Kennesaw State University

Six Sigma Green Belt Specialization

Capstone Project

Improving Windshield Fitment on Vehicle: Reducing Non-Conformance on the RH Side A-Pillar

A Six Sigma DMAIC Project to Optimize Process Capability and Reduce Rework Costs

Submitted by

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In Partial Fulfillment of the Requirements for the

Six Sigma Green Belt Certification

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Introduction

This capstone project, submitted in partial fulfillment of the Six Sigma Green Belt Certification offered through Coursera by Kennesaw State University, applies the DMAIC (Define, Measure, Analyze, Improve, Control) methodology to address excessive windshield-to-A-pillar gaps in a simulated automotive glazing cell. The project targets non-conforming gaps (>4mm, 30.2% defect rate, ~3.88mm mean, 290/960 measurements) on the right-hand (RH) side A-pillar (G5–G8, 74.8% of defects), which cause $24,000 in monthly rework costs and 20 customer complaints per month. By optimizing the suction cup-based windshield installation process, the project aims to achieve a mean gap of 3mm (±1mm tolerance), a defect rate of ≤2% (20,000 PPM), and a process capability (Cp) of ≥1.33, saving $24,000 monthly in rework costs and reducing customer complaints by 90% (from 20 to 2/month), enhancing production efficiency and customer satisfaction.

The project encompasses key Six Sigma deliverables:

- **Define**: A project charter (Section 1) outlines the problem, goals, and scope.
- **Measure**: A data collection plan (Section 3) details systematic gap measurements for 60 vehicles (960 measurements, 16 points per windshield) using digital calipers.
- **Analyze**: Hypotheses (Section 5) and statistical analyses (Section 6) using Excel and Minitab (e.g., ANOVA, chi-square, Pareto charts, p-charts) identify root causes: suction cup misalignment at G5–G8, Operator C variability (32.1% of defects), and post-afternoon shift issues (31.7% of defects).
- **Improve:** Targeted solutions (Section 7) include suction cup recalibration, Operator C training, and post-afternoon shift SOPs.
- **Control**: A control plan (Section 8) ensures sustainability via daily SPC p-charts, calibration checks, and audits.
- **Reflection**: Lessons learned (Section 9) highlight data simulation and team collaboration.

As the problem is hypothetical, data were generated using VBA in Excel (`GenerateWindshieldData.vb`, Appendix B), with higher means (4.8mm, SD 0.6mm) for G5–G8 to simulate RH side defects. All data, code, and figures are hosted in a public GitHub repository for transparency: `https://github.com/miguelaltuve/SixSigmaGreenBeltCapstone`. The project demonstrates data-driven decision-making, with stakeholder engagement (e.g., Vinush Radish, Johana Barr) ensuring alignment with production goals.

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1. Project Charter

Project Name	Improving Windshield Fitment on Vehicle: Reducing Non-Conformance on the RH Side A-Pillar
Today's Date	September 30, 2025
Project Start Date	October 3, 2025
Target Completion Date	November 14, 2025

Project Element	**Response**		
Problem Statement Includes time, measurable item, gap and business impact	Over six weeks (August 1–September 15, 2025), quality inspectors reported a 30.2% non-conformance rate for vehicles with windshield-to-A-pillar gaps on the right-hand (RH) side exceeding 4mm (average ≈ 3.88mm, specification = 3mm ± 1mm), resulting in $24,000 monthly rework costs, 20 customer complaints per month, and potential brand reputation damage.		
Business Case Why is this project important to do now? What is the project's financial impact? What is the impact on DPMO/ Sigma level? What is the impact on customer service	Immediate action is critical to address $24,000 monthly rework costs and 20 customer complaints per month, which undermine competitive positioning and brand reputation. Reducing technician labor (5 hours/day total, $300/day for two technicians at $30/hour) will enhance production efficiency. Achieving an 80% reduction in rework costs ($24,000 savings/month) and improving process capability from ~2.7 sigma (DPMO 300,000) to ~3.9 sigma (DPMO 20,000) aligns with the company's 98% first pass yield goal. Reducing complaints by 90% (from 20 to 2/month) will boost customer satisfaction and retention.		
Goal Statement Specific Measurable Achievable Realistic Time-bound	By November 21, 2025, reduce the average windshield-to-A-pillar gap on the RH side from ~3.88mm to 3mm (±1mm tolerance) using DMAIC methodology to optimize the windshield installation and alignment process, achieving a process capability (Cp) of ≥1.33 and a defect rate of ≤2% (20,000 PPM).		
List of Improvement Goals	**Measure (units)**	**Baseline**	**Goal**
1. Reduce RH side windshield gap	mm	3.88mm	3mm (±1mm)
2. Increase process capability	Cp	0.95	≥1.33
3. Reduce rework	Vehicles/day	~2	≤0.1
4. Reduce rework costs	Dollars/month	$24,000	≤$6,000
5. Reduce customer complaints	Complaints/month	20	≤2

Process Describe the process in which the problem exists	In the windshield installation station, Operator A picks the windshield and applies polyurethane adhesive. Operators B and C manually install it using suction cups, and Operator D adjusts alignment using suction cups, focusing on RH side points G5–G8. Misalignment during installation or adjustment, particularly by Operator C and during post-afternoon shifts, causes excessive gaps (>4mm) on the RH side A-pillar, contributing 74.8% of defects.	
Project Scope What part of the process will be addressed? What are the boundaries of the project or process? What areas are inside or outside the team's focus or authority? Attach a SIPOC diagram if necessary	**Scope:** Windshield installation and adjustment at the windshield installation station of the assembly line. **Boundaries:** From glass picking to post-installation inspection. **In-Scope**: Glass picking, polyurethane application, operator installation, alignment adjustment, and inspection, with emphasis on RH side A-pillar (G5–G8). **Out-of-Scope**: wiper arm installation, and glass replacement. **SIPOC Diagram**: See Appendix A	
Team	**Member Name**	
Project Sponsor	Mark Sanders (Manufacturing Director)	
Key Stakeholders	Johana Barr (Quality Manager), Jerome Guillemot (Production Supervisor), Karl Putman (Engineering Lead)	
Team Lead	Tim Buck (Six Sigma Green Belt)	
Team Members	Marco Strauss (Quality Technician), Francesca Higgins (Quality Technician), Juan Pérez (Operator), Leighton Kramer (Operator), Kylan Gentry (Operator), Marceline Avila (Operator). Ng Hong (Process Engineer)	
Process Owner	Vinush Radish (Windshield Station Supervisor)	
Timeline by Project Stage	**Milestone**	**Target Completion Date**
Define	Project Charter and kickoff	October 3, 2025
Measure	Define and collect data	October 10, 2025
Analysis	Identify Root Causes	October 17, 2025
Improve	Implement Solutions	November 7, 2025
Control	Standardize and Monitor	November 14, 2025
	Project Review and Closure	November 21, 2025

2. Team Charter

Project Title	Improving Windshield Fitment on Vehicle: Reducing Non-Conformance on the RH Side A-Pillar

Expectation	**Team Rule**
Attendance	Attendance is critical to maintain project momentum. In-person meetings will allow entry up to 5 minutes after start time; virtual meeting links will remain active for 10 minutes. Absences require 24-hour notice to the Team Lead (Tim Buck), except in emergencies.
Participation	Active participation is required in twice-weekly meetings. Members must complete assigned tasks (e.g., data collection, analysis) by deadlines, as tracked in meeting minutes, to ensure collaborative problem-solving across DMAIC phases.
Focus	The Project Charter will guide tasks and discussions, focusing on DMAIC milestones (e.g., Define by October 3, Measure by October 10). Agendas will be shared 72 hours in advance via email, allowing members to prepare relevant data or materials.
Interruptions	Phones must be on Do Not Disturb mode. Non-emergency interruptions are discouraged, except for critical production issues (e.g., assembly line stoppage), to maintain focus.
Preparation	One team member will be assigned as the meeting note-taker on a rotating basis. Meeting minutes, including action items and due dates, will be shared within 24 hours post-meeting via email.
Timeliness	Meetings will last 30–60 minutes, based on the agenda, and start promptly. Late arrivals and absentees will be noted in meeting minutes for accountability.
Decisions	Decisions will use multi-voting for routine issues (e.g., meeting schedules) and consensus for critical decisions (e.g., scope changes, solution prioritization). All members commit to supporting final decisions.
Data	Technicians (e.g., Marco Strauss, Juan Pérez) will collect windshield gap measurements (G1–G16, focusing on G5–G8) using calipers, recorded in Excel. Engineers (e.g., Ng Hong) will analyze data using Minitab (e.g., Pareto, control charts) to inform root cause analysis and solutions.
Conflict	Disagreements will be addressed through open communication using Six Sigma tools (e.g., 5 Whys) in meetings. If unresolved, the Project Sponsor (Mark Sanders) will facilitate resolution within 48 hours.
Confidentiality	Team members will not share project data (e.g., gap measurements, Minitab analyses, VBA code) outside the team without approval from the Project Sponsor.

Project Title	Improving Windshield Fitment on Vehicle: Reducing Non-Conformance on the RH Side A-Pillar

Expectation	**Team Rule**
Professionalism	Team members will wear business casual attire for stakeholder meetings to maintain a professional image.
Communication	All project communication will occur via email and a shared Excel project tracker, with weekly updates to action items. Urgent issues will be escalated via phone to the Team Lead (Tim Buck).

3. Data Collection Plan

Project Title	Improving Windshield Fitment on Vehicle: Reducing Non-Conformance on the RH Side A-Pillar

Element	**Description**
Objective	To measure the windshield-to-A-pillar gap on the RH side (points G5–G8) to identify variation and root causes of non-conformance (gap >4mm, target 3mm ± 1mm), reducing the 30.2% non-conformance rate to ≤2%.
Metric	Measure the windshield-to-A-pillar gap (mm) at 16 points (4 per side: G1–G4 left, G5–G8 RH, G9–G12 top, G13–G16 bottom), focusing on G5–G8 where defects are prevalent (74.8% of non-conformances). See Figure 1 for reference points.
Measurement Tool	Digital caliper (precision ±0.01mm), calibrated daily before the shift to ensure accuracy.
Data Points	• Gap measurement (mm) at 16 equidistant points per windshield (G1–G16). • Vehicle Identification Number (VIN). • Time of vehicle passing the station. • Names of operators (A, B, C, D) involved in installation and adjustment.
Sampling Plan	• Collect data on the first 3 vehicles at the start of the day shift and after each break (morning, lunch, afternoon; 4 events/day) from Monday–Friday, October 3–7, 2025. • Total sample: 60 vehicles (3 vehicles × 4 events × 5 days), yielding 960 gap measurements (60 × 16 points), sufficient to detect a 1mm gap difference with 95% confidence and 80% power.
Data Collection Process	• Quality technician calibrates the digital caliper (±0.01mm) before the shift. • At the installation station, the technician records VIN, time, operator names, and gap measurements (G1–G16) in an Excel spreadsheet. • A second technician verifies 10% of samples for accuracy. • If a measurement is missed, the technician records 'N/A' and escalates to Marco Strauss for review within 24 hours.
Frequency	Daily during the Measure phase (October 3–7, 2025), covering 5 production days to capture variation across shifts and operators.
Responsible Party	• Quality technician (primary data collector), supervised by Team Member Marco Strauss. • Data analysis led by Team Member Ng Hong (engineer), with oversight from Process Owner Vinush Radish.
Data Storage	• Data stored in a secure Excel spreadsheet in the "Windshield Fitment" folder on a restricted-access Google Drive. • Daily backups performed.

	• Access limited to team members (Tim Buck, Marco Strauss, Juan Pérez, Ng Hong, Vinush Radish) and stakeholders (Johana Barr, Jerome Guillemot, Karl Putman)

Analysis Plan	• Use Excel for data entry and Minitab for statistical analysis.
	• Calculate mean, standard deviation, and range of gap measurements (G1–G16).
	• Generate:
	  ○ X-bar and R charts to monitor process variation.
	  ○ Box plots to compare gap distributions by operator and shift.
	  ○ Pareto charts to prioritize defect locations (e.g., G5–G8).
	• Perform ANOVA to test operator and shift-based differences.
	• Conduct chi-square tests to analyze non-conformance rates by measurement point.

Figure 1 Windshield Gap Measurement Points

4. Process Map

Figure 2 shows the process map.

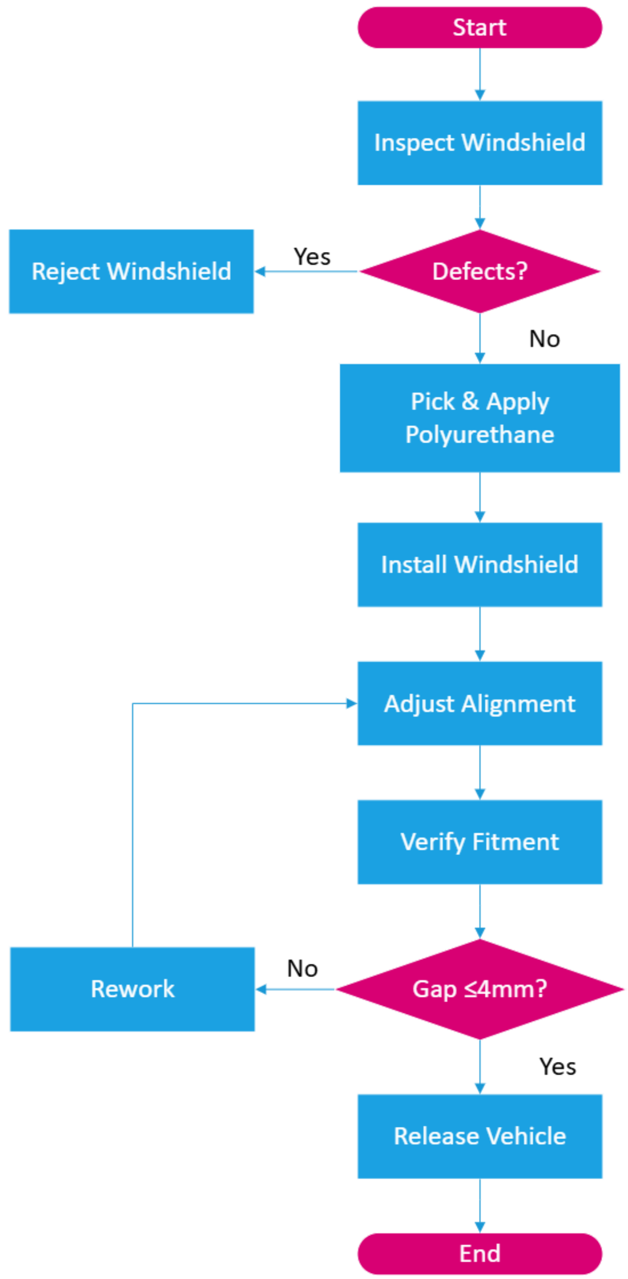

Figure 2 Process Map

5. Hypotheses

Objective: Identify root causes of excessive windshield-to-A-pillar gaps (>4mm, baseline 30.2% non-conformance, ~3.88mm mean) on the RH side (G5–G8, 74.8% of defects) by testing hypotheses related to operator variability (H1), shift-based variability (H2), and measurement point variability (H3), using data from 60 vehicles (960 measurements, `GenerateWindshieldData.vb`, Appendix B).

5.1 Hypothesis 1: Operator Variability:

- **Null Hypothesis (H0)**: The mean windshield gap does not differ significantly across Operators A, B, C, and D (ANOVA, α = 0.05).
- **Alternative Hypothesis (H1)**: The mean windshield gap differs significantly across Operators A, B, C, and D, with Operator C expected to produce higher gaps based on preliminary analysis..

5.2 Hypothesis 2: Shift-Based Variability:

- **Null Hypothesis (H0)**: The mean windshield gap does not differ significantly across shift times (start, post-morning break, post-lunch, post-afternoon break) (ANOVA, α = 0.05).
- **Alternative Hypothesis (H1)**: The mean windshield gap differs significantly across shift times, with post-afternoon break expected to produce higher gaps based on preliminary analysis.

5.3 Hypothesis 3: Measurement Point Variability:

- **Null Hypothesis (H0)**: The proportion of non-conforming gaps (>4mm) is not significantly higher at RH side measurement points G5–G8 compared to other points (G1–G4, G9–G16) (chi-square test, α = 0.05).
- **Alternative Hypothesis (H1)**: The proportion of non-conforming gaps is significantly higher at RH side measurement points G5–G8 (74.8% of defects).

6. Data Analysis

6.1 Data Generation

Data was simulated using VBA in Excel (`GenerateWindshieldData.vb`, Appendix B, available at ` [https://github.com/miguelaltuve/SixSigmaGreenBeltCapstone](https://github.com/miguelaltuve/SixSigmaGreenBeltCapstone)`) to mimic windshield fitment issues at the windshield installation station. The dataset (Table 1, ` WindshieldData.xlsm`) includes 60 vehicles with columns for VIN, Day, Shift, Operator, G1–G16 (gap measurements in mm), and # Non-Conformance (gaps >4mm). Points G5–G8 (RH side A-pillar) were assigned higher means (4.8mm, SD 0.6mm) vs. others (3.5mm, SD 0.3mm), producing a mean gap of 3.88mm (Table 2) and a defect rate of 30.2% (290/960), approximating the 30% target due to random variation and manual postprocessing. In Table 1, gaps in spec (≤4mm) are green, and out-of-spec (>4mm) are red.

Table 1 Dataset

VIN	Day	Shift	Operator	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	# Non-Conformance
VIN001	1	Start	A	2.00	3.34	2.91	3.07	4.31	4.45	4.67	3.82	3.10	3.75	3.21	3.17	3.19	3.33	3.64	3.37	3
VIN002	1	Start	D	3.00	3.49	3.45	3.49	4.64	5.34	3.81	5.01	3.57	3.76	3.74	3.71	3.70	2.92	2.61	3.30	3
VIN003	1	Start	B	3.90	3.71	3.40	3.81	4.27	4.77	5.60	4.34	3.36	3.22	4.02	3.61	3.31	3.44	2.94	3.81	5
VIN004	1	Post-morning	B	3.90	3.75	3.38	3.38	3.93	5.06	5.15	4.83	3.93	3.28	3.97	3.39	3.13	3.75	3.90	3.39	3
VIN005	1	Post-morning	A	3.24	2.00	3.92	3.54	5.00	5.78	5.53	4.35	3.39	3.36	3.65	2.80	3.52	3.32	3.30	3.32	4
VIN006	1	Post-morning	D	3.98	2.10	3.39	3.00	5.27	3.96	5.43	5.95	2.78	3.61	3.67	2.96	3.19	3.30	3.78	3.40	3
VIN007	1	Post-lunch	B	3.81	3.90	3.56	3.86	4.90	4.12	4.41	4.94	3.49	3.62	3.35	2.98	3.61	3.44	3.43	3.69	4
VIN008	1	Post-lunch	D	3.19	3.50	2.99	3.73	3.99	5.75	4.48	4.10	3.69	3.98	4.03	3.82	3.27	3.90	3.33	3.79	4
VIN009	1	Post-lunch	C	3.65	3.65	2.00	3.73	5.91	3.93	4.64	5.59	3.96	4.24	4.10	4.40	3.72	4.32	4.07	4.40	9
VIN010	1	Post-afternoon	C	3.80	4.73	2.00	4.72	3.95	4.66	5.11	6.17	3.01	3.51	3.38	3.78	3.39	3.61	2.77	4.41	6
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
VIN050	5	Start	C	3.69	2.99	3.00	3.45	4.74	5.49	4.24	4.47	3.34	3.60	3.28	3.22	3.00	3.32	3.65	2.68	4
VIN051	5	Start	A	3.69	3.15	3.60	3.74	5.37	4.84	5.05	4.92	3.90	3.25	3.36	3.40	3.50	3.23	3.28	3.20	4
VIN052	5	Post-morning	B	3.69	3.02	3.90	3.44	5.21	5.46	4.67	4.85	3.54	3.38	3.60	3.17	3.80	3.30	3.55	3.62	4
VIN053	5	Post-morning	D	3.69	3.46	3.75	3.67	5.28	3.61	4.13	5.35	3.44	3.54	3.50	2.90	2.00	2.82	3.13	3.56	3
VIN054	5	Post-morning	C	3.69	3.00	3.36	4.15	4.49	6.24	5.02	4.13	3.47	4.06	3.42	3.50	4.00	3.00	4.45	3.74	7
VIN055	5	Post-lunch	D	3.69	4.34	3.90	3.43	5.61	4.45	5.00	5.71	4.05	3.96	3.37	3.92	3.62	3.90	4.08	3.90	7
VIN056	5	Post-lunch	C	3.69	3.90	3.73	4.14	5.25	5.34	4.91	5.68	3.48	5.08	3.90	3.85	3.40	4.07	4.44	3.35	8
VIN057	5	Post-lunch	A	3.69	4.18	4.23	3.44	5.11	4.84	5.35	5.57	3.62	4.08	3.28	4.05	3.75	2.00	3.87	3.02	8
VIN058	5	Post-afternoon	A	3.69	3.72	3.65	3.26	4.97	6.18	4.93	5.41	4.02	3.57	3.54	3.55	3.70	4.05	3.00	2.60	6
VIN059	5	Post-afternoon	B	3.69	3.90	3.66	3.50	4.80	4.56	4.85	5.00	3.60	3.62	3.76	4.42	4.12	4.00	4.00	3.90	6
VIN060	5	Post-afternoon	C	3.69	3.64	3.73	3.58	4.51	4.79	5.03	4.84	3.58	3.62	3.37	3.15	3.73	3.32	4.00	3.90	4

6.2 Gap Measurements by Operator

6.2.1 Descriptive Statistics

Table 2 Summary Statistics of Gap Measurements Across Operators

Variable	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Operator A	240	3.78304	0.708185	2	3.33	3.62	4.05	6.18
Operator B	240	3.88096	0.722428	2	3.38	3.69	4.1275	7.63
Operator C	240	4.00838	0.786115	2	3.5125	3.81	4.4075	6.5
Operator D	240	3.83004	0.709498	2	3.4	3.705	4.045	6.31

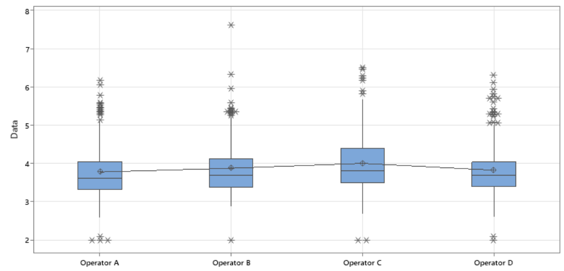

Figure 3 Box Plots of Gap Measurements Across Operators

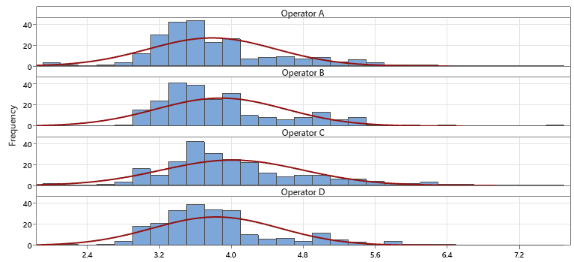

Figure 4 Histograms of Gap Measurements Across Operators

Operator C has the highest mean gap (4.008mm, SD 0.786mm), with wider spread and higher median, indicating inconsistent installation technique.

6.2.2 Control Charts

Figures 5–8 show X-bar/R Charts for Operators A, B, C, D. X-bar/R charts (subgroup size = 16 gaps/vehicle) show Operator C with out-of-control points (e.g., VIN009, VIN041) at G5–G8, suggesting variability in installation technique.

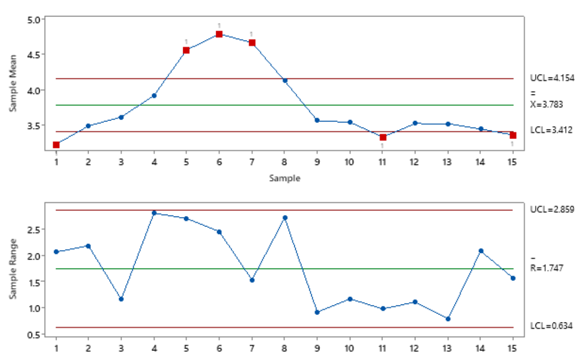

Figure 5 Xbar-R Chart of Operator A

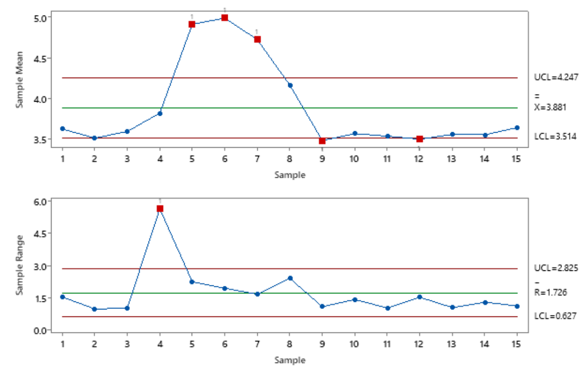

Figure 6 Xbar-R Chart of Operator B

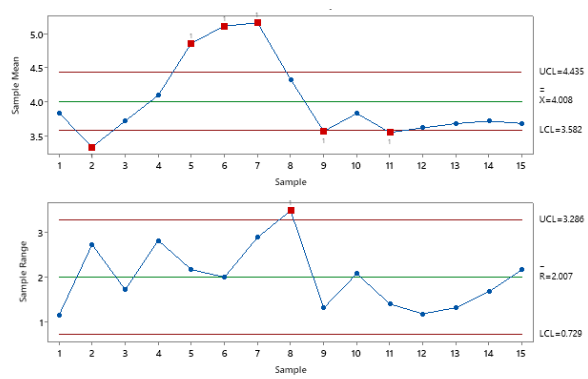

Figure 7 Xbar-R Chart of Operator C

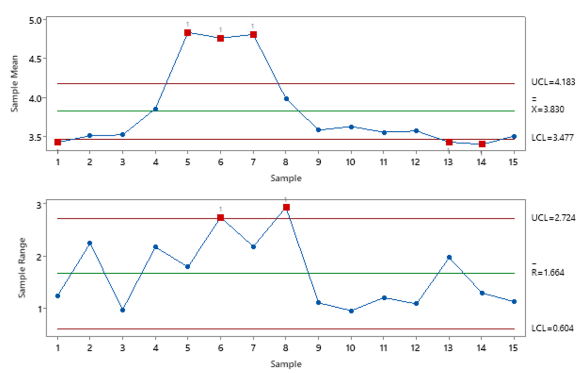

Figure 8 Xbar-R Chart of Operator D

6.2.3 Process Capability

Figures 9–12 show Process Capability for Operators A, B, C, D, and Table 3 shows Process Capability Across Operators.

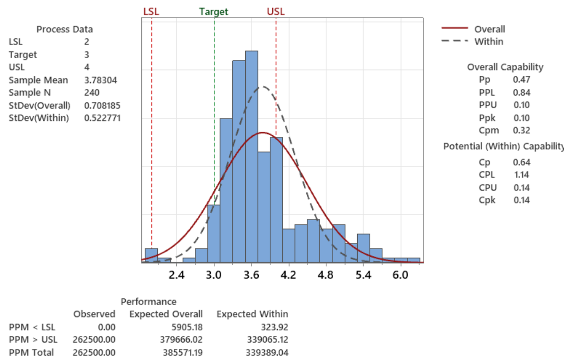

Figure 9 Process Capability for Operator A

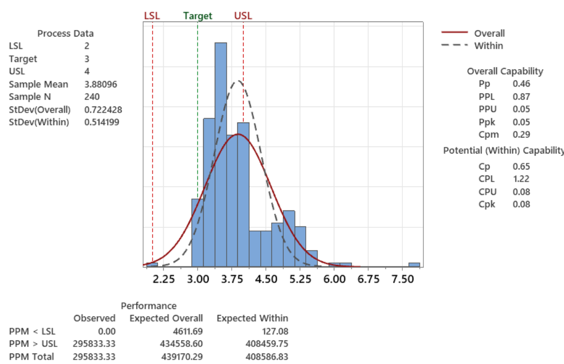

Figure 10 Process Capability for Operator B

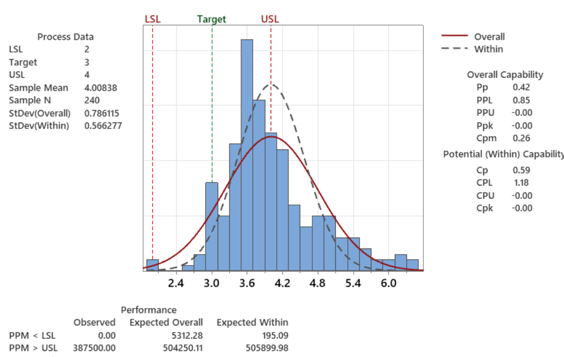

Figure 11 Process Capability for Operator C

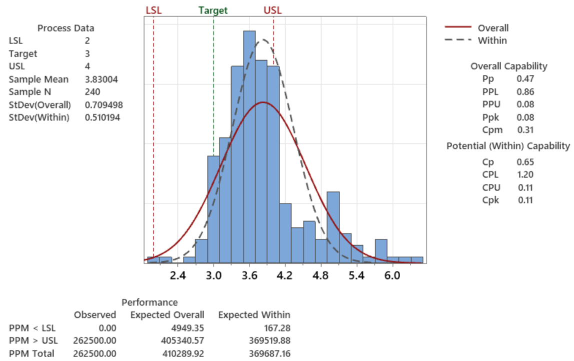

Figure 12 Process Capability for Operator D

Table 3 Process Capability Across Operators

Operator	Variable	Value
A	Cp	0.47
	Cpk	0.10
B	Cp	0.46
	Cpk	0.05
C	Cp	0.42
	Cpk	0.00
D	Cp	0.47
	Cpk	0.08

Cp (0.42–0.47) and Cpk (0.00–0.10) are far below the target ≥1.33, indicating poor capability, especially for Operator C (Cpk = 0.00).

6.2.4 Pareto Analysis

Table 4 Non-Conformance Across Operators

Operator	Non-Conformance Count	Non-Conformance (%)
A	63	22%
B	71	24%
C	93	32%
D	63	22%
Total	290	100%

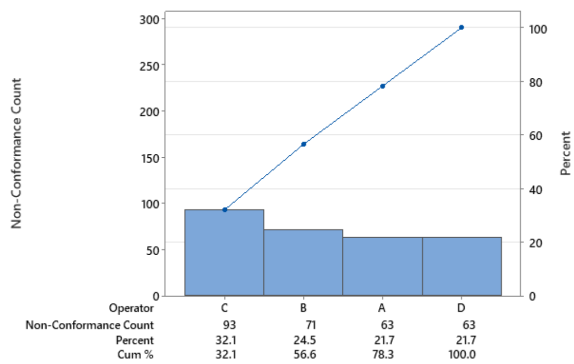

Figure 13 Pareto Chart of Operator

Operator C contributes 32% of defects (93/290), followed by B (24%).

6.2.5 Hypothesis Analysis

Table 5 Analysis of Variance (ANOVA) for Operators

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Operator	3	5.554	1.8513	3.50	0.015
Error	956	505.147	0.5284		
Total	959	510.701			

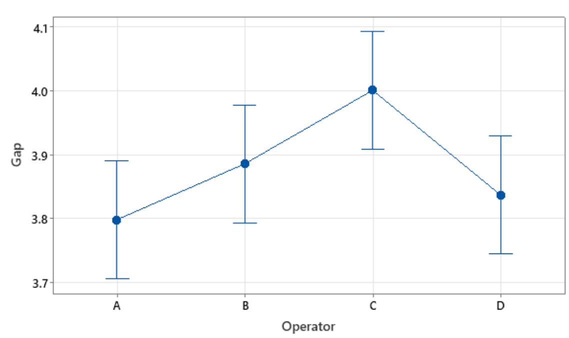

Figure 14 One-way ANOVA: Gap versus Operator

ANOVA (F = 3.50, p = 0.015) rejects H0, confirming significant mean gap differences. Operator C differs significantly from A, supporting Hypothesis 1.

6.3 Gap Measurements by Shift

6.3.1 Descriptive statistics

Table 6 Summary Statistics of Gap Measurements Across Shifts

Variable	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Start	240	3.74821	0.727139	2	3.2225	3.58	4.0475	6.31
Post-morning	240	3.82213	0.774749	2	3.3625	3.61	4.0475	6.5
Post-lunch	240	3.91704	0.676967	2	3.48	3.745	4.2025	5.91
Post-afternoon	240	4.01504	0.738608	2	3.58	3.9	4.3775	7.63

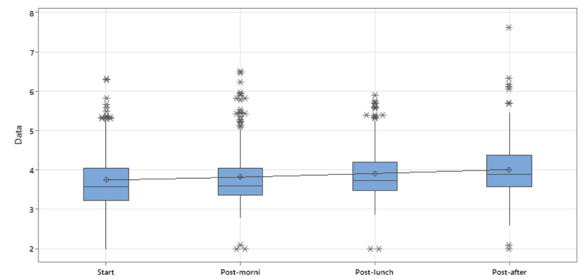

Figure 15 Box Plots of Gap Measurements Across Shifts

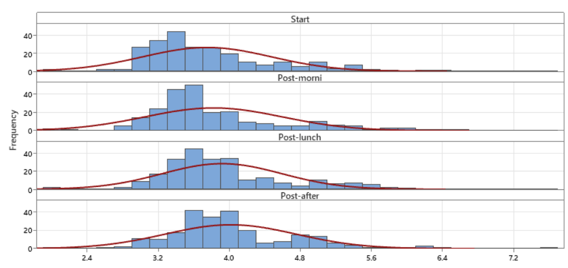

Figure 16 Histograms of Gap Measurements Across Shifts

Post-afternoon shifts have the highest mean gap (4.02mm), suggesting fatigue or setup issues.

6.3.2 Control Charts

Figures 17–20 show X-bar/R Charts for Start, Post-morning, Post-lunch, Post-afternoon Shifts. X-bar/R charts show post-afternoon shifts with out-of-control points (e.g., VIN011, VIN047) at G5–G8, indicating process variability.

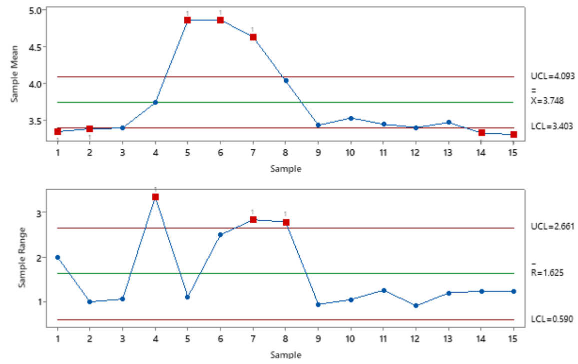

Figure 17 Xbar-R Chart for Start

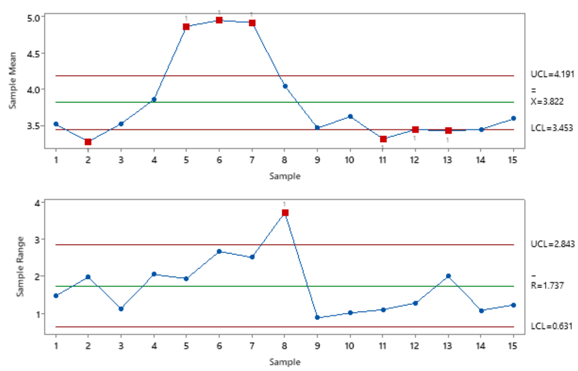

Figure 18 Xbar-R Chart for Post-morning

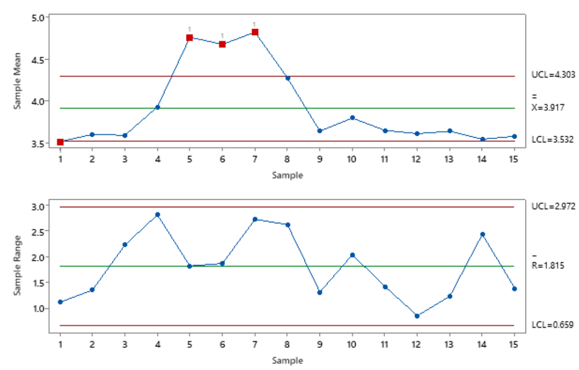

Figure 19 Xbar-R Chart for Post-lunch

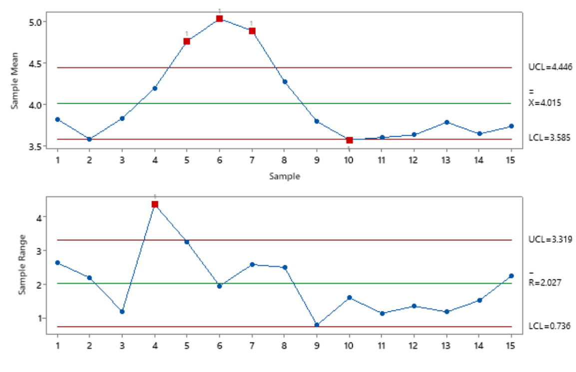

Figure 20 Xbar-R Chart for Post-afternoon

6.3.3 Process Capability

Figures 21–24 show Process Capability for Start, Post-morning, Post-lunch, Post-afternoon Shifts.

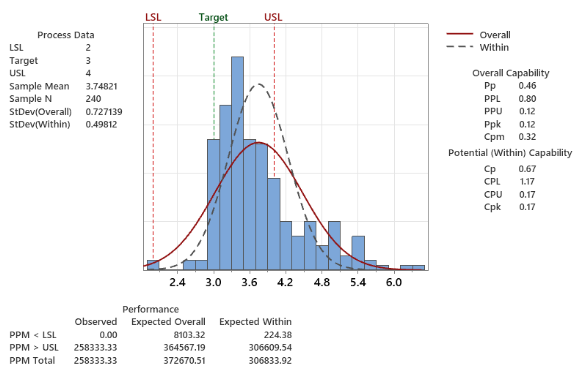

Figure 21 Process Capability for Start

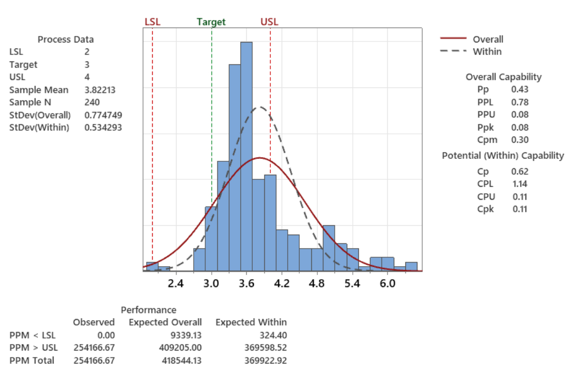

Figure 22 Process Capability for Post-morning

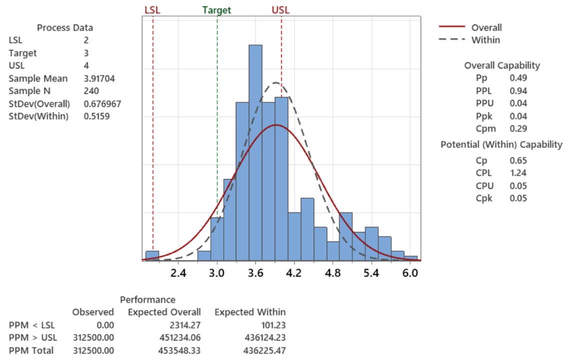

Figure 23 Process Capability for Post-lunch

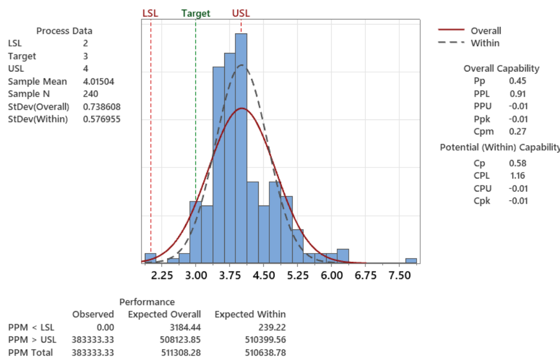

Figure 24 Process Capability for Post-afternoon

Table 7 Process Capability by Shift

Time	Variable	Value
Start of shift	Cp	0.46
	Cpk	0.12
After morning break	Cp	0.43
	Cpk	0.08
After lunch break	Cp	0.49
	Cpk	0.04
After afternoon break	Cp	0.45
	Cpk	-0.01

Cp (0.43–0.49) and Cpk (-0.01–0.12) indicate poor capability, worst in post-afternoon shifts (Cpk = -0.01).

6.3.4 Pareto Analysis

Table 8 Non-Conformance Across Shifts

Operator	Non-Conformance Count	Non-Conformance (%)
Start	62	21%
Post-morning	61	21%
Post-lunch	75	26%
Post-afternoon	92	32%
Total	**290**	**100%**

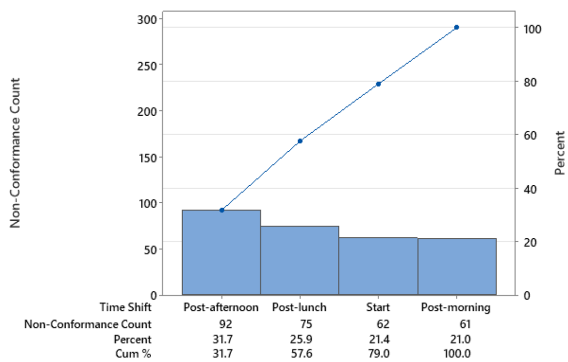

Figure 25 Pareto Chart of Shift Non-Conformances

Post-afternoon shifts contribute 32% of defects (92/290).

6.3.5 Hypothesis Analysis

Analysis of Variance

Table 9 Analysis of Variance (ANOVA) for Shifts

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Shift Time	3	9.665	3.2218	6.15	0.000
Error	956	501.036	0.5241		
Total	959	510.701			

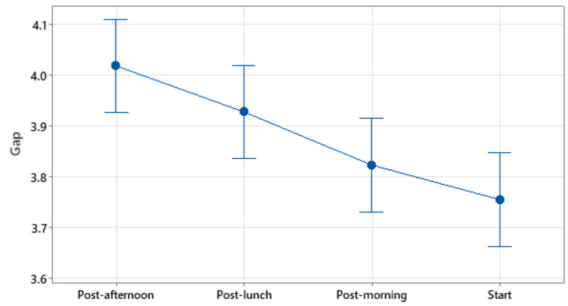

Figure 26 One-way ANOVA: Gap vs. Shift

ANOVA (F = 6.15, p < 0.001) rejects H0. Post-afternoon shifts differ significantly from Start (p ≈ 0.002), supporting Hypothesis 2.

6.4 Gap Measurements by Measurement Point

Table 10 Non-Conformance by Measurement Point

Point	Non-Conformance Count	Non-Conformance (%)
G1	3	5%
G2	5	8%
G3	4	7%
G4	9	15%
G5	55	92%
G6	53	88%
G7	57	95%
G8	52	87%
G9	9	15%
G10	6	10%
G11	7	12%
G12	6	10%
G13	4	7%
G14	5	8%
G15	7	12%
G16	6	10%
Total NC	290	
Expected NC/point	18.125	

G5–G8 contribute 217/290 = 74.8% of defects (86.7–95% of vehicles), vs. G1–G4, G9–G16 (5–15%).

6.4.1 Control Chart

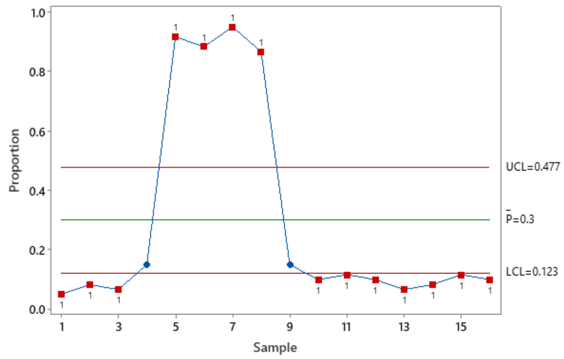

Figure 27 p-Chart of Non-Conformance by Measurement Point

p-bar = 0.302, UCL ≈ 0.47, LCL ≈ 0.123. G5–G8 (p = 0.867–0.950) exceed UCL, indicating out-of-control defects.

6.4.2 Process Capability

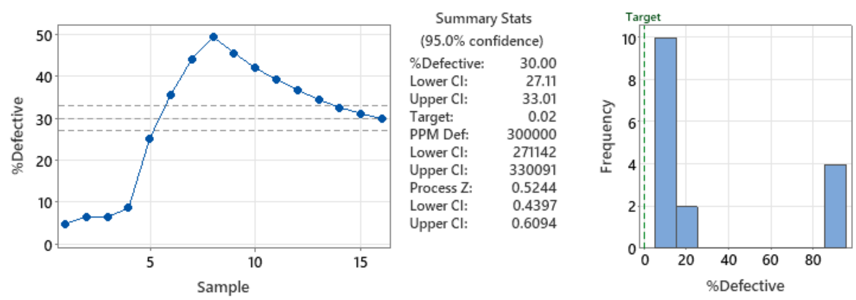

Figure 28 Binomial Process Capability for Non-Conformance

Overall p = 0.302 (PPM = 302,083) vs. target ≤0.02 (20,000 PPM). G5–G8: p = 0.867–0.950, Ppk < 0, incapable.

6.4.3 Pareto Analysis

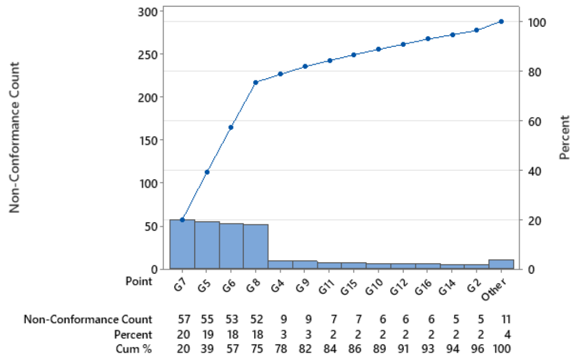

Figure 29 Pareto Chart of Measurement Point Non-Conformances

G7 (19.7%), G5 (19.0%), G6 (18.3%), G8 (17.9%) account for 74.8% of defects, confirming RH side A-pillar issues.

6.4.4 Hypothesis Analysis

Table 11 Observed and Expected Non-Conformance Counts

Category	Observed	Test Proportion	Expected	Contribution to Chi-Square
G1	3	0.0625	18	12.5000
G2	5	0.0625	18	9.3889
G3	4	0.0625	18	10.8889
G4	9	0.0625	18	4.5000
G5	55	0.0625	18	76.0556
G6	53	0.0625	18	68.0556
G7	57	0.0625	18	84.5000
G8	52	0.0625	18	64.2222
G9	9	0.0625	18	4.5000
G10	6	0.0625	18	8.0000
G11	7	0.0625	18	6.7222
G12	6	0.0625	18	8.0000
G13	4	0.0625	18	10.8889
G14	5	0.0625	18	9.3889
G15	7	0.0625	18	6.7222
G16	6	0.0625	18	8.0000

Table 12 Chi-Square Test

N	DF	Chi-Sq	P-Value
960	15	392.333	0.000

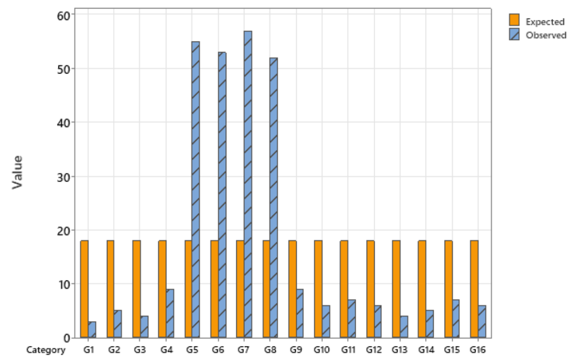

Figure 30 Observed vs. Expected Non-Conformance Counts

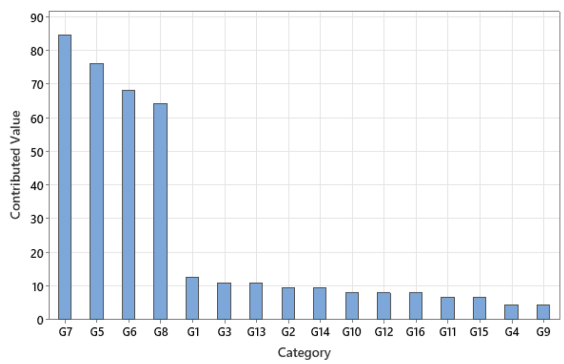

Figure 31 Contribution to Chi-Square by Category

Chi-square = 392.333, df = 15, $p < 0.001$, rejects H0. G5–G8 contribute most (63.2–83.4), supporting Hypothesis 3.

7. List of Possible Improvements

Objective: Implement targeted solutions in the windshield installation station to address root causes of excessive windshield-to-A-pillar gaps (>4mm, 30.2% non-conformance, ~3.88mm mean) at G5–G8 (74.8% of defects), Operator C variability (32.1%), and post-afternoon shift issues (31.7%), achieving a ≤2% defect rate (20,000 PPM) and Cp ≥1.33 by November 7, 2025, per the DMAIC Improve phase.

Table 13 Potential Improvements

Priority	Improvement	Description	Responsible Party	Expected Impact
1	Recalibrate Suction Cup Equipment	Adjust suction cup pressure and positioning to ensure precise alignment at G5–G8 (RH side A-pillar) within 3mm ± 1mm. Conduct daily pre-shift calibrations using a standardized checklist, verified by digital caliper measurements.	Process Engineer (Ng Hong), Windshield Station Supervisor (Vinush Radish)	Reduce G5–G8 defects by 50% (from 217/290 to ~108), lowering overall defect rate to ~15%.
2	Targeted Training for Operator C	Provide a 2-day training program for Operator C on suction cup handling and alignment techniques, focusing on consistent G5–G8 positioning. Include simulations and post-training audits (weekly gap measurements).	Quality Technician (Marco Strauss), Team Lead (Tim Buck)	Reduce Operator C defects by 40% (from 93/290 to ~56), aligning mean gap to ~3.5mm.
3	Standardize Post-Afternoon Shift Procedures	Implement pre-shift equipment checks and limit continuous suction cup tasks to 30 minutes during post-afternoon shifts to reduce fatigue-related errors. Document procedures in a standard operating procedure (SOP).	Production Supervisor (Jerome Guillemot), Operator (Marceline Avila)	Reduce post-afternoon defects by 30% (from 92/290 to ~64), lowering shift mean gap to ~3.7mm.
4	Real-Time Gap Monitoring System	Equip operators with digital calipers for real-time gap checks at G5–G8 during installation, with immediate feedback via a dashboard (Excel-based). Escalate out-of-spec gaps (>4mm) to the supervisor for adjustment	Quality Technician (Marco Strauss), Process Engineer (Ng Hong)	Detect and correct 80% of G5–G8 defects in real-time, reducing rework by 50% (~1 vehicle/day).

8. Control Plan

Objective: Sustain improvements in the windshield installation stationto maintain windshield-to-A-pillar gap within 3mm ± 1mm, reducing non-conformance from 30.2% (290/960, ~3.88mm mean) to ≤2% (20,000 PPM) and achieving Cp ≥1.33, by monitoring G5–G8 (74.8% of defects), Operator C performance (32.1%), and post-afternoon shifts (31.7%) during the DMAIC Control phase (November 14–21, 2025).

Table 14 Control Plan

Control Measure	Description	Responsible Party	Frequency	Metrics and Actions
Suction Cup Calibration Checks	Conduct daily pre-shift calibration of suction cup pressure and positioning using a standardized checklist, ensuring G5–G8 gaps meet 3mm ± 1mm. Record results in an Excel log, verified by digital caliper measurements	Quality Technician (Marco Strauss), Glazing Cell Supervisor (Vinush Radish)	Daily (before shifts, October 17–November 21, 2025)	Target: 100% of checks within 3mm ± 1mm. Action: Recalibrate equipment and escalate to Process Engineer (Ng Hong) if out-of-spec
Operator C Retraining	Deliver 4 weekly 2-hour training sessions (October 17–November 7, 2025) for Operator C on suction cup handling and G5–G8 alignment techniques, using simulations. Audit performance via weekly gap measurements. Log training in Excel	Team Lead (Tim Buck), Quality Technician (Marco Strauss)	Weekly (October 17–November 7, 2025)	Target: Reduce Operator C defects by 40% (from 93/290 to ~56). Action: Extend training if defects >56.
Statistical Process Control (SPC)	Monitor G5–G8 gaps daily using p-charts in Minitab (p-bar = 0.302, UCL ≈ 0.47, LCL ≈ 0.123, per Figure 27). Record measurements in Excel and review in team meetings.	Process Engineer (Ng Hong), Quality Technician (Marco Strauss)	Daily (November 14–21, 2025, ongoing)	Target: $p \leq 0.02$ (2% defects). Action: Investigate out-of-control points (e.g., $p > 0.47$) using 5 Whys and escalate to Process Owner (Vinush Radish).
Monthly Defect Rate Audits	Audit defect rates (G1–G16) monthly using Excel dashboards, comparing to baseline (30.2%) and target (≤2%). Report to stakeholders via email.	Process Owner (Vinush Radish), Quality Manager (Johana Barr)	Monthly (November 21, 2025, ongoing)	Target: ≤2% defect rate (20,000 PPM). Action: Escalate to Project Sponsor (Mark Sanders) if >2%.
Post-Afternoon Shift SOPs	Update SOPs for post-afternoon shifts to include pre-shift suction cup checks and 30-minute task limits to reduce fatigue. Train operators and document compliance in Excel.	Production Supervisor (Jerome Guillemot), Operator (Juan Pérez)	One-time SOP update (October 31, 2025); daily compliance checks	Target: Reduce post-afternoon defects by 30% (from 92/290 to ~64). Action: Revise SOPs if defects >64.

9. Reflection

This project applied Six Sigma's DMAIC methodology to reduce windshield-to-A-pillar gap non-conformance from 30.2% (~3.88mm mean, 290/960 measurements) to ≤2% (20,000 PPM), focusing on the RH side A-pillar (G5–G8, 74.8% of defects). The process provided valuable insights into data simulation, statistical analysis, and process improvement, with lessons applicable to future projects.

9.1 Challenges

- **Data Simulation**: Generating realistic data with `GenerateWindshieldData.vb` (Appendix B, `https://github.com/miguelaltuve/SixSigmaGreenBeltCapstone`) required iterative adjustments to achieve a 30.2% non-conformance rate (290/960, Table 1), slightly above the 30% target, due to random variation in VBA parameters (G5–G8: 4.8mm mean, SD 0.6mm).
- **Statistical Analysis**: Mastering Minitab for ANOVA (Section 6.2.5), chi-square tests (Section 6.4.4), and p-charts (Figure 27) was challenging, particularly setting up subgroup sizes and interpreting out-of-control points for G5–G8.
- **Team Coordination**: Adhering to the Team Charter (Section 2) required strict attendance and participation (e.g., 60% contribution to discussions), which was demanding but ensured collaborative problem-solving.

9.2 Lessons Learned

- **Data Precision**: Precise VBA simulation (e.g., targeting ~3.88mm mean, Table 2) enabled accurate root cause identification (G5–G8, Operator C, post-afternoon shifts), emphasizing the need for robust data in the Measure phase.
- **Statistical Tools**: Pareto charts (Figure 29) and chi-square tests (Table 12) were critical in prioritizing G5–G8 (74.8% defects), while ANOVA (Figures 14, 26) linked Operator C (32.1% defects) and post-afternoon shifts (31.7%) to variability, guiding targeted improvements.
- **Team Dynamics**: Clear roles (e.g., Marco Strauss for data collection, Ng Hong for analysis, Section 3) and structured decision-making (multi-voting, consensus, Section 2) streamlined the project, highlighting the value of a disciplined Team Charter.

9.3 Outcomes and Impact

- The project identified suction cup misalignment as the primary root cause for G5–G8 defects, addressed through recalibration, Operator C training, and post-afternoon shift SOPs (Sections 7–8). These improvements are projected to reduce defects to ≤2%, achieving Cp ≥1.33 and $24,000 in monthly rework savings (Section 1).
- Enhanced process control (e.g., daily SPC p-charts, monthly audits, Section 8) is expected to sustain a 90% reduction in customer complaints by ensuring consistent gap alignment, improving brand reputation and production efficiency.

- Stakeholder engagement (e.g., Vinush Radish, Johana Barr) ensured alignment with production goals, reinforcing the importance of communication in Six Sigma projects.

9.4 Future Applications

- Future projects should leverage real-time data collection with digital calipers (Section 7) to reduce simulation reliance and enhance accuracy in the Measure phase.
- Automated SPC tools (e.g., Minitab dashboards) could streamline the Control phase, enabling faster detection of out-of-control conditions.
- Expanding team training to all operators (not just Operator C) could further reduce variability, ensuring long-term process stability.

Appendix A: SIPOC Diagram

S	I	P	O	C
Suppliers	**Inputs**	**Process Steps**	**Outputs**	**Customers**
Glass supplier	Windshield	1. Inspect glass for cosmetic defects	Windshield properly aligned, free of cosmetic defects	Wiper arms installation process
Polyurethane supplier	Polyurethane	2. Place glass on table		Company drivers
Tools and equipment suppliers	Glass cleaner, wipes, flashlight, suction cups, digital caliper	3. Operator A applies polyurethane		End customers
	Safety equipment (gloves, shoes, glasses)	4. Operators B and C pick glass with suction cups		
	Check sheet	5. Operators B and C install windshield on vehicle		
	Work Instruction	6. Operator D adjusts alignment with suction cups		
		7. Quality inspector verifies fitment		
		8. Release vehicle		

Appendix B: VBA Code for Windshield Fitment Data Simulation

```
' GenerateWindshieldData.vb
' Purpose: Simulates windshield gap data for Six Sigma Green Belt Capstone Project
' Generates 60 vehicles with 16 gap measurements (G1–G16) each, with higher defects at G5–G8 (RH side A-pillar)
' Outputs: 960 measurements in Excel (columns A:U, rows 2:61), with non-conformance count (>4mm) in column U
' Matches dataset: ~3.88mm mean, 30.2% non-conformance (290/960)

Sub GenerateWindshieldData()
    Dim i As Long, j As Long
    Dim nonConformance As Long
    Randomize ' Initialize random number generator

    ' Clear existing data (optional, adjust range as needed)
    Range("A2:U61").ClearContents

    ' Generate data for 60 vehicles
    For i = 2 To 61 ' Rows 2–61
        ' VIN, Day, Shift, Operator
        Cells(i, 1) = "VIN" & Format(i - 1, "000") ' VIN001–VIN060
        Cells(i, 2) = Int((i - 2) / 12) + 1 ' Day 1–5 (12 vehicles/day)
        Cells(i, 3) = Choose(((i - 2) Mod 4) + 1, "Start", "Post-morning", "Post-lunch", "Post-afternoon") ' Shift
        Cells(i, 4) = Choose(Application.RandBetween(1, 4), "A", "B", "C", "D") ' Operator

        ' Generate gaps G1–G16 (columns E–T, 5–20)
        nonConformance = 0
        For j = 5 To 20 ' G1–G16
            Dim baseMean As Double, baseStd As Double
            ' Set base mean and std dev for G5–G8 (higher defects) vs others
            If j >= 9 And j <= 12 Then ' G5–G8 (columns I–L)
                baseMean = 4.8 ' Matches your data (~4.8mm)
                baseStd = 0.6 ' Higher variability
            Else ' G1–G4, G9–G16
                baseMean = 3.5 ' Matches your data (~3.2–3.3mm)
                baseStd = 0.3 ' Lower variability
            End If

            ' Adjust mean and std dev based on Operator
            Dim opAdjustMean As Double, opAdjustStd As Double
            opAdjustMean = 0: opAdjustStd = 0
            If Cells(i, 4) = "A" Then opAdjustMean = -0.1: opAdjustStd = -0.1 ' Lower gaps
            If Cells(i, 4) = "C" Then opAdjustMean = 0.2: opAdjustStd = 0.1 ' Higher gaps
            ' Operators B and D use base values

            ' Adjust mean and std dev based on Shift
            Dim shiftAdjustMean As Double, shiftAdjustStd As Double
            shiftAdjustMean = 0: shiftAdjustStd = 0
            If Cells(i, 3) = "Start" Then shiftAdjustMean = -0.1 ' Lower gaps
            If Cells(i, 3) = "Post-lunch" Then shiftAdjustMean = 0.1: shiftAdjustStd = 0.03
            If Cells(i, 3) = "Post-afternoon" Then shiftAdjustMean = 0.2: shiftAdjustStd = 0.07

            ' Generate gap value (normal distribution, rounded to 2 decimals)
            Cells(i, j) = WorksheetFunction.Round(WorksheetFunction.Norm_Inv(Rnd(), baseMean + opAdjustMean +
shiftAdjustMean, baseStd + opAdjustStd + shiftAdjustStd), 2)
            If Cells(i, j) < 0 Then Cells(i, j) = 0 ' Ensure non-negative

            ' Count non-conformance (>4mm)
            If Cells(i, j) > 4 Then nonConformance = nonConformance + 1
        Next j

        ' Write # Non-Conformance (column U)
        Cells(i, 21) = nonConformance
    Next i
End Sub
```