Pitt Manufacturing Vehicle Body Side Assembly Quality Improvement

November 30th , 2023

Chang Wang
Shumiao Xie
Chenzhe Wang
University of Michigan

Executive Overview

- **Problem Statement**

  Pitt faces a critical challenge in meeting the stringent quality standards that they need to achieve Ppk greater than 1.33 for all critical assembly dimensions to comply with the quality standards set by PPAP. Historically, PM has taken one year to meet PPAP criteria resulting additional quality control processes and an estimated annual cost of $ 545,500.
- **Current Performance Level**

  6 of the 12 assembly dimensions have Ppk less than 1.33.
- **Target Performance Level**

  All critical assembly dimensions have Ppk greater than 1.33.
- **Approaches and Findings**

  The team measures the current performance level based on a observational study of 30 samples. Using methods such as regression analysis, GLM, DOE, they narrow the causes and proposed 4 recommendations
- **Recommended Solutions**
  - Modify assembly control factor B and C
  - Change Process Setting tonnage to 946
  - Rework die on A-pillar location 1 and 4

Define Phase

Problem Statement

Recently, Pitt Manufacturing (PM) faces a critical challenge in meeting the stringent quality standards outlined in the newly awarded contract for supplying a body side assembly for a new vehicle. The contract specifies the need to achieve a Process Performance Index (Ppk) greater than 1.33 for all critical assembly dimensions to comply with the quality standards set by Production Part Approval Process (PPAP). Historically, PM has taken one year to meet PPAP criteria resulting additional quality control processes and an estimated annual cost of $ 545,500.

Scope

This project will focus on the improvement on body side assembly dimensions. Though body side assembly includes multiple components, in this study, we only focus on 4 key elements: Body side outer panel, A-pillar reinforcement panel, Windshield Frame reinforcement panel, and B-pillar reinforcement panel. Among the 4 elements, we also explore the stamping process effect to the body side outer panel.

Improvement Goal

Produce body side assemblies where all critical dimensions meet Ppk > 1.33.

D M A I C

Potential Projected Savings for Meeting PPAP

By eliminating the cost of die rework and lost revenue for not meeting PPAP standard, we might save **$545,000** in total.

Table.1 Historical Cost for Not Meeting PPAP

Tooling Item	Investment Cost	90% Payment	Remaining 10% Payment	Annualized Tooling Carrying Cost on Remaining 10% for not Obtaining PPAP (assume i=5%)	Historical Tooling Rework Cost*
Body Side Outer Stamping Panel Dies	920,000	828,000	92,000	4,600	76,800
A-pillar reinforcement stamping dies	310,000	279,000	31,000	1,550	24,000
B-pillar reinforcement dies	325,000	292,500	32,500	1,625	28,200
Windshield Frame reinforcement dies	280,000	252,000	28,000	1,400	22,800
Assembly Tooling	505,000	454,500	50,500	2,525	43,600
			Total	11,700	195,400

Final Body Side Assembly Unit Cost	$28.20
Projected Annual Volume	120,000
Annual Lost Revenue for Non-PPAP Parts	338,400
Total Projected Cost to Meet PPAP (for rework/resolving quality issues)	**545,500**

Measure Phase:
Current Process- Flow Chart

Stamping the BS

⇩

Weld A to BS

⇩

Weld W to BS

⇩

Weld B to BS

⇩

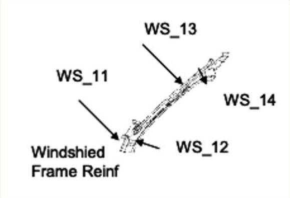
Check all critical *assembly* dimensions achieve a Ppk ≥ 1.33

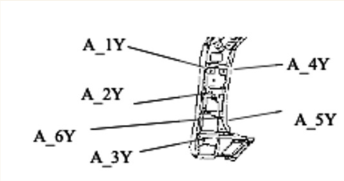
⇨

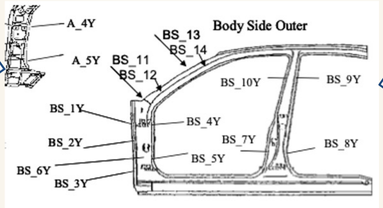
All achieve a Ppk ≥ 1.33

Yes ⇧ Finish a body side assembly

No ⇨ Detect whether the issue arises in the stamping step or during assembly







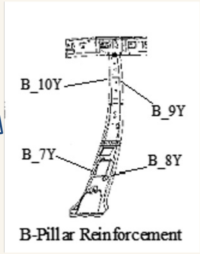


Figure.1 Major Body Side Assembly

A: A-pillar reinforcement panel

B: B-pillar reinforcement panel

W: Windshield Frame reinforcement panel

BS: Body side outer panel

D M A I C

Measure Phase:
Current State Performance – KPI

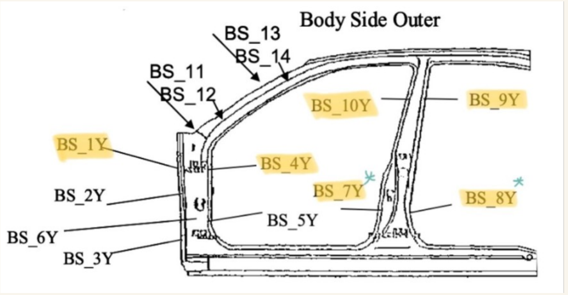


Figure.2 Body Side Assembly (ASM) Dimension not Meeting PPAP Criteria

Ppk value is the KPI:

Failing dimension(Ppk<1.33):

ASM_1Y, ASM_4Y, ASM_7Y, ASM_8Y, ASM_9Y, ASM_10Y

(Marked in red in table.1 yellow in figure.2)

Table.2 Current State Statistical Summary

	ASM_1Y	ASM_2Y	ASM_3Y	ASM_4Y	ASM_5Y	ASM_6Y	ASM_7Y	ASM_8Y	ASM_9Y	ASM_10Y	ASM_11Y	ASM_12Y
Mean	0.757	0.248	0.009	0.709	-0.330	-0.284	0.608	0.413	0.521	0.395	0.074	-0.249
St Deviation	0.106	0.129	0.114	0.106	0.144	0.159	0.412	0.425	0.178	0.190	0.137	0.133
Pp	3.157	2.588	2.918	3.135	2.318	2.094	0.809	0.784	1.868	1.757	2.440	2.513
Ppk	**0.766**	1.946	2.893	**0.913**	1.553	1.499	**0.317**	**0.460**	**0.894**	**1.062**	2.259	1.887

D M A I C

Measure Phase:
Current State Performance - ASM Dimension Defects

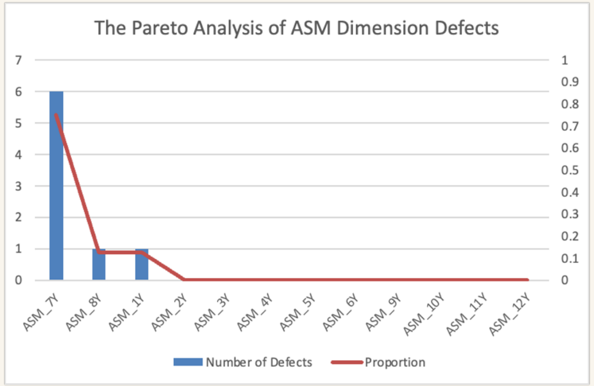


Figure.3 Pareto Analysis of ASM Dimension Defects

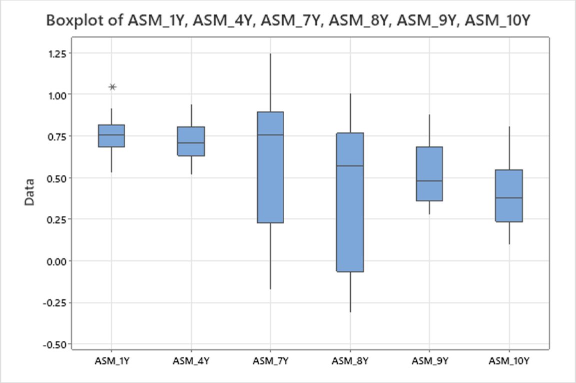


Figure.4 Box Plot of ASM Dimension not Meeting PPAP Criteria

- Based on the Pareto analysis (Figure.3) of ASM dimension defects, which are the ASMs do not fit into the tolerance (0+/-1.0 mm), ASM_7Y and ASM_8Y account for the majority of defects.

- Through Figure.3, ASM_7Y and ASM_8Y have a much wider range than other failing ASM dimensions.

Therefore, in later analysis, ASM_7Y and ASM_8Y are of high significance.

Measure Phase:
Current Process – Process Capability Analysis

Table.2 Assembly Problem Summary

ASM Dimension	Assembly Problem
ASM_1Y	Mean off Target
ASM_4Y	Mean off Target
ASM_7Y	Mean off Target & Special Cause
ASM_8Y	Mean off Target & Special Cause
ASM_9Y	Mean off Target
ASM_10Y	Mean off Target

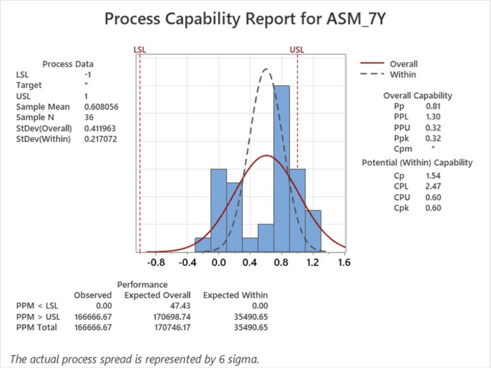


Figure.5 Process Capability Report of ASM_7Y

Fig.5 and 6 are examples for Process Capability Analysis

ASM_1Y follows a normal distribution:

- Ppk<<Pp (mean issue)
- Pp >1.33 (mean off Target)

ASM_7Y & ASM_8Y follows bimodal distributions:

- Ppk<<Pp (mean issue)
- Cp > Pp (mean off target and special cause)

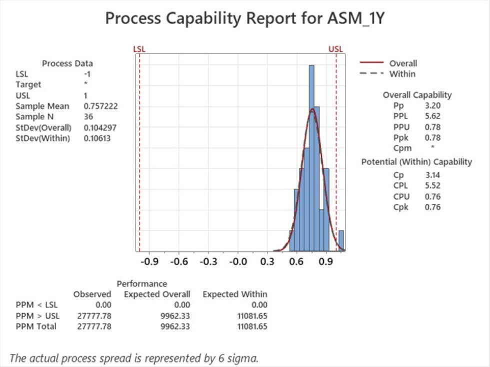


Figure.6 Process Capability Report of ASM_1Y

Measure Phase:
Current Process – Process Stability Analysis

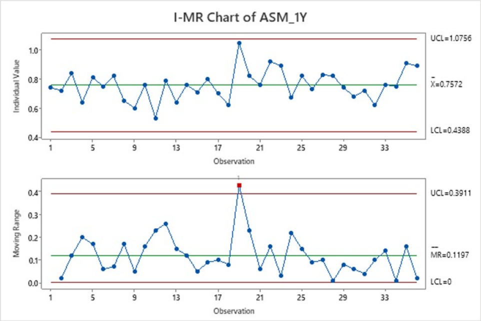


Figure.7 I-MR chart of ASM_1Y

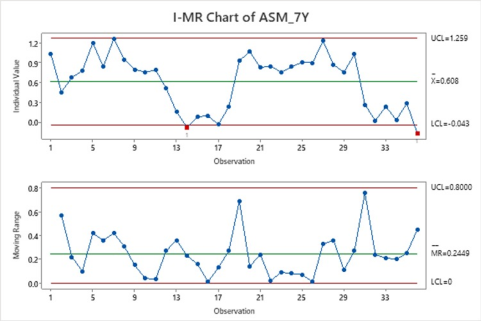


Figure.8 I-MR chart of ASM_7Y

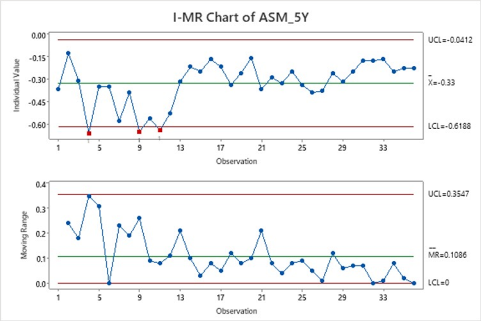


Figure.9 II-MR chart of ASM_5Y

Among all the failing assembly dimensions, ASM_1Y, ASM_7Y, and ASM_8Y are out of control. Also, there is a clear mean shift in ASM_7Y and ASM_8Y. (Details in Appendix)

For the non-failing assembly dimensions, ASM_5Y and ASM_6Y are also out of control with a clear mean shift.

D M A I C

Analyze Phase– (Qualitative) Root Cause Tree

We first list all the potential causes for failing assembly dimensions. Measurement System is not involved since it meets Gage R&R standards. We will go through each potential causes.

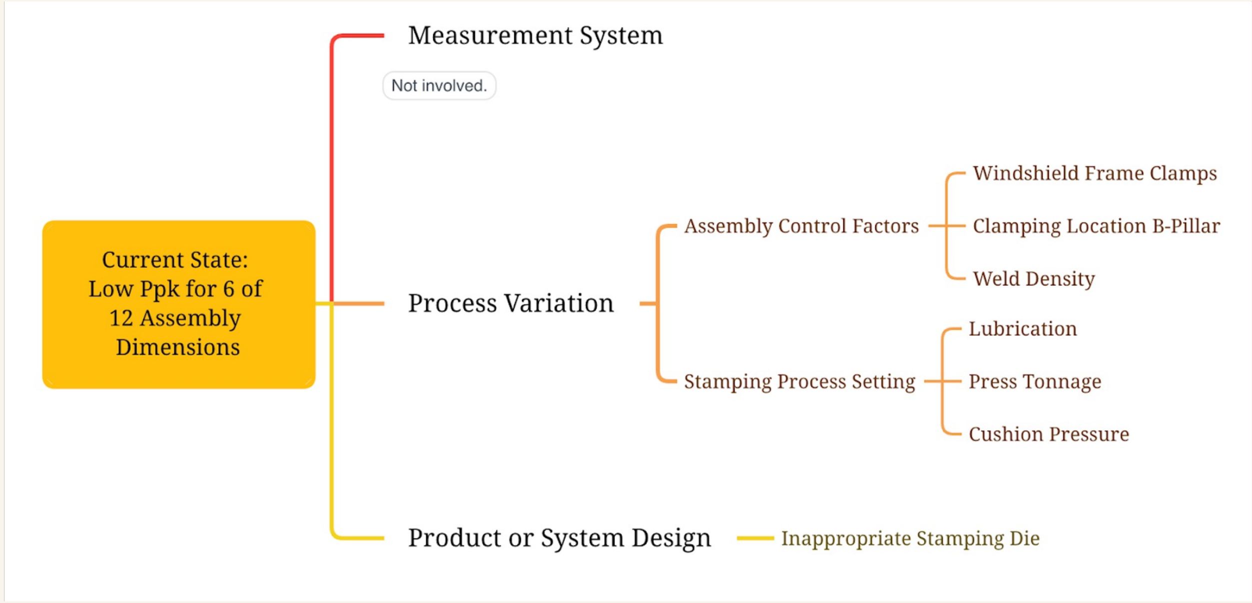


Figure. 10. Root Cause Tree

Analyze Phase - (Quantitative) Correlation Matrix

In body side assembly dimensions:

- ASM_7Y and ASM_8Y are positively correlated(0.952).
- No significant correlation between other dimensions.

In body side outer dimensions:

- Correlated Group 1: BS_1Y, BS_3Y, BS_11Y, BS_12Y
- Correlated Group 2: BS_7Y, BS_8Y

In other reinforcements dimensions:

- No further experiment on other reinforcements dimensions

- Dimension within the correlated group are positively correlated.
- Correlations of dimension between Group 1 and 2 are negative.

Table.3 Correlation Table of Body Side Dimensions

Dimension 1	Dimension 2	Correlation
BS_1Y	BS_3Y	0.956
BS_1Y	BS_7Y	-0.75
BS_1Y	BS_8Y	-0.744
BS_1Y	BS_11Y	0.75
BS_1Y	BS_12Y	0.833
BS_3Y	BS_7Y	-0.778
BS_3Y	BS_8Y	-0.777
BS_3Y	BS_11Y	0.764
BS_3Y	BS_12Y	0.853
BS_7Y	BS_8Y	0.973
BS_7Y	BS_11Y	-0.836
BS_7Y	BS_12Y	-0.912
BS_8Y	BS_11Y	-0.813
BS_8Y	BS_12Y	-0.915
BS_11Y	BS_12Y	0.838

D M A I C

Note: For simplicity, BS_1Y and BS_7Y will be used as examples for illustration.

Analyze Phase - (Quantitative) Assembly Dimensions vs. Components Dimensions

Stepwise Linear Regression

- To understand the relationship between the assembly dimensions with the component dimensions, we performed 12 linear regressions for each dimension, respectively.
- Only **4** of the ASMs have strong linear relationships with the components.
- Only ASM7 and ASM8 have linear relationship with Body Side Panel

1. $\text{ASM\_1Y}=-0.482 + 1.775\ \text{A\_1Y}$
2. $\text{ASM\_4Y}=-0.0757 + 1.130\ \text{A\_4Y}$
3. $\text{ASM\_7Y} = -0.4076 + 1.0078\ \text{BS\_7Y} + 0.993\ \text{B\_7Y}$ (Rsq = 98.21% ; p-value = 0)
4. $\text{ASM\_8Y} = 0.1002 + 0.9838\ \text{BS\_8Y} + 1.052\ \text{B\_8Y}$ (Rsq = 98.02%; p-value =0)

Analyze Phase – (Quantitative) Assembly DOE

The team conduct a 2^3 full factorial experiment. They identify 3 potential assembly factors: A-Windshield Clamp Location, B-Pillar Clamp Location, and C-Weld density.

Input Variable	Level 1 (code = -1)	Level 2 (code = 1)
Windshield Frame Clamps	Use Existing	Add 2 Clamps
Clamping Location B-Pillar	Location 1	Location 2
Weld density (weld per *X* inches)	1.0	1.33

Table.4 DOE Factor Levels

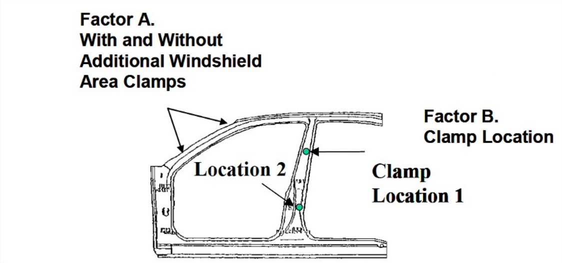


Figure.11 Alternatives for Clamp Location

The team will then perform factorial analysis to determine significant main effects and possibly interaction between either of the two clamp location and the weld density.

Analyze Phase – (Quantitative)
Factorial Analysis for Assembly DOE

- Only 4 assembly dimensions have statistically significant factors, and those are ASM3, ASM4, ASM9, and ASM10.
- ASM3 already has Ppk >1.33, we don't need to do any further analysis. Focus on the remaining three.

Factorial Analysis Result (Details in Appendix)

Assembly Dimension	Factor	p-value	Linear Regression
ASM1	A	0.032	ASM1=0.7413 + 0.0425 A
ASM7	Blocks	0.000	-
ASM8	Blocks	0.000	-
ASM9	B	0.000	ASM9=0.3156+ 0.2556 B
ASM10	B, C	0.00, 0.012	ASM10=0.2544 + 0.1569 B - 0.0569 C

Table.5 Factorial Analysis Result

Assumed Alpha = 0.05

A: Windshield Clamp Location

B: Pillar Clamp Location

C: Weld Density

Analyze Phase – (Quantitative)
Stamping Process Settings

Apply **General Linear Model** to explore the relationship between Body Side Component and the three stamping process settings: Pressure, Tonnage, and lubrication.

Stepwise Selection of Terms

Candidate terms: Pressure, Tonnage, Lubrication

------Step 1-----

	Coef	P
Constant	-7.84	
Tonnage	0.00852	0.000
S		0.106833
R-sq		61.73%
R-sq(adj)		60.60%
R-sq(pred)		57.50%
Mallows' Cp		2.90
AICc		-54.17
BIC		-50.17

α to enter = 0.05, α to remove = 0.05

Figure.12 GLM for BS1

Stepwise Selection of Terms

Candidate terms: Pressure, Tonnage, Lubrication

------Step 1------

	Coef	P
Constant	21.66	
Tonnage	-0.02254	0.000
S		0.142849
R-sq		86.34%
R-sq(adj)		85.94%
R-sq(pred)		84.84%
Mallows' Cp		2.15
AICc		-33.25
BIC		-29.25

α to enter = 0.05, α to remove = 0.05

Figure.13 GLM for BS7

Stepwise Selection of Terms

Candidate terms: Pressure, Tonnage, Lubrication

------Step 1------

	Coef	P
Constant	22.02	
Tonnage	-0.02347	0.000
S		0.162879
R-sq		84.05%
R-sq(adj)		83.58%
R-sq(pred)		82.27%
Mallows' Cp		0.91
AICc		-23.81
BIC		-19.81

α to enter = 0.05, α to remove = 0.05

Figure.14 GLM for BS8

Stepwise Selection of Terms

Candidate terms: Pressure, Tonnage, Lubrication

-------Step 1-------

	Coef	P
Constant	2.234	
Tonnage	-0.002006	0.005
S		0.0616620
R-sq		21.17%
R-sq(adj)		18.86%
R-sq(pred)		13.77%
Mallows' Cp		0.29
AICc		-93.74
BIC		-89.74

α to enter = 0.05, α to remove = 0.05

Figure.15 GLM for BS9

Stepwise Selection of Terms

Candidate terms: Pressure, Tonnage, Lubrication

-----Step 1-----

	Coef	P
Constant	0.7219	
Lubrication	0.1053	0.000
S		0.148399
R-sq		34.76%
R-sq(adj)		32.84%
R-sq(pred)		26.86%
Mallows' Cp		1.29
AICc		-30.51
BIC		-26.51

α to enter = 0.05, α to remove = 0.05

Figure.16 GLM for BS10

- Tonnage is statistically significant to ASM1, ASM7, ASM8, and ASM9.
- Lubrication is statistically significant to ASM10.
- No clear significance shown in pressure settings.

D M A I C

Analyze Phase – (Quantitative) Stamping Process Settings

Body side component at Location 10 is closer to nominal when applying Lubrication B during the stamping process(Figure 17). However, BS10 is not significant to ASM10 according to our previous linear regression model, which means improving BS10 won't enhance ASM10.

Besides, extra $10,000 annually cost will applied if using Type B lubrication. Thus, we should use Type A lubrication during stamping process.

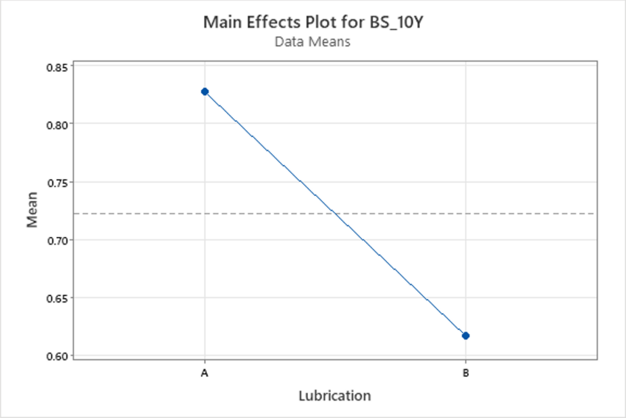
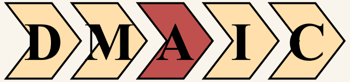


Figure.17 Main Effect Plot for BS10 on Lubrication



Analyze Phase Findings-Summary

Analyzing through 3 studies, we get the result as shown in the table below. ASM7 and AMS8 could be adjust by changing the tonnage level on BS panels as they are significant to ASM7 and ASM8 respectively. Besides, we can adjust control factor B and C to improve the Ppk value of ASM9 and ASM10.

Dimension	Slow_build _study	Stamping Setting	Assembly Control Factor
ASM_1Y	**A-Pillar**	**Tonnage**	**A-**
	ASM_1Y=-0.482 + 1.775 A_1Y	BS_1Y=-7.84 + 0.00852 Tonnage	ASM-LTP-1=0.7413 + 0.0425 A
ASM_4Y	**A-Pillar**	-	-
	ASM_4Y=-0.0757 + 1.130 A_4Y		
ASM_7Y	**Body Side Outer, B-Pillar**	**Tonnage**	**Blocking Variable**
	ASM_7Y=-0.4076 + 1.0078 BS_7Y + 0.993 B_7Y	BS_7Y=21.66 - 0.02254 Tonnage	
ASM_8Y	**Body Side Outer, B-Pillar**	**Tonnage**	**Blocking Variable**
	ASM_8Y=0.1002 + 0.9838 BS_8Y + 1.052 B_8Y	BS_8Y=22.02 - 0.02347 Tonnage	
ASM_9Y	-	**Tonnage**	**B**
		BS_9Y=2.234 - 0.002006 Tonnage	ASM-LTP-9=0.3156+ 0.2556 B
ASM_10Y	-	**Lubrication**	**B, C**
			ASM-LTP-10=0.2544 + 0.1569 B - 0.0569 C

Table.6 Assembly Dimension and its Significant Factors

A: Windshield Clamp Location
B: Pillar Clamp Location
C: Weld Density

DMAIC

Improve Phase

- To ensure that all dimensions meet the PPAP requirements, the following actions are recommended:
  - Set Tonnage value to 946 at Stamping process to improve ASM7 and ASM8.
  - Apply lubrication A to all stamping process
  - Set B-pillar clamping location to Location 1 to improve ASM9 and ASM10.
  - Set C-Weld Density to 1.33 to improve ASM10.
  - Rework A-pillar reinforcement die to improve ASM1 and ASM4.

DMAIC

Improve Phase ：
Verification - Stamping Process Setting

Applied to all body side outer panel dimensions:

Set tonnage amount to 946. *(Example BS_7Y)*

Modified previous regression analysis of ASM_7Y v.s. BS_7Y & B_7Y.

As B_7Y cannot be simply improved by current study, estimate ASM_7Y by only BS_7Y and the new model has a good performance. (R-sq=94.80%)

From the result of response optimization of the new linear regression, targeting BS_7Y=0.3219 in response optimization of the stamping process setting GLM.

>> Tonnage amount = 946

Solution

Solution	BS_7Y	ASM_7Y Fit	Composite Desirability
1	0.321946	0	1

Figure.18 Response Optimization of Regression Analysis of BS_7Y

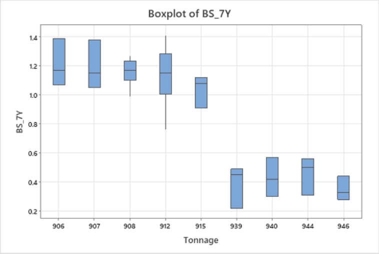


Figure.19 Boxplot of BS_7Y

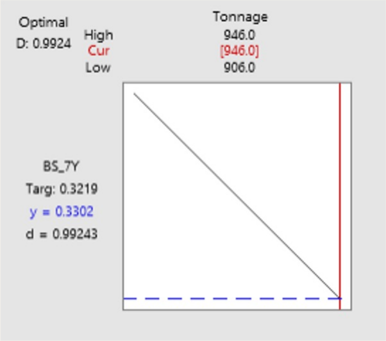


Figure.20 Response Optimization of GLM of BS_7Y

D M A I C

Improve Phase：
Verification - Stamping Process Setting

Applied to all body side outer panel dimensions:

Use lubrication type A.

Lubrication type is only significant for ASM_10Y, which lubrication type B will lead to a better BS_10Y dimension (closer to 0). However, we cannot conclude how will BS_10Y influence the ASM_10Y dimension based on the regression result. Therefore, from the cost effectiveness perspective, the cheaper lubricant A is recommended.

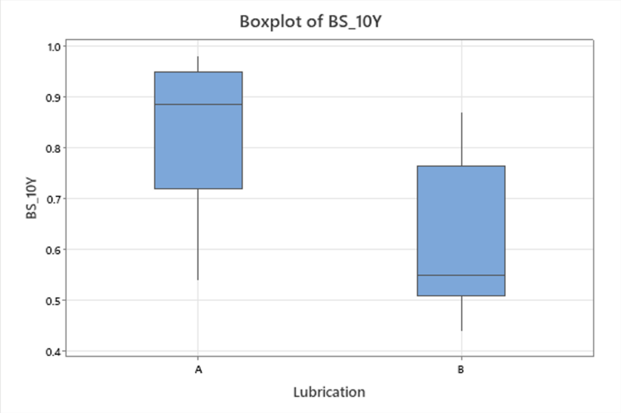
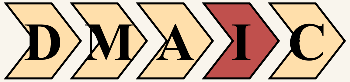


Figure.21 Boxplot of BS_10Y



Improve Phase ：
Verifications - Assembly Control Factors

Using the response optimizer of factorial analysis:

For ASM_9Y:

Using clamping B-pillar location 1 (coded -1) will lead to a better ASM_9Y dimension.

For ASM_10Y:

Using clamping B-pillar location 1 (coded -1) and welding density of 1.33 will lead to a better ASM_10Y dimension.

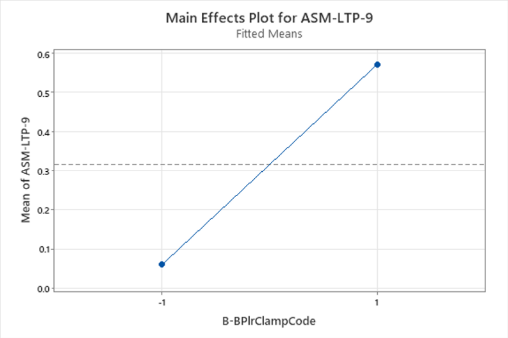


Figure.22 Main Effects Plot of ASM_9Y

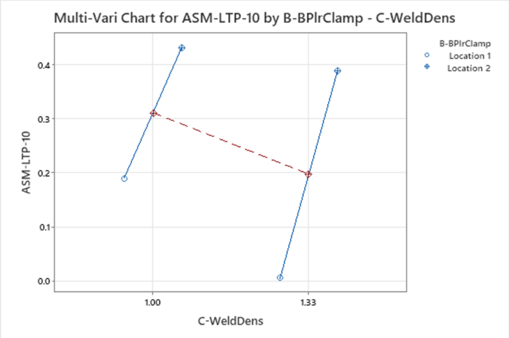


Figure.23 Multi-vari Chart of ASM_10Y

D M A I C

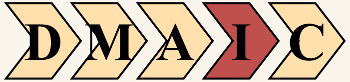
Improve Phase ：
Verifications - A-pillar Die Rework

For ASM_1Y:

From the regression analysis of ASM_1Y v.s. BS_1Y and A_1Y, BS_1Y is not significant, and thus trying to improve ASM_1Y by improving body side panel stamping process isn't necessary. Although from DOE study of assembly factors, it shows that using the existing windshield frame clamps make ASM_1Y dimension get closer to zero. But this result doesn't make Ppk (Ppk=1.25) greater than 1.33. The team will not improve ASM_1Y through this aspect.

For ASM_4Y:

Only A_4Y is significant when predicting ASM_4Y, and no significant factor in stamping settings and assembly process influencing both BS_4Y and ASM_4Y.



Improve Phase ：
Verifications - A-pillar Die Rework

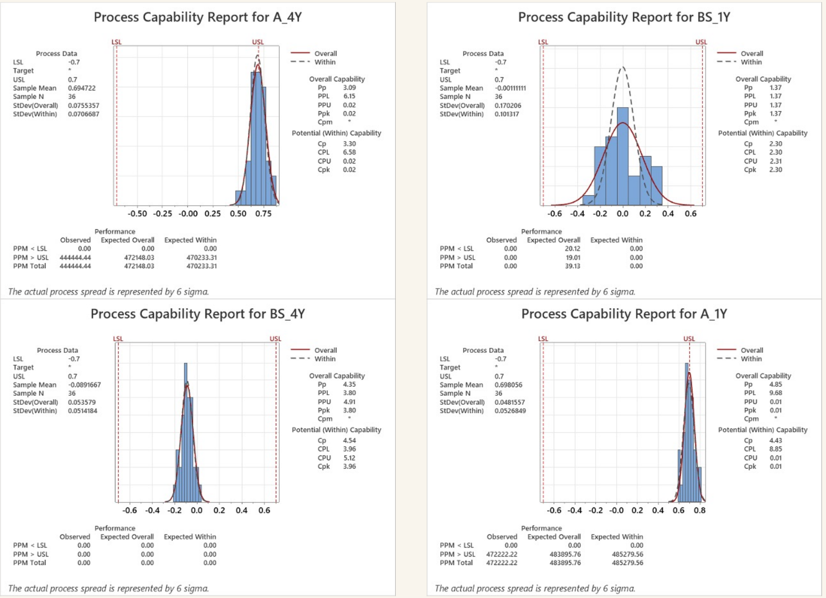


Figure.24 Capability Analysis of A_1Y, BS_1Y, A_4Y, BS_4Y

There is a clear mean-off-target problem shown in A_1Y and A_4Y.

Therefore, the team choose to rework A-pillar reinforcement panel die, rather than reworking body side outer panel die as it is much more cheaper and avoiding influence other dimension of body side outer panel.

Control Phase

There are 5 ways to continuously monitor and control the production after the improvement.

- **Monitoring**: Regularly monitor the stamping process to ensure the sustainability of the improvement measures.
- **Training**: Continuously train employees to ensure they understand and follow the new processes and standards, including regular calibration and regular maintenance.
- **Feedback**: Establish a feedback mechanism that allows employees to report any issues or suggestions if they encounter during stamping or assembly process
- **Re-Evaluation**: Periodically reassess the production process to ensure targets are met.
- **Continuous Improvement**: Based on new data and feedback, continuously seek opportunities for improvement.

Post DMAIC – PPAP Requirement Satisfaction

	ASM_1Y	ASM_4Y	ASM_7Y	ASM_8Y	ASM_9Y	ASM_10Y
Mean	0.00	0.00	0.33	0.01	0.06	0.04
St Deviation	0.08	0.06	0.14	0.16	0.12	0.08
Pp	4.16	5.31	2.33	2.05	2.75	4.39
Ppk	4.16	5.31	1.56	2.03	2.58	4.21

Table.7 Statistical Summary of Failing Dimensions.

All the previously failing dimensions are currently satisfy the PPAP requirements, which is Ppk greater than 1.33 after improvement.

Post DMAIC – Cost Avoidance

Total Cost Avoidance: $470,500 ($545,500-$75,000)

Savings - when meeting PPAP requirement ($545,500)

- Annualized 10% tooling carrying cost in total: $11,700
- Annual revenue loss from Non-PPAP parts: $338,400
- Historical tooling rework cost in total: $195,400

Costs - from our recommendation ($75,000)

- Rework stamping die of A-pillar: $25,000
- Assembly tool modification: $50,000

Summary

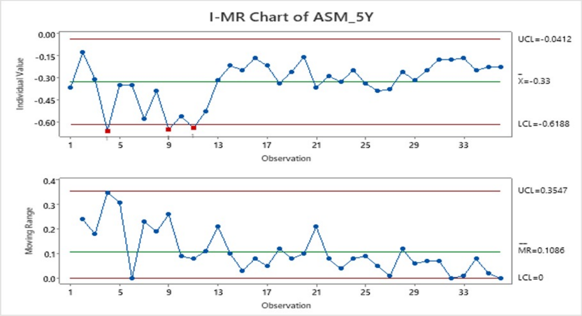
- **Problem Statement**

  Pitt faces a critical challenge in meeting the stringent quality standards that they need to achieve Ppk greater than 1.33 for all critical assembly dimensions to comply with the quality standards set by PPAP. Historically, PM has taken one year to meet PPAP criteria resulting additional quality control processes and an estimated annual cost of $ 545,500.
- **Approaches**

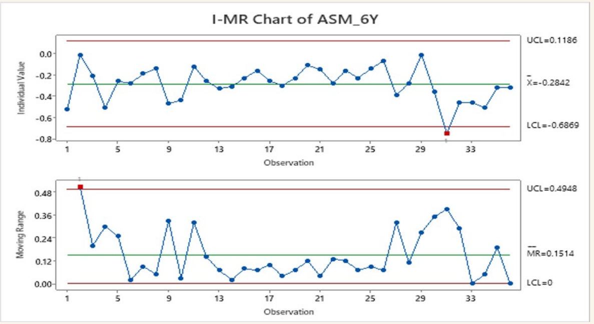
  The team measures the current performance level based on a observational study of 30 samples. They proposed several methods to improve the Ppk and they narrow down to 4 recommendations.
- **Recommended Solutions**
  - Modify assembly control factor B and C
  - Change Process Setting tonnage to 946
  - Rework die on A-pillar location 1 and 4
- **Potential Cost Avoidance**

  Avoid $470,500 of cost in total

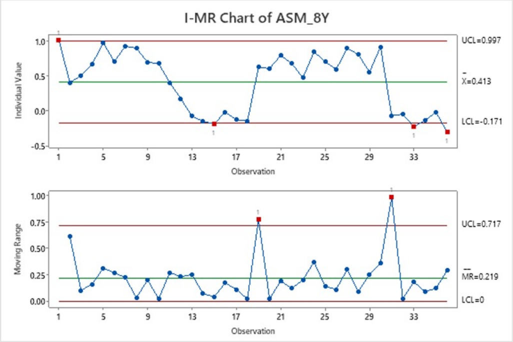
Appendix A–Process Stability Analysis



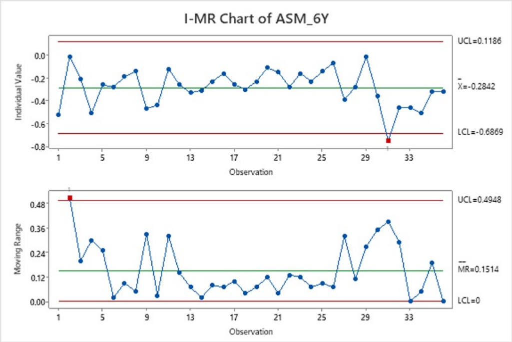
Appendix.1 I-MR chart of ASM_5Y



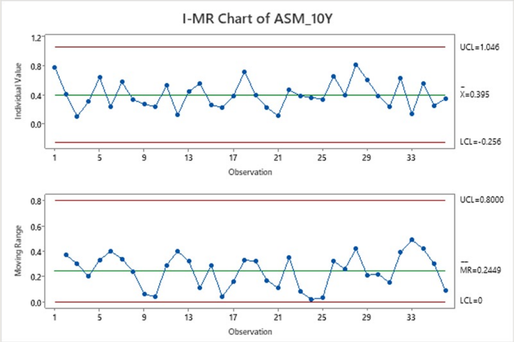
Appendix.2 I-MR chart of ASM_6Y



Appendix.3 I-MR chart of ASM_8Y

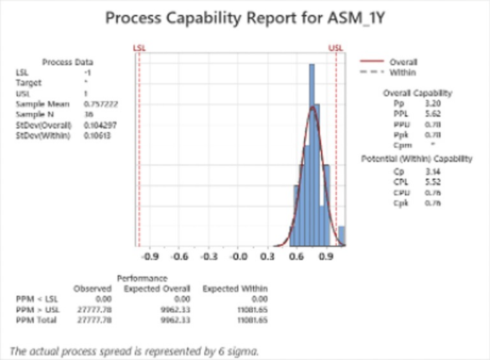


Appendix.4 I-MR chart of ASM_6Y

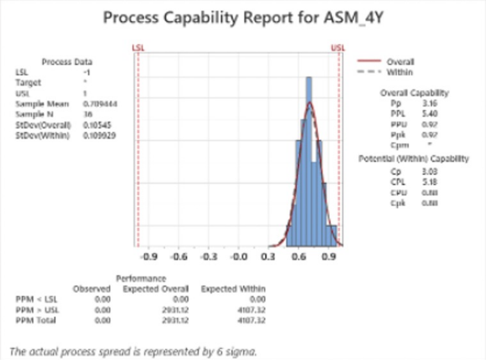


Appendix.5 I-MR chart of ASM_10Y

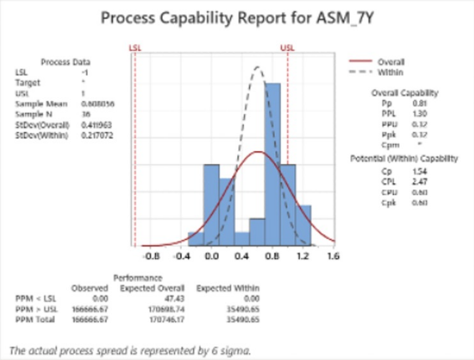
Appendix B–Process Capability Analysis



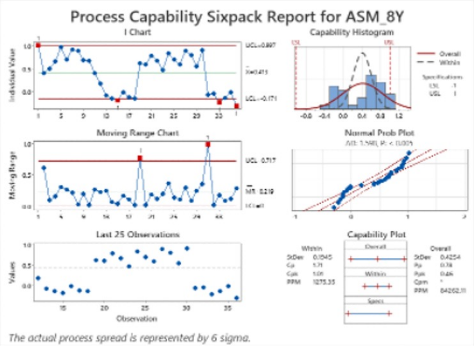
Appendix.6 Process Capability for ASM1



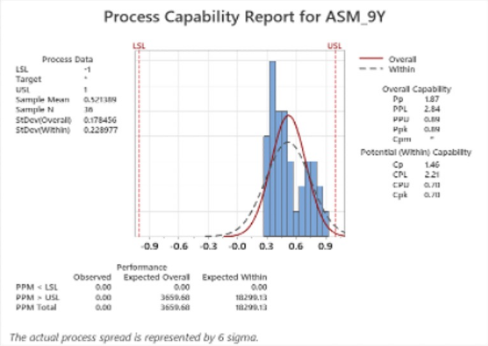
Appendix.7 Process Capability for ASM4



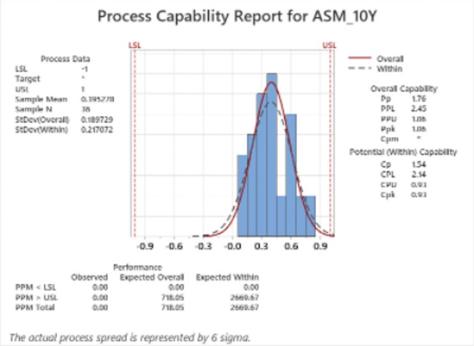
Appendix.8 Process Capability for ASM7



Appendix.9 Process Capability for ASM8



Appendix.10 Process Capability for ASM9



Appendix.11 Process Capability for ASM10

Appendix C–Factorial Analysis for Assembly DOE

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.134957	89.69%	77.92%	46.16%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	1.10970	0.13871	7.62	0.007
Blocks	1	0.00006	0.00006	0.00	0.957
Linear	3	1.08482	0.36161	19.85	0.001
A-WSClampCode	1	0.01756	0.01756	0.96	0.359
B-BPlrClampCode	1	1.04551	1.04551	57.40	0.000
C-WeldDensCode	1	0.02176	0.02176	1.19	0.311
2-Way Interactions	3	0.02432	0.00811	0.45	0.728
A-WSClampCode*B-BPlrClampCode	1	0.00076	0.00076	0.04	0.844
A-WSClampCode*C-WeldDensCode	1	0.00601	0.00601	0.33	0.584
B-BPlrClampCode*C-WeldDensCode	1	0.01756	0.01756	0.96	0.359
3-Way Interactions	1	0.00051	0.00051	0.03	0.872
A-WSClampCode*B-BPlrClampCode*C-WeldDensCode	1	0.00051	0.00051	0.03	0.872
Error	7	0.12749	0.01821		
Total	15	1.23719			

Appendix.12 Factorial Analysis on BS9

Model Summary

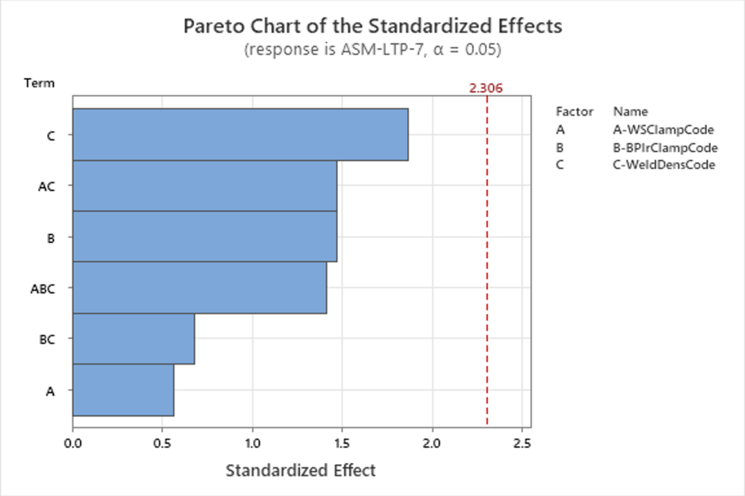
S	R-sq	R-sq(adj)	R-sq(pred)
0.0680270	93.77%	86.65%	67.45%

Analysis of Variance

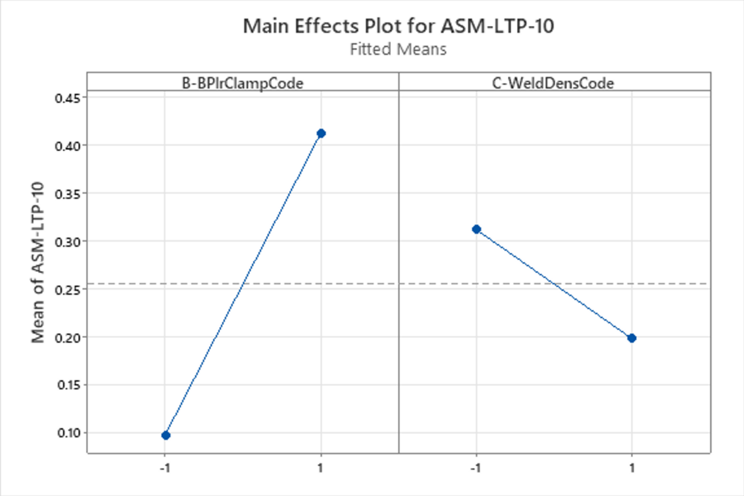
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	0.487600	0.060950	13.17	0.001
Blocks	1	0.005256	0.005256	1.14	0.322
Linear	3	0.450769	0.150256	32.47	0.000
A-WSClampCode	1	0.005256	0.005256	1.14	0.322
B-BPlrClampCode	1	0.393756	0.393756	85.09	0.000
C-WeldDensCode	1	0.051756	0.051756	11.18	0.012
2-Way Interactions	3	0.031569	0.010523	2.27	0.167
A-WSClampCode*B-BPlrClampCode	1	0.005256	0.005256	1.14	0.322
A-WSClampCode*C-WeldDensCode	1	0.006006	0.006006	1.30	0.292
B-BPlrClampCode*C-WeldDensCode	1	0.020306	0.020306	4.39	0.074
3-Way Interactions	1	0.000006	0.000006	0.00	0.972
A-WSClampCode*B-BPlrClampCode*C-WeldDensCode	1	0.000006	0.000006	0.00	0.972
Error	7	0.032394	0.004628		
Total	15	0.519994			

Appendix.13 Factorial Analysis on BS10

Appendix D - Assembly Process



Appendix.14 Pareto Chart of Assembly Effect on ASM7



Appendix.15 Main Effect plot for ASM10