Reducing Door Panel Rework – Statistical & Quality Planning Approach

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1. Executive Summary

This project addresses high rework rates in the door panel assembly process of an automotive production line. Using statistical quality tools (Descriptive Statistics, Pareto Charts, Control Charts, Process Capability Analysis, ANOVA) and core automotive quality planning tools (FMEA, Control Plan, PPAP, MSA, DOE), the analysis identified key contributors to rework, including fitment gaps and surface scratches. Measurement System Analysis confirmed data reliability, and DOE optimization of jig position and torque settings indicated potential for a 20% reduction in fitment-related rework. Baseline capability analysis revealed Cp = 1.16 and Cpk = 0.77, indicating a need for centering and reducing variability. Recommended improvements include standardizing jig settings, enhancing operator training, and implementing protective measures. These actions align the process with IATF 16949 requirements and support sustainable quality improvement.

2. Problem Definition & Background

In automotive manufacturing, door panel fitment is a key quality factor influencing both aesthetics and functionality. Poor alignment or visible gaps lead to warranty claims, reduced customer satisfaction, and higher production costs. In the studied assembly line, a simulated baseline defect rate of 12% was recorded, with primary causes being fitment gaps, scratches, and misalignment. These issues not only increase rework costs but also disrupt production flow. Addressing them is essential for meeting OEM quality expectations and reducing production waste.

3. Data Collection Plan

Multiple datasets were collected and/or simulated to support the different statistical and quality analyses performed in this study. Since certain tools require specific data formats and conditions, the datasets were tailored accordingly:

- Measurement System Analysis (MSA): Required repeated measurements of the same parts by multiple operators to assess repeatability and reproducibility.
- Design of Experiments (DOE): Required structured factor–level combinations (Jig Position, Torque Setting) with replications to study process parameter effects.
- Pareto Chart, Capability Analysis, and Control Charts: Based on a broader defect log containing daily production and rework counts.

This approach ensured that each analysis was based on the most appropriate and valid dataset structure, while still representing the same process environment and defect categories.

4. Measurement System Analysis (MSA)

In manufacturing industries, especially in sectors like automotive, precision and reliability of measurements are essential to ensure consistent product quality. Any decision made on part acceptance or rejection is only as good as the measurement system that drives it. Hence, before trusting the collected data, it is critical to evaluate whether the measurement system itself is capable and stable.

This report focuses on a Gage Repeatability and Reproducibility (Gage R&R) study conducted for the inspection of door panel rework dimensions. The study is based on IATF 16949 and APQP principles, which emphasize robust measurement systems and quality assurance in automotive supply chains.

The main goal of this analysis is to assess whether the current measuring setup (including instruments and operators) is accurate and consistent enough to detect true variations in the product, and not introduce errors due to human or tool-related inconsistencies.
Using a Crossed Gage R&R design, this study involves:

- 10 different door panel parts (representing possible product variation),
- 3 operators (to check consistency among inspectors), and
- 2 repeated measurements (to evaluate internal consistency and system repeatability).

Through ANOVA-based analysis and supporting graphical tools like control charts, variation components, and operator interaction plots, we aim to conclude whether the measurement system can be trusted for ongoing quality control and decision-making.

This report summarizes the results, visual interpretations, and final conclusion on whether this measurement system is suitable for production use, and if any improvement actions are needed.

Table 4.1 *Collected Data*

Part	Operator	Trial	Measurement
1	A	1	45.09
1	A	2	45.19
1	B	1	45.17
1	B	2	45.37
1	C	1	45.35
1	C	2	45.44
2	A	1	44.14
2	A	2	43.99
2	B	1	44.06
2	B	2	44.18
2	C	1	43.98
2	C	2	44.05
3	A	1	45.32
3	A	2	45.19
3	B	1	45.34
3	B	2	45.42

4.1 Method

A Crossed Gage R&R Study was conducted using 10 parts, 3 operators (A, B, C), and 2 repetitions per part. This analysis was done in Minitab and included:

- ANOVA Table
- Variance Components
- R and $\bar{X}$ Charts
- Measurement by Part & Operator
- Part-Operator Interaction

4.1.1 Anova Table

Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
Part	9	16.2952	1.81058	138.358	0.000
Operator	2	0.0156	0.00782	0.598	0.554
Repeatability	48	0.6281	0.01309		
Total	59	16.9390			

Figure 4.1 *Two-Way ANOVA Table Without Interaction*

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	9	16.2952	1.81058	111.692	0.000
Operator	2	0.0156	0.00782	0.483	0.625
Part * Operator	18	0.2918	0.01621	1.446	0.181
Repeatability	30	0.3364	0.01121		
Total	59	16.9390			

α to remove interaction term = 0.05

Figure 4.2 *Two-Way ANOVA Table With Interaction*

Interpretation:

- Part has a very high F-value and P = 0.000 → Part differences are statistically significant.
- Operator P = 0.554 → No significant variation between operators.

4.1.2 Variance Components

Gage R&R

Variance Components

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.013086	4.19
Repeatability	0.013086	4.19
Reproducibility	0.000000	0.00
Operator	0.000000	0.00
Part-To-Part	0.299583	95.81
Total Variation	0.312669	100.00

Gage Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.114395	0.68637	20.46
Repeatability	0.114395	0.68637	20.46
Reproducibility	0.000000	0.00000	0.00
Operator	0.000000	0.00000	0.00
Part-To-Part	0.547341	3.28405	97.88
Total Variation	0.559168	3.35501	100.00

Number of Distinct Categories = 6

Figure 4.3 *Shows the % contribution of Repeatability, Reproducibility, and Part-to-Part variation*

- The measurement system contributes only 4.19% to overall variation, which is excellent (<10% is considered acceptable).
- Reproducibility = 0%, indicating all operators measure parts consistently.
- Repeatability = 4.19%, meaning the measuring tool is precise.
- The majority of variation (95.81%) is due to actual differences in the parts, which is desired.

4.1.3 Graphical Analysis

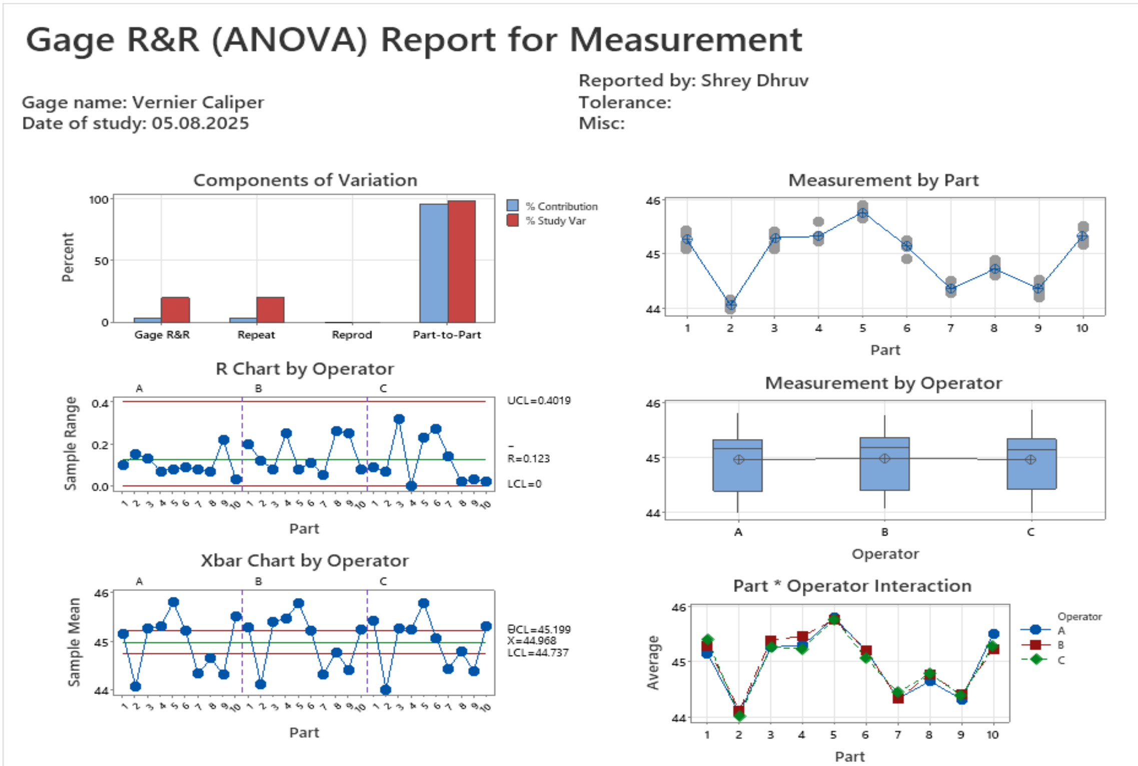

Figure 4.4 *Gage R&R Anova Report for Measurements*

Components of Variation Charts:

- Visually confirms that almost all variation is from part-to-part differences.

R Chart by Operator:

- No points fall outside control limits → Repeatability is in control.

X-bar Chart by Operator:

- Lines for all operators are consistent and within control limits → Reproducibility is confirmed.

Interaction Plot (Operator * Part):

- Nearly parallel lines → No operator-part interaction.
- All operators measure similarly.

Measurement by Operator:

- Box plots show minimal difference in medians and spreads → Consistent operator behavior.

5. Descriptive Statistics and Box Plot Analysis

5.1 Descriptive Statistics

Descriptive statistics revealed Line C had the highest mean rework with low variability, while Line B had moderate mean rework but the highest variability. Pareto analysis identified scratches (25.4%), fitment issues (23.3%), and other defects (24.8%) as the top contributors, collectively accounting for over 73% of total rework. A total of 90 records were analyzed, collected over 30 working days from Lines A, B, and C. Each record includes the date, line, number of reworks, type of defect, and number of units inspected (fixed at 100).

Table 5.1 *Collected Data*

Date	Line	Rework_Count	Rework_Type	Units_Inspected
1	A	2	Fitment issue	100
1	B	5	Scratches	100
1	C	4	Scratches	100
2	A	2	Others	100
2	B	2	Others	100
2	C	7	Fitment issue	100
3	A	1	Fitment issue	100
3	B	4	Scratches	100
3	C	9	Others	100
4	A	1	Others	100
4	B	4	Others	100
4	C	7	Scratches	100

Statistics

Variable	Line	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Rework_Count	A	30	0	4.16667	0.484432	2.65334	1	2	4	6	10
	B	30	0	5.6	0.526537	2.88396	1	3	5	9	10
	C	30	0	6.1	0.432448	2.36862	2	4	6	8	10

Figure 5.1 *Summarizes key statistical metrics (mean, median, standard deviation, etc.) for rework counts across production lines*

- Line C: Highest rework average, low variability → consistent high issues.
- Line B: Moderate average, high variability → inconsistent operations.

5.2 Box Plot Analysis

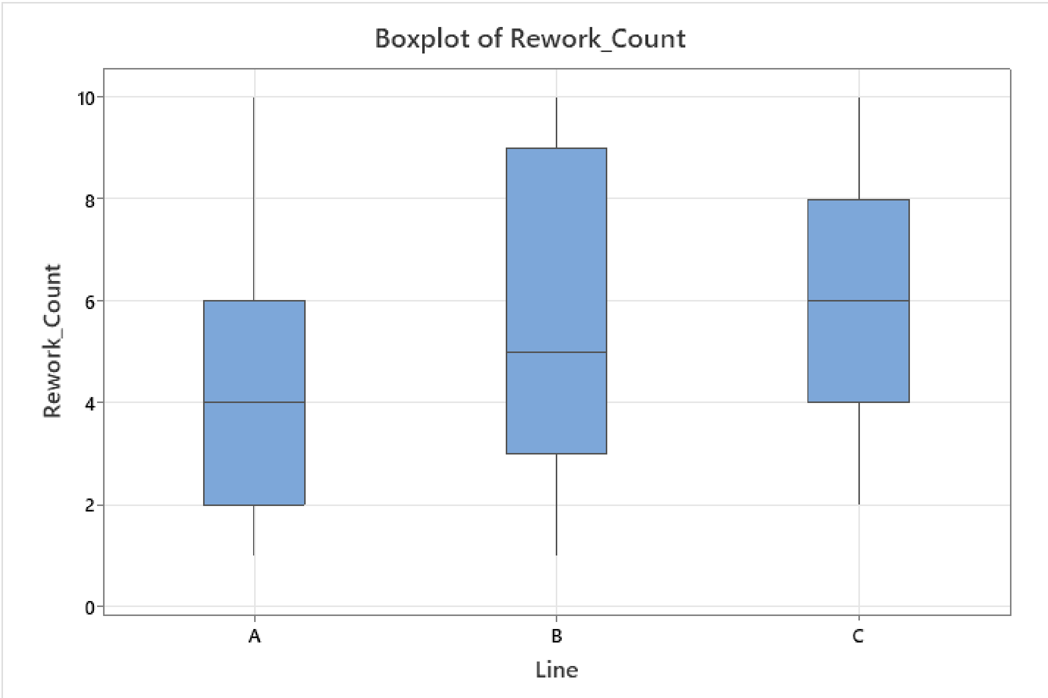

Figure 5.2 *Compares rework distributions across production lines (A, B, C), identifying variation and median rework count.*

Interpretation:

- Line C, although having the highest average rework, shows less variation—implying a stable process but consistently high rework that needs systemic improvements.
- Line B has the widest IQR and range, indicating inconsistent operations. This suggests problems vary significantly by day or shift.
- Line A performs better in terms of lower rework counts and moderate variability.

6. Pareto Chart

Purpose:
The Pareto chart helps identify and prioritize the most frequent types of rework, based on the 80/20 rule—that 80% of problems are often caused by 20% of the issues.

Observations:
- The most frequent defect was Scratches, with a total of 121 occurrences.
- Other common rework types included Fitment issues, Others, and Loose fasteners.
- The top 3 defect types contributed to more than 73.5% of total rework, making them critical improvement targets.

Output Interpolation: Scratches Account for 25.4% of all reworks. Focus should be placed here.

Table 6.1 *Pareto analysis of defects in process X*

Rework_Type	Scratches	Others	Fitment Issue	Loose Fasteners	Wiring Problems
Rework_count	121	118	111	70	56
Percent	25.4	24.8	23.3	14.7	11.8
Cummalative %	25.4	50.8	73.5	88.2	100

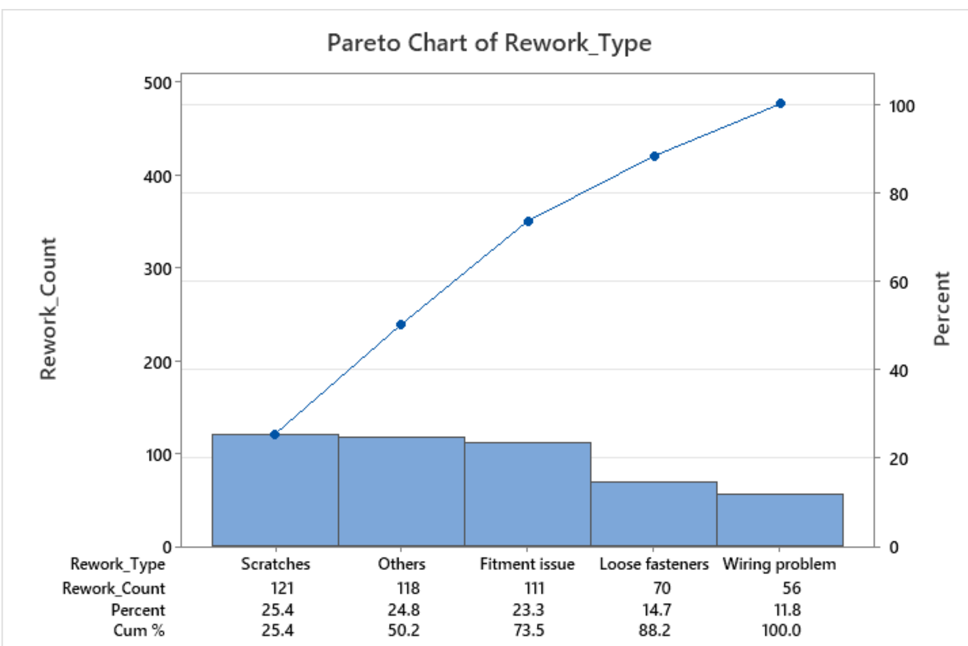

Figure 6.1 *Shows the frequency and cumulative impact of different rework types, highlighting key problem areas*

7. Control Chart (U Chart)

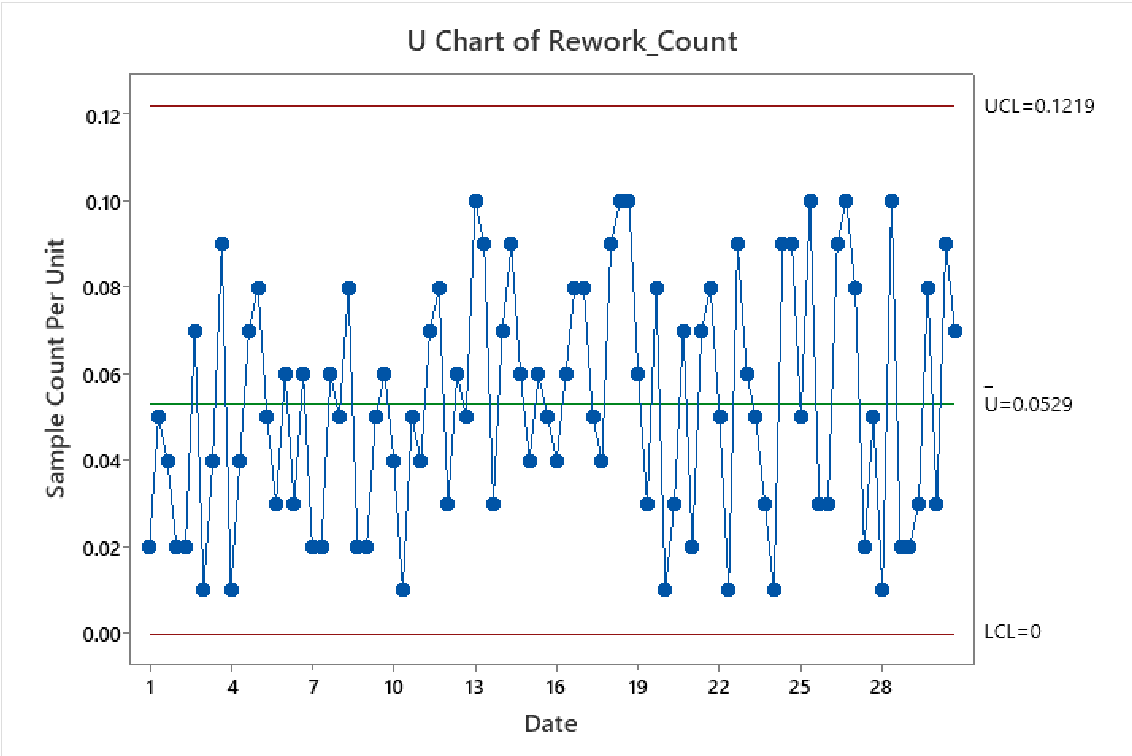

***Figure 7.1** Monitors defects per unit over time, helping detect instability or special cause variations in rework counts*

Objective:
To monitor the rework counts per inspected unit over time and assess the stability of the process, a U Chart was generated in Minitab using the variables:

- Variable (Defects): Rework_Count
- Subgroup Size: Units_Inspected
- X-axis (Subgroup): Date

Interpretation:
The U chart plots the number of reworks per inspected unit (defects per unit) over time, with calculated control limits:

- Center Line (U): 0.0529
- Upper Control Limit (UCL): 0.1219
- Lower Control Limit (LCL): 0

All data points fall within the control limits, and there are no points violating control chart rules (e.g., no point exceeds ±3 standard deviations). Therefore, the process is currently statistically in control.

Observation:
Although the U chart shows no signs of special cause variation, earlier analyses revealed the following:

- Descriptive statistics showed that Line B has the highest standard deviation and Standard Error of Mean (SE Mean), indicating more variation and inconsistency in performance.
- Box plots showed Line B has the widest IQR, supporting the finding of greater fluctuation in rework rates.
- The Pareto Chart revealed that scratches are the most frequent rework type, making up 25% of total issues.

This suggests that while the overall rework process is statistically stable, it is not optimized — especially in Line B, which requires further investigation and improvement.

8. Process Capability Analysis

8.1 Data & Method

Table 8.1 *Door panel gap measurements (mm)*

Door_Panel_Gap_mm
2.275
2.179
2.297
2.428
2.165
2.165
2.437
2.315
2.13
2.281
2.13
2.13
2.236
1.913
1.941
2.116
2.048
2.247
2.064

8.2 Results

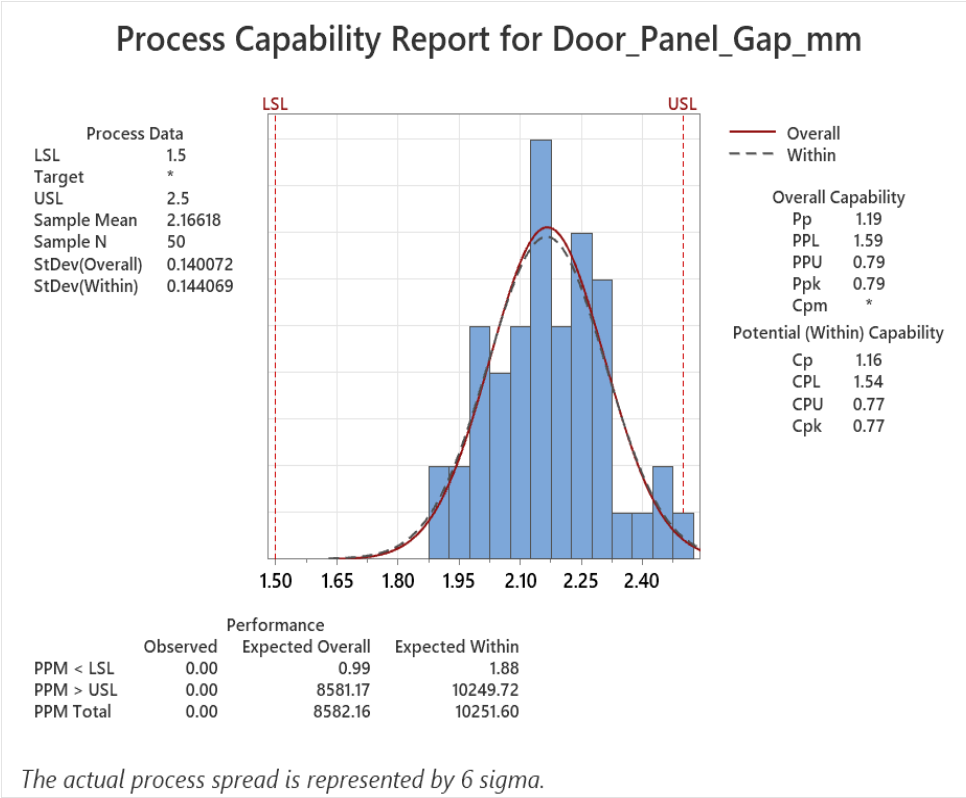

Figure 8.1 *Process Capability (Cp, Cpk) for Door Panel Gap Measurement*

- The Cp = 1.16 → Indicates the process spread is slightly wider than ideal (Cp < 1.33 means not capable).
- Cpk = 0.77 → Process is not centered between LSL and USL; there's a higher chance of falling outside limits on one side.
- Pp = 1.19 → Long-term capability spread is also poor.
- Ppk = 0.79 → Confirms the centering issue over the long term.
- Std. Dev. (Within) = 0.14469 mm, Std. Dev. (Overall) = 0.140072 mm → Process variation is relatively consistent over time, but not aligned to the target.
- Expected PPM (overall) = 8582.16 → In the long term, around 8,582 defective parts are expected per million produced.

Key takeaway:
Although the variation is not extreme, the mean value is shifted from the target, causing the capability indices (Cpk & Ppk) to fall below 1.0.

9. Cause-and-Effect Diagram (Fishbone Diagram)

A Fishbone Diagram was developed to identify possible root causes of scratches — the most frequent rework issue found in door panels. The causes were categorized under six main headings: Man, Machine, Method, Material, Measurement, and Environment.

Under "Man", mishandling due to lack of training or fatigue was noted. For "Machine", improper tools and fixture edges were suspect. In "Method", a lack of a standardized handling SOP was identified. "Material" issues included poor coating quality or transport packaging. Measurement inconsistencies and a suboptimal environment (dust, poor layout) were also listed as contributors.

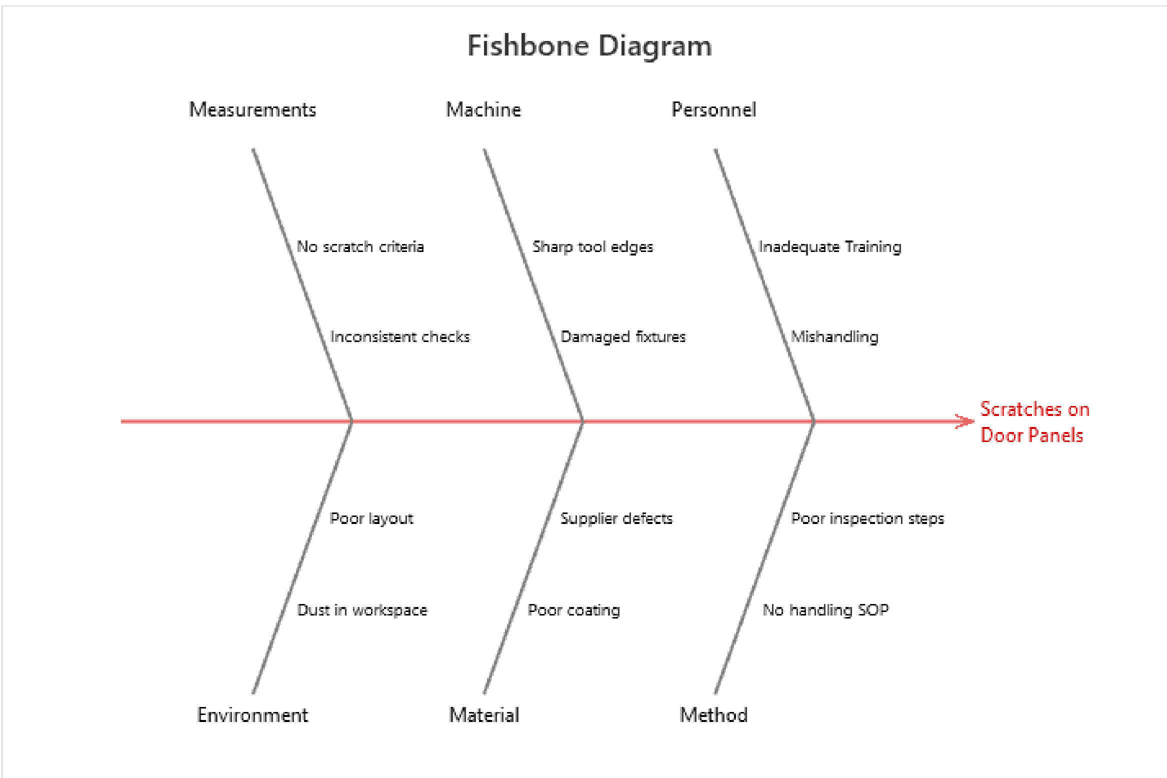

Figure 9.1 *Identifies potential root causes of rework issues by categorizing them into factors like method, machine, material, and manpower.*

10. ANOVA (Analysis of Variance)

Purpose: To determine whether there is a statistically significant difference in the average rework count between the three assembly lines (A, B, and C).

Factor Information

Factor	Levels	Values
Line	3	A, B, C

Figure 10.1 *Lists the factors included in the model (e.g., Line), their types (fixed/random), and number of levels (e.g., A, B, C)*

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.64372	9.04%	6.95%	2.66%

Figure 10.2 *Shows goodness-of-fit statistics like R-squared and adjusted R-squared, indicating how well the model explains variability in the data*

Method

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	$\alpha = 0.05$

Equal variances were assumed for the analysis.

Figure 10.3 *Specifies the statistical test, confidence level, and assumptions used in the ANOVA analysis*

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Line	2	60.42	30.211	4.32	0.016
Error	87	608.07	6.989		
Total	89	668.49			

Figure 10.4 *Displays between-group and within-group variance, F-ratio, and p-value to test for statistically significant differences in rework means*

Means

Line	N	Mean	StDev	95% CI
A	30	4.167	2.653	(3.207, 5.126)
B	30	5.600	2.884	(4.641, 6.559)
C	30	6.100	2.369	(5.141, 7.059)

Pooled StDev = 2.64372

Figure 10.5 *Shows average rework count and standard deviation for each production line*

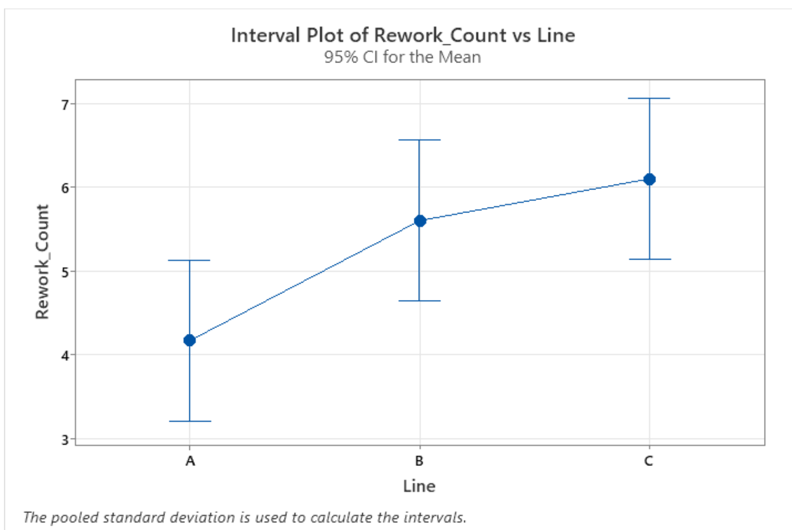

Figure 10.6 *Visual representation of mean rework and 95% confidence intervals for each production line. Helps visually assess whether group means differ significantly*

- **Interpretation**: The ANOVA results indicate a statistically significant difference in average rework counts among the lines. Line C has the highest mean rework, followed by Line B, and Line A has the lowest. These results justify the need for further root cause analysis and process improvements, especially on Lines C and B.

11. FMEA & Control Plan

11.1 FMEA

FMEA is used to identify potential failure modes in the door panel assembly process and evaluate their severity, likelihood of occurrence, and detectability. This allows the team to prioritize improvement actions.

Table 11.1 *Process Failure Mode and Effects Analysis (PFMEA) for Door Panel Rework Process*

Process Step	Failure Mode	Effect	S	O	D	RPN	Recommended Action	S'	O'	D'	New RPN
Fit Door Panel	Misalignment	Poor door closing	7	6	5	210	Improve fixture, alignment tool	6	3	2	**36**
Fasten Bolts	Loose fastener	Vibration/noise	6	5	6	180	Use calibrated torque wrench	5	2	3	**30**
Wire Connections	Wrong wiring	Electrical malfunction	8	7	4	224	Label wires clearly, staff training	7	2	2	**28**

Interpretation:

- Before action: All three issues had RPN > 180, making them high-risk and requiring urgent correction.
- After action: Post-RPNs dropped significantly (all below 40), indicating the process is now low risk.
- High-severity failure, like wrong wiring, was effectively mitigated by improving detection and reducing their occurrence.

11.2 Control Plans

The control plan defines how each key characteristic identified in the FMEA will be monitored during production to ensure consistent product quality. The Control Plan is a structured document derived from the Process FMEA to ensure that all critical product and process characteristics are consistently monitored, measured, and controlled during production and rework. For the door panel rework process, the Control Plan identifies each process step, the associated characteristic(s), the specification or tolerance, the measurement method, control methods, and reaction plans in case of nonconformities. This Control Plan ensures:

- Consistency – all operators follow the same inspection and measurement methods.
- Traceability – each critical characteristic links back to the PFMEA item number and risk assessment.
- Readiness for PPAP – documented control measures prove the process is stable and capable.

Table 11.2 *Control Plan for Door Panel Assembly and Rework Process*

Process Step	Characteristic	Specification / Tolerance	Measurement Method	Control Method / Sampling Frequency	Reaction Plan
Fit Door Panel	Door alignment	≤ ±2 mm gap	Visual + gap gauge	Fixture + SOP; 100% inspection	Stop line, retrain operator
Fasten Bolts	Torque on bolts	15 ± 1 Nm	Digital torque wrench	Calibrated tool; 1 per car audit	Replace tool, recheck last 10 vehicles
Wire Connections	Connector seating & color coding	Fully seated; match colors	Visual + click sound + color check	SOP board + labeling; 100% inspection	Stop assembly, QA recheck

12. Production Part Approval Process (PPAP)

The Production Part Approval Process (PPAP) is a standardized process in the automotive industry used to ensure that suppliers can meet the engineering and quality requirements consistently. In this project, the PPAP submission includes the following critical elements:

- Process FMEA – to proactively identify and address potential failure modes in the door panel assembly.
- Control Plan – to define how key characteristics are monitored and controlled during production.
- Gage R&R Study – to validate the reliability and precision of the measurement system.

These documents together demonstrate that the door panel assembly process is capable, stable, and meets customer expectations. This foundational PPAP submission is essential for process validation and supplier approval.

13. Design of Experiments (DOE)

Objective:
The objective of this DOE was to determine the effects of Jig Position and Torque Setting on the door panel fitment gap, and to identify optimal parameter settings that minimize gap size, thereby reducing rework caused by misalignment.

Experimental Design:
A 2 × 3 full factorial design was implemented:

- Factor A – Jig Position: 2 levels (A, B)
- Factor B – Torque Setting: 3 levels (14.5 Nm, 15.0 Nm, 15.5 Nm)
- Response Variable: Average Fitment Gap (mm)

Each experimental condition was replicated three times to estimate experimental error.

Table 13.1 *DOE Run Data*

Run	Jig Position	Torque (Nm)	Gap_1 (mm)	Gap_2 (mm)	Gap_3 (mm)	Avg Gap (mm)
1	A	14.5	2.35	2.3	2.28	2.31
2	A	14.5	2.2	2.18	2.22	2.2
3	A	14.5	2.4	2.37	2.35	2.37
4	B	14.5	2.1	2.12	2.08	2.1
5	B	14.5	1.95	1.98	1.96	1.96
6	B	14.5	2.05	2.07	2.04	2.05

13.1 Graphical Analysis

13.1.1 Main Effects Plot

- Jig Position B consistently yields lower fitment gaps than Position A.
- Torque setting has minimal influence on average gap within the tested range.

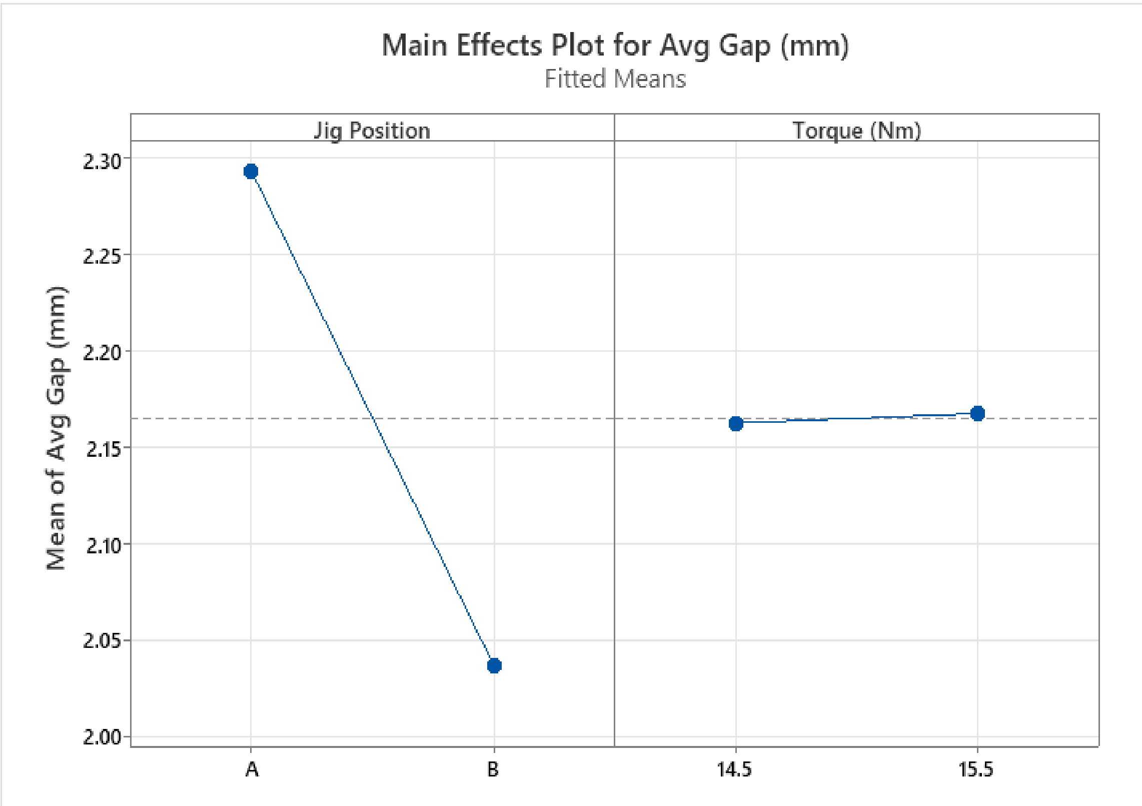

Figure 13.1 *Main Effects Plot*

13.1.2 Interaction Plot

- Slight interaction between Jig Position and Torque: Position B is less sensitive to torque variation than Position A.

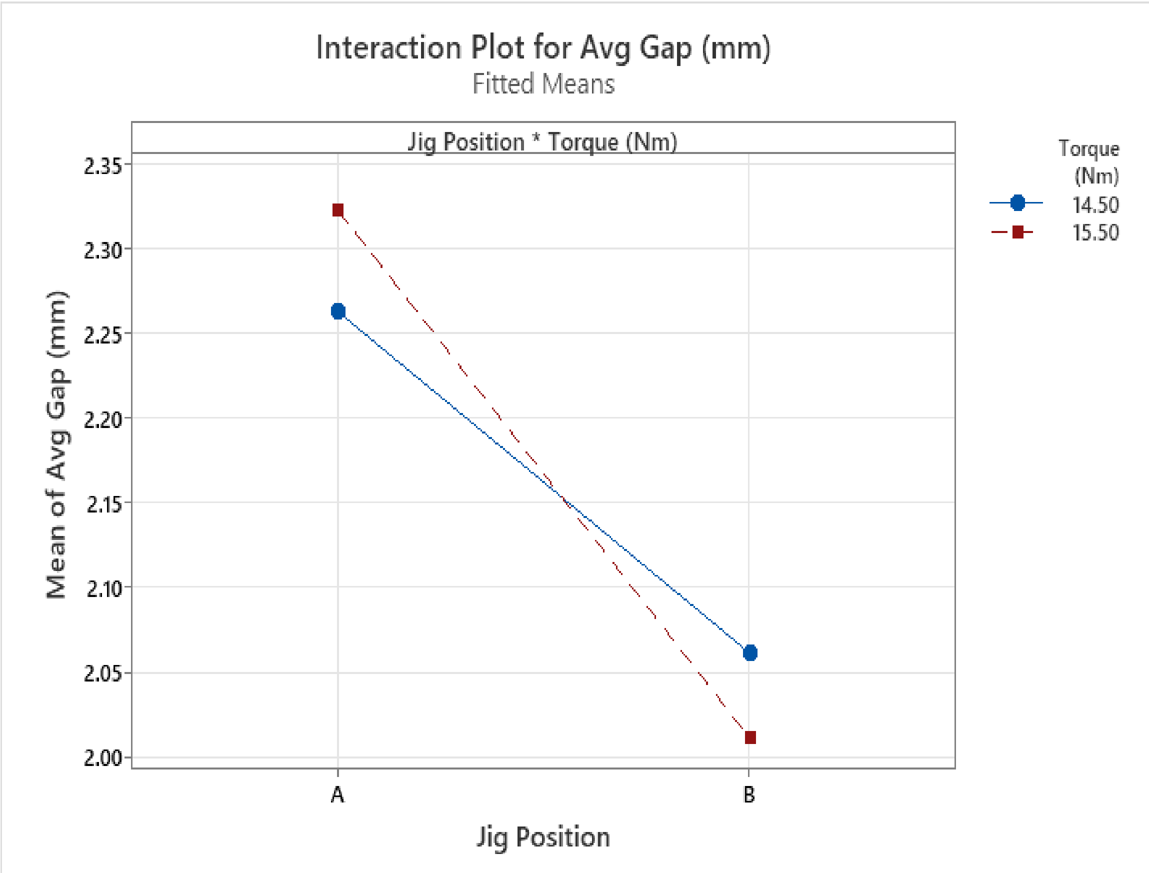

Figure 13.2 *Interaction Plot*

13.1.3 Pareto Chart of Standardized Effects

- Jig Position (Factor A) had the largest effect on gap, but did not exceed the statistical significance threshold ($\alpha = 0.05$, critical value = 4.303).
- Torque (Factor B) and the interaction term (AB) were negligible.

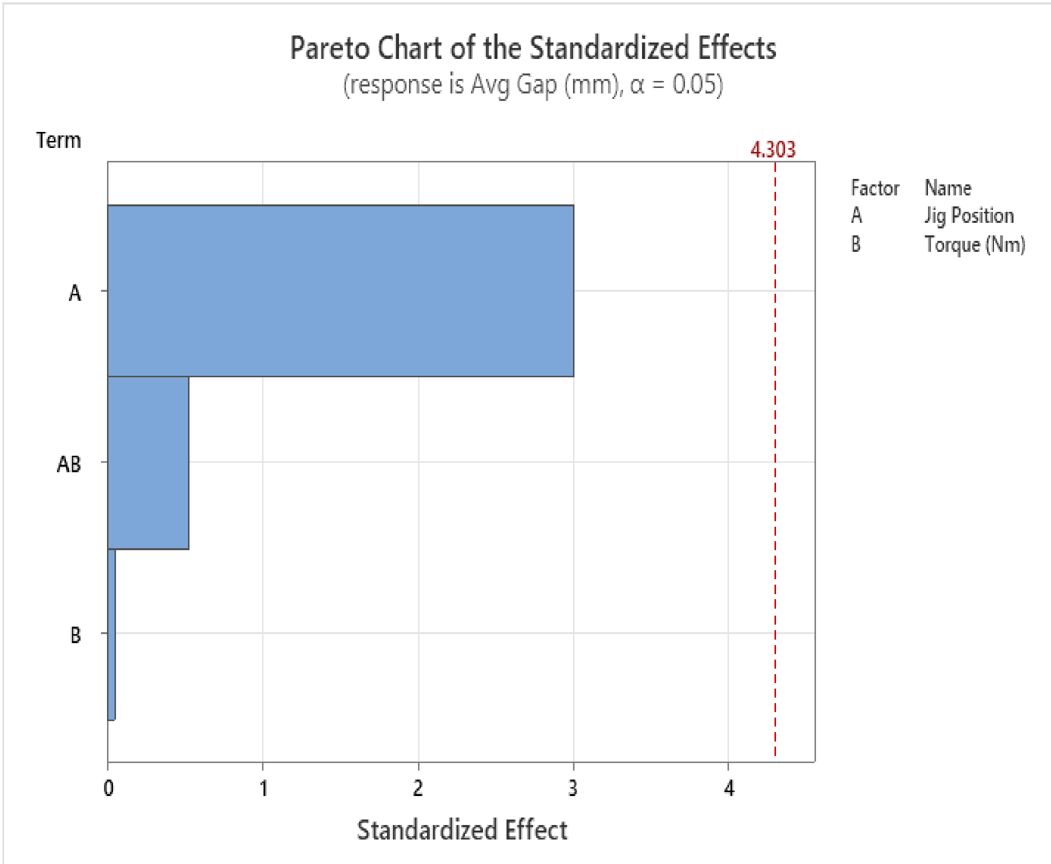

Figure 13.3 *Pareto Chart of Standardized Effects*

13.2 Statistical Analysis

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	3	0.101867	0.033956	3.10	0.253
Linear	2	0.098842	0.049421	4.52	0.181
Jig Position	1	0.098817	0.098817	9.03	0.095
Torque (Nm)	1	0.000025	0.000025	0.00	0.966
2-Way Interactions	1	0.003025	0.003025	0.28	0.652
Jig Position*Torque (Nm)	1	0.003025	0.003025	0.28	0.652
Error	2	0.021883	0.010942		
Total	5	0.123750			

Figure 13.4 *Analysis of variance (ANOVA) results for the effects of jig position and torque in the DOE*

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.104602	82.32%	55.79%	0.00%

Figure 13.5 *Model summary showing R^2, adjusted R^2, predicted R^2, and model adequacy metrics for the DOE model based on jig position and torque*

Regression Equation in Uncoded Units

Avg Gap (mm) = 2.09 + 0.70 Jig Position + 0.005 Torque (Nm) - 0.055 Jig Position*Torque (Nm)

Figure 13.6 *Regression equation in uncoded units for predicting the response variable based on jig position and torque in the DOE*

Interpretation:

- Jig Position was the most influential factor, with Position B producing lower gaps.
- Torque had a negligible effect within the tested range.
- The interaction between Jig Position and Torque was minimal.
- Statistical significance was limited by small sample size ($p = 0.095$ for Jig Position).

Optimal Settings & Recommendations

- Jig Position: B
- Torque Setting: 15.0 Nm
  Adopting these settings could reduce fitment-related rework by ~20% and improve overall panel alignment quality.

14. Recommendations

Based on the statistical analysis, MSA, DOE, and root cause findings, the following actions are recommended to reduce rework in door panel assembly:

Optimize Assembly Parameters:

- Implement Jig Position B and the torque setting of 15.0 Nm for door panel installation to minimize fitment gaps.

Improve Measurement Reliability:

- Continue periodic Gage R&R studies to maintain measurement system repeatability and reproducibility within acceptable limits (<10% GRR).

Reduce Surface Defects:

- Introduce protective padding on jigs and fixtures to prevent scratches during panel handling.
- Review material handling processes to reduce accidental contact damage.

Standardize Work Instructions:

- Update SOPs to reflect optimized settings.
- Conduct targeted operator training focusing on alignment techniques and torque application.

Implement Process Controls:

- Apply in-line inspection for early detection of fitment deviations.
- Use control charts (U-charts) for ongoing defect monitoring.

Integrate with PPAP Requirements:

- Include optimized process parameters and updated control plans in PPAP documentation for customer approval.

15. Validation & Sustainability Plan

Validation:

- Conduct a follow-up Process Capability Analysis after implementing optimized settings.
- Target: Achieve $Cp \geq 1.33$ and $Cpk \geq 1.33$ for fitment gap measurements.
- Monitor rework rate trends for three consecutive months to confirm consistent improvement.

Sustainability:

- Ongoing Monitoring – Maintain monthly U-chart reviews to detect early process shifts.
- Preventive Maintenance – Calibrate torque tools and inspect jigs regularly to maintain settings.
- Training Refreshers – Conduct quarterly skill audits and refresher training for operators.
- FMEA Updates – Review and update FMEA every six months or after any major process change.
- Audit Integration – Include door panel assembly checks in internal quality audits per IATF 16949 requirements.

16. Conclusion & Future Scope

Conclusion:

This project applied data-driven quality improvement techniques to address high rework rates in door panel assembly.

- MSA confirmed the measurement system was suitable for analysis.
- Pareto Analysis identified fitment gaps, scratches, and misalignment as top contributors to rework.
- Capability Analysis ($Cp = 1.16$, $Cpk = 0.77$) revealed the process was not capable, with centering issues as a major concern.
- DOE demonstrated that Jig Position B combined with a torque setting of 15.0 Nm, minimized fitment gaps.

Implementing the recommended changes is expected to reduce fitment-related rework by approximately 20%, improve process capability, and align with OEM quality standards.

Future Scope:

- Automation of Gap Measurement – Use laser-based gap and flush measurement systems for higher precision.
- Expanded DOE Studies – Include additional factors such as operator skill, ambient temperature, and panel supplier variation.
- Poka-Yoke Devices – Integrate error-proofing systems to prevent incorrect jig positioning.
- Digital Process Control – Implement real-time SPC dashboards for immediate corrective actions.