protocols and improved material handling procedures, ensuring that improvements aligned with Lean Six Sigma principles for defect reduction and process optimization.

The root causes of rear cushion wrinkling were systematically categorized into six key areas:

1) Material: The extruded fleece's excessive stiffness from plastic reinforcement reduced flexibility around curved seat sections, creating stress points.

2) Process: Inconsistent sewing techniques and improper fleece cutting introduced localized tension, worsening wrinkles in high-stress zones.

Equipment: Hog ring tension imbalances and needle misalignment in stitching machines produced uneven seams, amplifying fabric stress.

3) Environment: Humidity fluctuations compromised material elasticity, causing unpredictable contraction/expansion, while poor lighting hindered defect detection.

4) People: Operator handling variability (e.g., inconsistent stretching and pressure application) and

lack of specialized training led to assembly inconsistencies.

5) Measurement: Inadequate quality checks allowed defects to pass undetected, and tolerance deviations in fleece dimensions occasionally exceeded specifications.

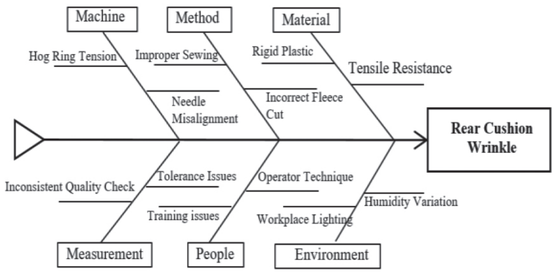

Fig. 3. Fishbone Diagram illustrating potential causes of rear cushion wrinkling in the MMTH 4P00 production line.

To further investigate the root causes of rear cushion wrinkling, the 5 Whys method [1] was applied to the key factors identified in the Fishbone Diagram: material stiffness, improper stitching techniques, and machine-related issues. This iterative approach involved repeatedly asking “Why?” to trace surface-level problems to their underlying causes. The cross-functional team collaborated to validate responses using production data, operator feedback, and machine logs. For instance, questioning why material stiffness occurred revealed inadequate plastic reinforcement specifications, while repeated “Whys” on stitching errors exposed outdated training protocols. The results, summarized in Table II, mapped the causal chain for each factor, providing actionable insights to address systemic gaps in material design, process standardization, and equipment calibration.

TABLE II
WHY-WHY ANALYSIS FOR PRIMARY CAUSES OF REAR CUSHION WRINKLING

Factor	Why 1	Why 2	Why 3	Why 4	Why 5	Root Cause
Material Stiffness	Q: Why does the fleece cause wrinkling? A: The plastic reinforcement makes it too stiff to flex around curved sections.	Q: Why is the fleece too stiff? A: The Plastic reinforcement was selected for durability, not flexibility.	Q: Why was this material chosen? A: It met the cost and longevity requirements during supplier selection.	Q: Why wasn’t flexibility prioritized? A: The material specification the process did not account for curvature demands of the MMTH 4P00 design.	Q: Why wasn’t curvature considered? A: There was a lack of collaboration between design and procurement teams.	Insufficient cross-functional collaboration during material specification led to the selection of an overly stiff fleece material.
Improper Sewing Techniques	Q: Why do improper sewing techniques cause wrinkling? A: Inconsistent stitching creates stress points on the fleece.	Q: Why is stitching inconsistent? A: Operators use varying techniques for curved sections.	Q: Why do operators use varying techniques? A: There is no standardized sewing procedure for curved areas.	Q: Why isn’t there a standardized procedure? A: Process documentation does not address curved stitching challenges.	Q: Why wasn’t this addressed in documentation? A: The process was developed without input from experienced operators.	Lack of operator input in process documentation resulted in the absence of a standardized sewing procedure for curved sections.
Machine Issues	Q: Why do hog ring tension and needle misalignment cause wrinkling? A: They Produce uneven stitching, increasing material tension.	Q: Why are hog rings and needles misaligned? A: The machines have not been calibrated regularly.	Q: Why haven’t machines been calibrated? A: There is no scheduled maintenance plan forstitching equipment.	Q: Why is there no maintenance plan? A: Maintenance responsibilities were not clearly assigned during production setup.	Q: Why weren’t responsibilities assigned? A: Management overlooked the need for a formal maintenance protocol.	The absence of a formal maintenance protocol resulted in uncalibrated machines, which in turn caused inconsistent stitching.

The 5 Whys analysis (Table II) identified three root causes driving rear cushion wrinkling:

1) Material Stiffness: Overly rigid fleece material, selected due to poor collaboration between the design and procurement teams.

2) Process Gaps: Inconsistent sewing techniques caused by incomplete process documentation and training.

3) Equipment Neglect: Uncalibrated stitching machines resulting from the lack of a preventive maintenance protocol.

These findings validated the initial hypothesis of excessive tension in the extruded fleece while exposing systemic flaws in cross-departmental coordination, process standardization, and equipment management. The tabular presentation of the 5 Whys (Table II) clarified causal chains—from surface defects to organizational weaknesses, enabling stakeholders to prioritize targeted interventions. For the Improve phase, solutions will focus on material redesign (e.g., flexible fleece alternatives), standardized sewing workflows, and calibrated maintenance schedules to address root causes holistically.

D. Improve Phase

Modifying the listing fleece to improve flexibility aligns with recent research on optimizing seat structure for both comfort and manufacturability [10]. Building on the root causes identified in the Analyze phase—specifically, material stiffness, improper sewing techniques, and machine-related issues—the Improve phase focused on developing and testing solutions to mitigate rear cushion wrinkling in a pickup truck seat production line. The primary intervention targeted the extruded fleece strip, which was found to exhibit excessive tension due to its plastic reinforcement, particularly in curved sections. The team proposed modifying the fleece strip design (length: 370 mm) by cutting rectangular slots to reduce plastic resistance. This adjustment was designed to achieve the project objectives, cutting wrinkle defects by 50% and bringing the defect rate below 2.0%. The redesign prioritized enhancing material flexibility while maintaining structural integrity, ensuring compatibility with standardized sewing processes and calibrated equipment.

1) Cutting the Listing Strip into Rectangular Slots

The intervention began by modifying the listing strip design, incorporating rectangular slots (15×5 mm) to reduce plastic resistance. Two configurations were tested: slots spaced at 60 mm intervals and those at 80 mm intervals. A total of 30 samples—15 for each configuration—were prepared to evaluate their effectiveness in minimizing wrinkling in curved seat sections. Fig. 4 provides a visual comparison of the original and modified listing strips, emphasizing the design adjustments aimed at enhancing material flexibility while maintaining structural integrity. The 60 mm and 80 mm slot spacings were selected based on preliminary design trials and sewing ergonomics. While 60 mm aimed to enhance stress relief, 80 mm offered a better balance between flexibility and material strength. Both values were evaluated under real-world conditions without modifying existing production tooling.

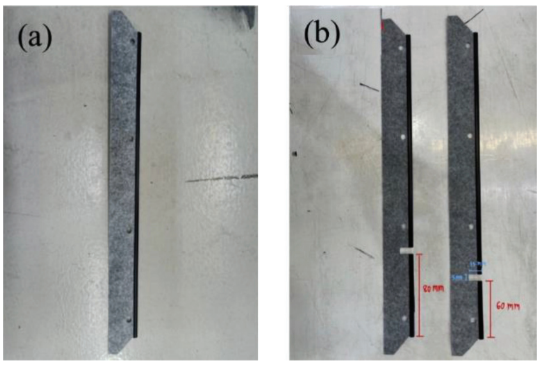

Fig. 4. Comparison of the original listing strip (a) and the modified strips with rectangular slots at 60 mm and 80 mm intervals (b).

2) Sewing Integration

The modified listing strips were integrated into the stitching system, with the 60 mm slots aligned at mark 2 and the 80 mm slots positioned between mark 2 and mark 3—areas susceptible to wrinkling due to material tension. Stitching operators reported that the slotted strips were easier to handle around curves, reducing stitching time. Fig. 5 illustrates this process.

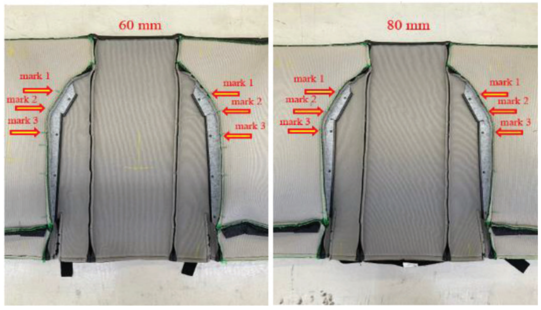

Fig. 5. Sewing integration of the modified listing strips with rectangular slots at 60 mm and 80 mm intervals.

Preliminary observations of the trim's display side showed wrinkling in all configurations (original (a), 60 mm (b), and 80 mm (c)); however, definitive results were deferred until the foam covering stage. Fig. 6 presents these initial observations.

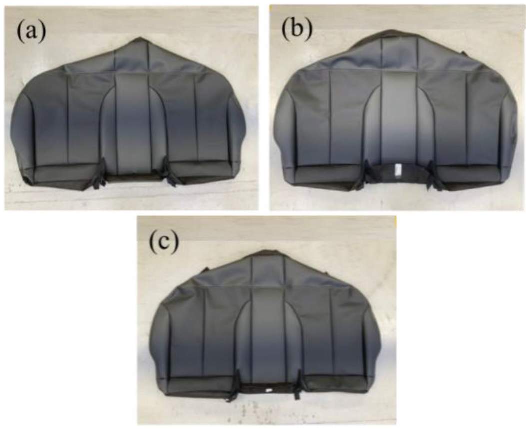

Fig. 6. External appearance of the trim's show side for the original and modified listing strips at 60 mm and 80 mm intervals.

3) Foam Covering

The stitched trims were then attached to the foam cushion to assess the effectiveness of the intervention. Fig. 7 depicts the foam covering process.


Fig. 7. Foam covering process for trims with modified listing strips.

The cushions were evaluated in comparison to the customer's master sample to ensure compliance with quality standards. The original strip exhibited excessive wrinkling, leading to a non-conformance (NG status) due to failure in meeting aesthetic and structural requirements. The 60 mm configuration demonstrated a reduction in wrinkling; however, the defect level remained beyond acceptable limits, resulting in an NG status. Conversely, the 80 mm configuration effectively mitigated wrinkling, achieving compliance with quality standards and receiving an OK status. Fig. 8 presents a comparative analysis of the results.

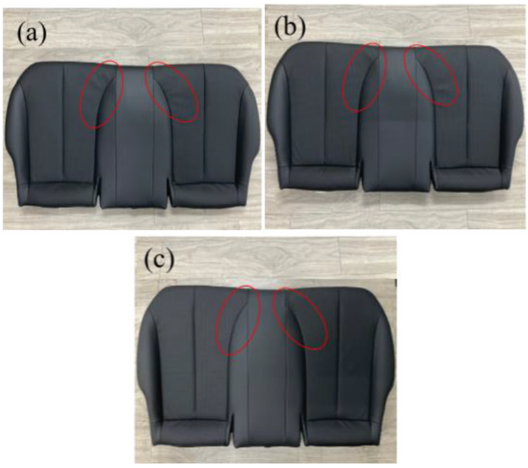

Fig. 8. Comparison of rear cushions after foam covering, using the original listing strip (a) and modified strips at 60 mm (b) and 80 mm (c) intervals.

4) Validation of the 80 mm Configuration

A follow-up trial with 30 additional samples using the 80 mm configuration confirmed its effectiveness, with nearly all samples meeting quality acceptance criteria, aligning with customer specifications, and successfully addressing the wrinkling issue in curved sections. Table III summarizes the initial trial results, showing that all 15 samples with the 60 mm slot spacing failed (100% NG), whereas the 80 mm slot spacing performed significantly better, with 13 out of 15 samples passing (86.67% OK) and only 2 failing (13.33% NG).

TABLE III
INSPECTION RESULTS FOR WRINKLING ACROSS 60 MM AND 80 MM CONFIGURATIONS

Slot Spacing Configuration	OK (Pieces)	NG (Pieces)	Total (Pieces)	OK Percentage	NG Percentage
60 mm	0	15	15	0%	100%
80 mm	13	2	15	86.67%	13.33%

Note: OK, the sample meets the customer's master sample standards with no visible wrinkling; NG: The sample fails to meet standards due to visible wrinkling.

A total of 30 samples were tested, with 15 samples for each slot spacing configuration (60 mm and 80 mm).

Although the difference in performance between the 60 mm and 80 mm configurations was visibly substantial, a two-proportion Z-test was performed to statistically confirm the significance of this improvement. The result ($Z = -4.79$, $p < 0.001$) validated that the 80 mm slot spacing significantly improved the proportion of acceptable parts, supporting the selection of this design for implementation.

E. Control Phase

After successfully implementing the 80 mm slotted listing strip in the Improve phase, the Control phase was implemented to sustain improvements and to prevent rear cushion wrinkling from recurring. Several control measures were implemented to maintain reduced defect rates and cost savings.

1) Standardization of Processes

The 80 mm slotted listing strip design was standardized for the pickup truck seat production line. Process documentation was updated to detail the cutting and sewing procedures for the modified strip, including precise slot measurements (15 × 5 mm) and alignment points (between mark 2 and mark 3). Sewing operators were trained in the updated procedure to ensure consistency, mitigating the improper sewing techniques identified in the Analyze phase. An SOP manual was distributed to all relevant personnel, and regular audits were scheduled to ensure adherence to the new standard.

2) Equipment Maintenance Protocol

To mitigate machine-related issues, a structured maintenance protocol was implemented for stitching machines. A scheduled monthly calibration plan was introduced, with designated maintenance responsibilities assigned to a specialized technician team. Calibration checklists were introduced to monitor maintenance schedules and ensure hog rings and needles met specified tolerances, preventing uneven stitching, which could lead to wrinkling defects.

3) Monitoring and Control Chart

A control chart was introduced to systematically monitor defect rates after the intervention. Daily defect counts for wrinkling were recorded and plotted against established control limits, with a target defect rate below 2.0%. This enabled the team to promptly identify deviations and implement corrective measures, such as re-inspecting listing strips or recalibrating machinery.

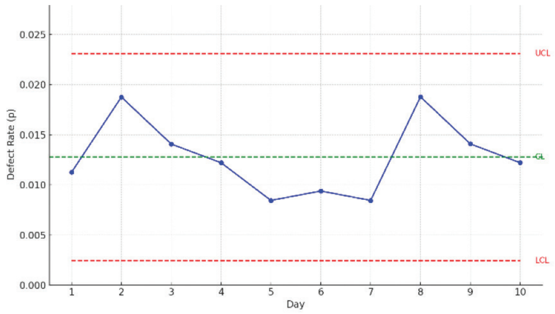

Fig.9. p-Chart for Wrinkling Defect Rate (October 2023, Sample of 10 Days)

This control chart illustrates the daily proportion of wrinkling defects after implementing the 80 mm slot design. The defect rates remained within the control limits (UCL and LCL), indicating that the process was statistically stable during the post-improvement period. Quality control personnel underwent training to effectively utilize the control chart, ensuring continuous monitoring and process stability.

V. Results and Discussion

A. Results

Successful Lean Six Sigma projects require robust change management and training strategies, especially when introducing new work processes [11].

The Lean Six Sigma project targeting rear cushion wrinkling in the MMTH 4P00 production line at a sample company in the automotive manufacturing industry led to notable enhancements in both quality and financial performance, as evaluated using the DMAIC framework. The following sections outline the project's outcomes concerning defect reduction and cost savings, validated through production data and quality inspection reports

Baseline defect rate was established at 4.05% during the Define and Measure phases, with 1,028 defective units identified out of 25,408 produced between April and June 2023, averaging 342.7 defective units per month. The primary cause was excessive tension in the extruded listing fleece, particularly in curved seat sections, leading to rear cushion wrinkling. Through root cause analysis and targeted process improvements—specifically, modifying the listing fleece design with rectangular slots (15 × 5 mm) at 80 mm intervals—the defect rate was lowered to 1.61% by October 2023. This marks a 60.27% reduction in the defect rate (from 4.05% to 1.61%), exceeding the project objective of achieving a rate below 2.0%. Specifically for wrinkling defects, the count decreased by 40%, from 312 pieces to 187 pieces over the intervention period.

Table IV compares the monthly defect counts before (April-June 2023) and after (July-October 2023) the intervention. Before the intervention, the average monthly defect count stood at 342.7 pieces. After the intervention, this number dropped to 171.5 pieces, reflecting a 50% reduction in overall defects. Statistical Process Control (SPC) tools, including control charts and Pareto analysis, confirmed process stability, with the sigma level improving from 3.2 (66,807 DPMO) to 4.1 (6,210 DPMO) according to standard conversion values [1], indicating enhanced process capability. Furthermore, cycle time was reduced by approximately 20%, enhancing overall production efficiency.

TABLE IV
Defect Counts in Production Line Before and After Improvement

Period	Month	Total Produced (Pieces)	Defect Count (Pieces)	Defect Rate (%)
Before Improvement	April	8,469	319	3.77%
	May	8,469	380	4.49%
	June	8,470	329	3.88%
	April-June	25,408	1,028	4.05%
After Improvement	July	10,652	204	1.92%
	August	10,652	189	1.77%
	September	10,652	157	1.47%
	October	10,653	136	1.28%
	July - October	42,609	686	1.61%

Reducing the number of defects in the manufacturing process directly results in cost reduction, with the unit cost of the rear seat production being 6,820 baht (During April to June 2023). There were 312 cushions with wrinkles found, representing a cost of 2,127,840 baht (312 × 6,820 baht). After improving (During July to October 2023), the number of cushions with wrinkling defects decreased to 187, reducing costs to 1,275,340 baht (187 × 6,820 baht). The cost savings of 852,500 baht, or 54.81%, exceeded the original target of 40%. This was primarily achieved through reduced rework and more efficient material usage. In addition, the reduced cycle time made the production process more agile and flexible. Additionally, customer satisfaction increased approximately 20% according to Voice of Customer (VOC) surveys, reflecting improved product quality. And consistency with Critical to Quality (CTQ) requirements.

B. Discussion

Successful Lean Six Sigma projects require robust change management and training strategies, especially when introducing new work processes [11]. This Lean Six Sigma project demonstrated the effectiveness of integrating Lean's waste-reduction principles with Six Sigma's data-driven methodology in addressing defects in automotive seat production. Root cause analysis was conducted using tools such as the Fishbone Diagram and Why-Why Analysis, which systematically identified key contributing factors. To mitigate this issue, the listing fleece design was modified by incorporating rectangular slots (15 × 5 mm), spaced at 80 mm intervals. This modification yielded a 60% reduction in wrinkling defects, decreasing from 312 to 187 pieces.

As of October 2023, the overall defect rate has decreased to 1.61%, exceeding the target of 2.0%. This result is consistent with past research, which has shown that Lean Six Sigma methods can reduce defect rates in automotive part manufacturing by 50-70% [2]. The results of this research study truly demonstrate the effectiveness of a Lean Six Sigma problem-solving approach.

However, some important issues should be further considered in future research, especially during the improvement process. The sewing workers had to adapt to the new process at first, which felt unfamiliar and uncomfortable. Therefore, to solve this problem, additional training, including practical training, was provided to make the workers more confident and able to follow the new steps correctly and efficiently. This data reflects the importance of effective change management in Lean Six Sigma projects [12].

Another challenge was the lack of real-time defect tracking, which resulted in delays in identifying issues. Additionally, limited data on cycle time and operator efficiency restricts in-depth analysis. These gaps highlighted the need for future improvements, such as implementing automated systems to monitor cycle time and operator performance in real time.

During the Control phase, the defect rate was maintained at 1.61% through regular audits and SPC, ensuring process stability. However, environmental factors such as humidity, identified through the Fishbone analysis, could pose future challenges, necessitating continuous monitoring and adjustments as needed.

VI. Conclusion

A. Summary

This Lean Six Sigma project addressed rear cushion wrinkling in a production line at a sample company in the automotive industry, demonstrating significant improvements using the DMAIC methodology. Wrinkling defects were reduced by 60%, from 312 to 187 pieces, lowering the overall defect rate from 4.05% to 1.61% within six months, surpassing the target of reducing it below 2.0%.

Identifying excessive tension in the listing fleece as the primary issue was crucial. Several modifications were implemented, including adding rectangular slots (15 × 5 mm, spaced 80 mm apart), standardizing sewing procedures, and incorporating SPC tools to ensure process stability.

The cost savings from wrinkling totaled 852,500 THB, which represented a 54.81% reduction, surpassing the original target of 40%. The process resulted in a 20% cycle time reduction while customer satisfaction increased by 20%, maintaining adherence to Critical to Quality (CTQ) like dimensional accuracy. The study by [2] presents clear evidence that Lean Six Sigma methods can lead to substantial improvements in quality, efficiency, and profitability within automotive seat production facilities.

B. Recommendations

To ensure the sustainability of these improvements, the following best practices should be adopted:

Continuous Training Programs: Conduct structured and ongoing training for operators on updated work standards and quality control procedures to ensure process consistency and minimize variability, mitigating initial operator resistance observed in the Improve phase.

• Real-Time Monitoring and Audits: Establish a structured system for regular quality audits and real-time defect tracking using SPC tools, such as control charts, to detect deviations early and maintain long-term stability, a proven practice in Lean Six Sigma implementations [1].

• Culture of Continuous Improvement: Embed a culture of continuous improvement within the organization to reduce resistance to change and support adherence to Lean Six Sigma principles, promoting long-term commitment from all stakeholders.

Future research could focus on predictive analytics to predict defect trends by leveraging historical control chart data to forecast wrinkling occurrences. Additionally, future studies could assess the scalability of these findings to other automotive components, such as front seat assemblies, to extend the applicability of Lean Six Sigma across various production processes.

C. Future Improvements

Future work could integrate AI-based real-time defect monitoring to further enhance quality control, consistent with current trends in industrial process monitoring [13]. The success of this project paves the way for expanding Lean Six Sigma methodologies to additional defect categories in the 4P00 production line, such as stitching inconsistencies, material delamination, and assembly misalignments. Utilizing the DMAIC framework, beginning with root cause analysis using tools such as the Fishbone Diagram, could achieve similar defect reductions and cost savings while enhancing overall product quality.

Furthermore, automation presents a significant opportunity for defect detection. IoT sensors combined with machine learning algorithms enable real-time tracking of fabric tension and sewing precision while monitoring environmental humidity, which was determined as a key factor in Fishbone analysis [14]. IoT sensors enable identification of excessive tension in listing fleece during production, which allows for real-time adjustments to prevent wrinkling.

Pilot studies could evaluate automated vision systems for real-time detection of wrinkles and other defects, with the potential to elevate the sigma level beyond 4.5 (e.g., reducing DPMO below 1,350), thereby establishing a new quality benchmark in automotive manufacturing.

ACKNOWLEDGMENT

We extend our sincere gratitude to the production team at a sample company in the automotive industry for their invaluable support, particularly for granting us access to their facility. Special appreciation is extended to the sewing team leader and the sewing team for their assistance in testing and for providing valuable feedback, as well as the QC team for ensuring the accuracy and completeness of our defect data.

We are also profoundly grateful to our university advisor for their invaluable guidance, which significantly contributed to the successful completion of this research.

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