



COLORADO SCHOOL OF
MINES®

Measurement & Analysis

AMFG 522 – Lean Manufacturing

Project 2

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Heat Sink

Executive Summary

The team conducted a Gage R&R study on the Heat Sink part with 6 individual operators for the first study and 10 unique parts. The first study found that the Operator*Part was a significant contributor to the variance in the Gage R&R study with a total %SV of (78.29, 85.46) for operator group 1 and 2 respectively. It is recommended that the company invests in operator training and another Gage R&R study is conducted, if problems persist it is recommended that the company invests in better measurement equipment due to the large %SV for Repeatability which had values of (53.15, 50.10). For the second study a Six pack analysis was performed on the same Heat Sink part, this time being measured in 5 locations on 21 unique parts. This second study showed similar issues with a low overall process capability Ppk value (0.32), and a high AD value (8.214) with a low p-value (<0.005).

Analysis of Variance

The heat sink part seen in Figure 1 below has been selected to be analyzed in a Gage R&R study. The 10 parts will be measured by two sets of operators measuring two separate sets of 5 parts. Operator Group 1 includes operators A, B, and C; Operator Group 2 includes operators X, Y, and Z. Operator Group 1 measures parts 1-5 while Operator Group 2 measures parts 6-10. All the measurements conducted by the operators will be in the same location on each of the parts. The specification for this part has a Lower Specification Limit of 0.077 inches and an Upper Specification Limit of 0.097. In Tables 1-3 a Two-Way ANOVA table, and a Gage R&R analysis with a Variance Components table and a Gage Evaluation table are shown for Operator Group 1.

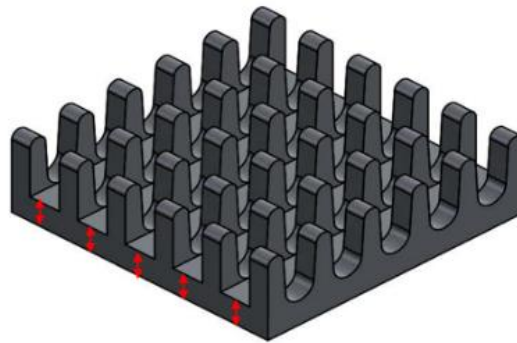


Figure 1. Heat Sink

Table 1. Two-Way ANOVA Table

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	4	0.0002508	0.0000627	1.4685	0.298
Operator	2	0.0000759	0.0000379	0.8884	0.448
Part * Operator	8	0.0003415	0.0000427	11.8481	0.000
Repeatability	60	0.0002162	0.0000036		
Total	74	0.0008844			

α to remove interaction term = 0.05

Table 2. Gage R&R Variance Components Table

Variance Components

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0000114	89.55
Repeatability	0.0000036	28.25
Reproducibility	0.0000078	61.29
Operator	0.0000000	0.00
Operator*Part	0.0000078	61.29
Part-To-Part	0.0000013	10.45
Total Variation	0.0000128	100.00

Process tolerance = 0.02

Table 3. Gage Evaluation

Gage Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.0033795	0.0202771	94.63	101.39
Repeatability	0.0018982	0.0113895	53.15	56.95
Reproducibility	0.0027960	0.0167762	78.29	83.88
Operator	0.0000000	0.0000000	0.00	0.00
Operator*Part	0.0027960	0.0167762	78.29	83.88
Part-To-Part	0.0011548	0.0069286	32.33	34.64
Total Variation	0.0035714	0.0214282	100.00	107.14

For Operator Group 2, a similar set of tables are shown below in Tables 4-6.

Table 4. Two-Way ANOVA Table

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part_1	4	0.0002573	0.0000643	1.0719	0.430
Operator_1	2	0.0000010	0.0000005	0.0087	0.991
Part_1 * Operator_1	8	0.0004801	0.0000600	15.5468	0.000
Repeatability	60	0.0002316	0.0000039		
Total	74	0.0009700			

α to remove interaction term = 0.05

Table 5. Gage R&R Variance Components Table

Variance Components

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0000151	98.13
Repeatability	0.0000039	25.10
Reproducibility	0.0000112	73.03
Operator_1	0.0000000	0.00
Operator_1*Part_1	0.0000112	73.03
Part-To-Part	0.0000003	1.87
Total Variation	0.0000154	100.00

Process tolerance = 0.02

Table 6. Gage Evaluation

Gage Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.0038846	0.0233076	99.06	116.54
Repeatability	0.0019647	0.0117881	50.10	58.94
Reproducibility	0.0033511	0.0201069	85.46	100.53
Operator_1	0.0000000	0.0000000	0.00	0.00
Operator_1*Part_1	0.0033511	0.0201069	85.46	100.53
Part-To-Part	0.0005365	0.0032190	13.68	16.10
Total Variation	0.0039215	0.0235289	100.00	117.64

For Table 1 and 4, the Part * Operator category is considered significant with a P-value of 0.000. In Tables 2 and 5 Operator * Part interaction makes up most of the variance %Contribution with values of 61.29% for Operator Group 1 and 73.03% for Operator Group 2. The Repeatability and Reproducibility %Contribution is also high while the Reproducibility values match the Operator*Part variance contribution values. The Part-To-Part variation %Contribution makes up only 10.45% and 1.87% respectively for Groups 1 and 2. For Tables 3 and 6, the Total Gage R&R %Study Var is unacceptable as both values are well above 30%, there is too much variation in each study. For Tables 3-6 the only marginal value is for Group 2, parts 5-10 with a %SV of 13.68, all other values are unacceptable.

In Figures 2 and 3 below graphs are shown for each Operator Group. The Components of Variation bar chart for both groups shows that repeatability and reproducibility were the largest contributors to the Gage R&R study. The Part * Operator Interaction chart also highlights this lack of repeatability and reproducibility. Out of the entire study it appears the operators are having a hard time measuring the parts. Operator X does appear to be able the parts well but struggled with part 8 while operators Y and Z did not. To find the root cause of this poor study and the

variance I would purpose the following actions which are to study operator X and Z, as well as investigate part 8. I recommend studying operators X and Z because they seem to have the most repeatable and reproducible results when looking at the Xbar and R charts. Also, if part 8 appears to have an issue, I would work with operator X and create training on how to perform these measurements. If part 8 doesn't have an issue I would investigate the measurement equipment as the company may not posses the correct measurement equipment.

Gage R&R (ANOVA) Report for Measurement

Gage name:
Date of study:

Reported by:
Tolerance:
Misc:

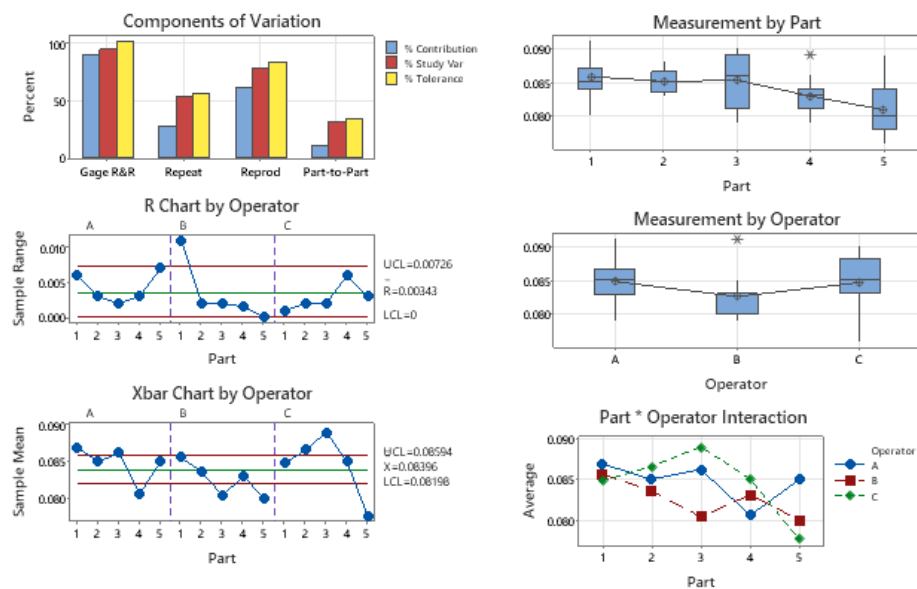


Figure 2. Operators ABC, parts 1-5

Gage R&R (ANOVA) Report for Measurement_1

Gage name:
Date of study:

Reported by:
Tolerance:
Misc:

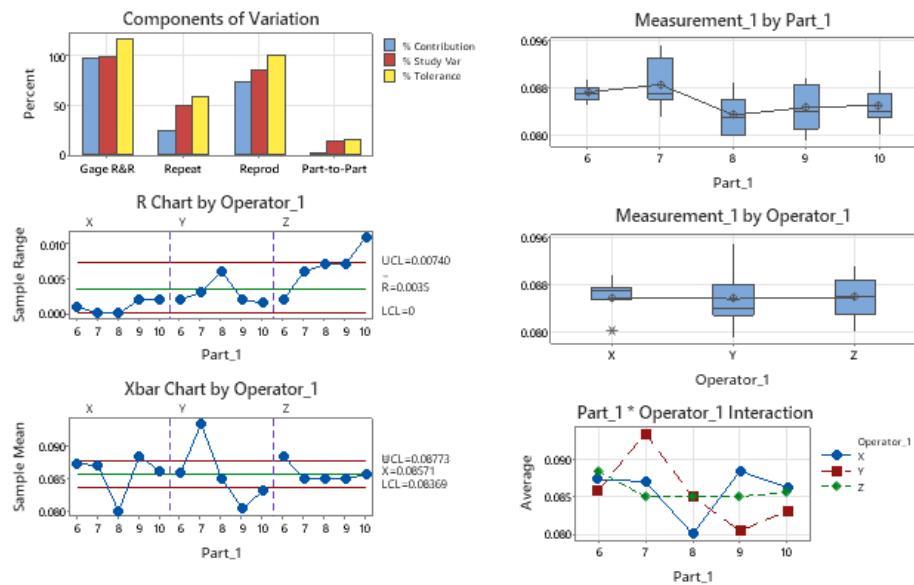


Figure 3. Operators XYZ, parts 6-10

Measurement and Process Capability

For the second part of the study, 3 of the same operators measured 21 Heat Sinks in 5 locations shown in Figure 4 below. The same tolerance values applied with a Lower Specification Limit of 0.077 inches and an Upper Specification Limit of 0.097 inches. A Process Capability Six Pack was created for these measurements shown in Figure 5 below.

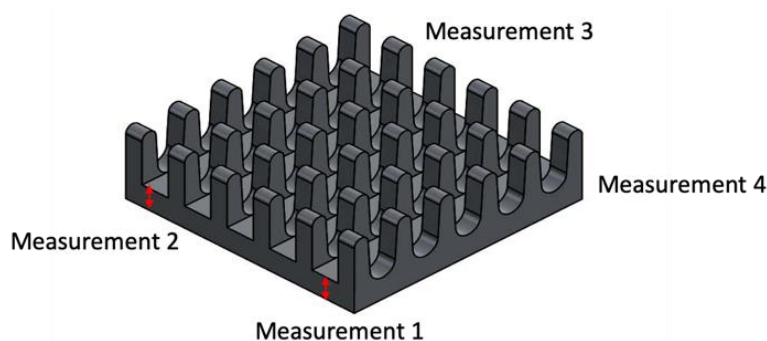
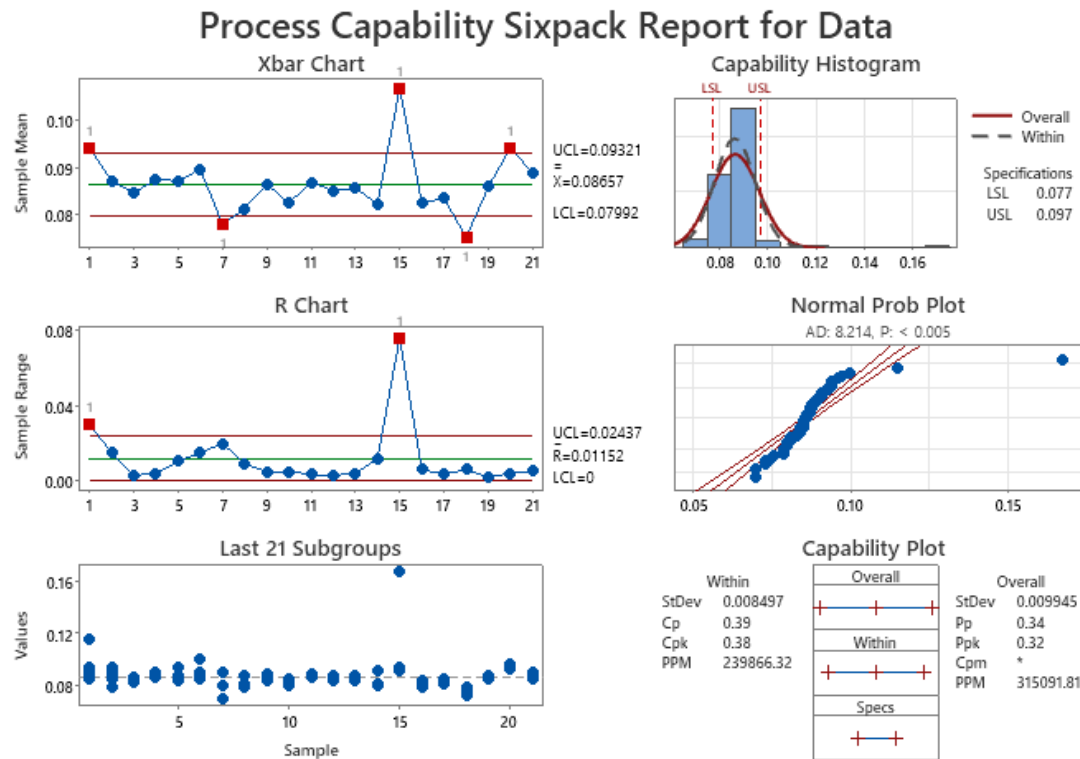


Figure 4. Heat Sink with measurement locations, measurement 5 is in the center



The actual process spread is represented by 6 sigma.

Figure 5. Six Pack Analysis

The Six Pack Analysis Xbar Chart shows an UCL of 0.093 inches which differs from the USL of 0.097 inches. The Xbar Chart also shows a LCL of 0.079 inches which also differs from the LSL of 0.077. The Xbar Chart has an $\bar{X}$ double bar of 0.08657 inches which falls within the specification limits but does not hold much value. There are multiple $\bar{X}$ double bar sample sets outside of the UCL and LCL including set 1, 7, 15, 18, and 20. For the R Chart set 1 and set 15 had values outside of the R chart's UCL. The capability histogram shows that the process is not capable with two bars outside of the LSL and USL. The AD value is high, and the P-value is less than 0.005 so the process is not normal. The Cp value is higher than the Pp value so there are some improvements that could be made to the overall process. The Cpk and Ppk values are very low and are not acceptable as they are well beneath a value of 1. The Cp and Cpk value are 0.01 apart so the process is likely centered. Again, the largest problem is the Cpk and Ppk values. Due to the multiple average of averages outside of the UCL and LCL, the operators likely need to be trained better and it is possible that better measurement equipment needs to be ordered. There could be a possibility that there are bad parts as well with lots of variability from different measurement points due to a bad manufacturing process, it is worth investigating the parts that had high ranges on the R-chart as well to pull this process into 6-sigma. Also, to bring this process into 6-sigma it is likely that the specification range would need to increase in both directions. Increasing the specification limits to .060 inches for the LSL and .114 inches for the USL gave a Cpk of 1.04 which would qualify as a 3-sigma process.

End of report 1.

Plastic Bracket

Executive Summary

The team conducted a Gage R&R and a Six Pack analysis on the length and thickness of a plastic part made in our facility. The team identified marginally acceptable Repeatability %SV (10.29, 20.57) for the length and thickness measurements. The Operator*Part %SV was very high (87.54, 95.72) which points to the operators not being able to reproduce measurements with the parts. The study also identified additional training is required for some operators with Operator B having multiple measurement errors compared to other operators. To save the company money it is likely that Operator C could lead training for measuring the length of the part, but a different operator would need to lead training for measuring the thickness. It is apparent that the specification limits should be reviewed to see if the process capability could be improved from the current Ppk for length and thickness (0.27, 0.15). The process also shows signs of not being centered or normal in distribution. It is recommended that operators are trained more and the study is performed a second time, if results are still not favorable the measurement equipment should be inspected and calibrated, if the results are still not favorable the manufacturing process and part specifications such as flatness and parallelism need to be studied.

Analysis of Variance

For this report a plastic part is studied shown below in Figure 1. The length and thickness of this part were studied in two different Gage R&R reports. The thickness portion of the part is shown below in Figure 2. The length of the plastic part had a USL of 1.56 and a LSL of 1.54 while the of the part thickness had a USL of 0.104 and a LSL of 0.096 with all dimensions being in inches. The study utilized three operators and measured 10 different parts for both length and thickness, they repeated each measurement on the part 5 times before moving to the next part. In Tables 1-3 below an Analysis of Variance (ANOVA) is shown which refers to the length portion of the study. Tables 4-6 will refer to the thickness portion of the study.

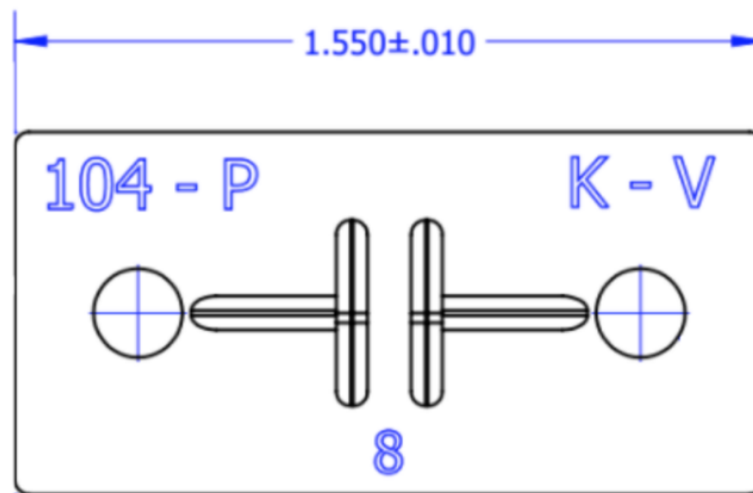


Figure 1. Top view of the plastic part with tolerance displayed

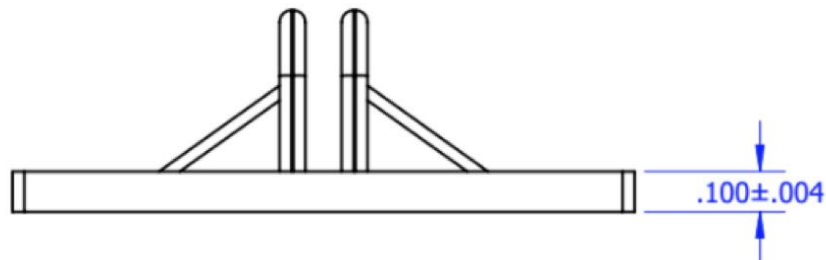


Figure 2. Side view of the plastic part with tolerance displayed

Table 1. Two-Way ANOVA Table

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	9	0.0174802	0.0019422	1.513	0.217
Operator	2	0.0056295	0.0028148	2.193	0.141
Part * Operator	18	0.0231075	0.0012837	362.726	0.000
Repeatability	120	0.0004247	0.0000035		
Total	149	0.0466419			

α to remove interaction term = 0.05

Table 2. Gage R&R Variance Components Table

Variance Components

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0002902	86.86
Repeatability	0.0000035	1.06
Reproducibility	0.0002867	85.80
Operator	0.0000306	9.16
Operator*Part	0.0002560	76.64
Part-To-Part	0.0000439	13.14
Total Variation	0.0003341	100.00

Process tolerance = 0.2

Table 3. Gage Evaluation

Gage Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.0170353	0.102212	93.20	51.11
Repeatability	0.0018813	0.011288	10.29	5.64
Reproducibility	0.0169311	0.101587	92.63	50.79
Operator	0.0055335	0.033201	30.27	16.60
Operator*Part	0.0160013	0.096008	87.54	48.00
Part-To-Part	0.0066257	0.039754	36.25	19.88
Total Variation	0.0182784	0.109671	100.00	54.84

Table 4. Two-Way ANOVA Table

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	9	0.0008666	0.0000963	1.083	0.420
Operator	2	0.0002082	0.0001041	1.171	0.333
Part * Operator	18	0.0015999	0.0000889	109.248	0.000
Repeatability	120	0.0000976	0.0000008		
Total	149	0.0027724			

α to remove interaction term = 0.05

Table 5. Gage R&R Variance Components Table

Variance Components

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0000187	97.43
Repeatability	0.0000008	4.23
Reproducibility	0.0000179	93.20
Operator	0.0000003	1.58
Operator*Part	0.0000176	91.62
Part-To-Part	0.0000005	2.57
Total Variation	0.0000192	100.00

Table 6. Gage Evaluation

Gage Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.0043281	0.0259684	98.71
Repeatability	0.0009020	0.0054120	20.57
Reproducibility	0.0042330	0.0253982	96.54
Operator	0.0005518	0.0033106	12.58
Operator*Part	0.0041969	0.0251815	95.72
Part-To-Part	0.0007027	0.0042159	16.02
Total Variation	0.0043847	0.0263084	100.00

Number of Distinct Categories = 1

Starting the analysis off with Table 1, the P-value for part and operator are both above 0.005 meaning they are not considered significant. The Part*Operator P-value is 0.000 which is significant. In Table 2 The majority of the VarComp came from Reproducibility and Operator*Part which means these are the largest contributing factors to variation in the Total Gage R&R. In Table 3, the %SV for the Gage R&R is 93.2 which is unacceptable and means there is too much variation in the Gage R&R. The %SV for Reproducibility is 92.63 which is unacceptable and the largest %SV followed by Operator*Part. The Part-To-Part %SV is also not acceptable. The repeatability of the Gage R&R is marginally acceptable at 10.29 %SV.

Table 4 has similar results to Table 1, the P-value for part and operator are both above 0.005 meaning they are not significant. The Part*Operator P-value is 0.000 so that is significant. In Table 5 the majority of the VarComp comes from Reproducibility and Operator*Part. For Table 6 the Total Gage R&R study is not acceptable with a %SV above 30%. The three marginally acceptable %SV categories are Part-To-Part, repeatability, and operator. Reproducibility has a 96.54 %SV while Operator*Part has a 95.72 %SV. Both the length and thickness data may represent that the equipment and the way the operators are measuring the parts may not be capable of measuring to the required specification limits.

In Figures 3 and 4 below two Gage R&R ANOVA reports are displayed with 6 graphs each for Length and Data. Starting off with the Comparison Charts the Reproducibility bars have the highest contribution percentages. The UCL and LCL have a smaller range than the USL and LSL for both the R Chart and the X Bar Chart. Operator C in appeared to be the best operator for measuring length, while operators A and B appeared to be the best operators for measuring thickness. Operator B struggled measuring part 4 and 8 when measuring for length. Operators A, B, and C all struggled with measuring thicknesses. I would recommend cross training the operators, it looks like Operator C should train operators A and B how to measure length and operators A and B should train operator C to measure thickness. The measurement devices should also be checked and possibly calibrated. If there are two different devices to measure length versus thickness such as calipers versus a depth gauge, these should both be calibrated or the same measurement device such as calipers should be used for both. The reproducibility needs to increase so this could be from equipment or operator training, it is unlikely the variation is coming from the part given the data, but more so how the operator is interacting with the equipment and part.

Gage R&R (ANOVA) Report for Measurement

Gage name:
Date of study:

Reported by:
Tolerance:
Misc:

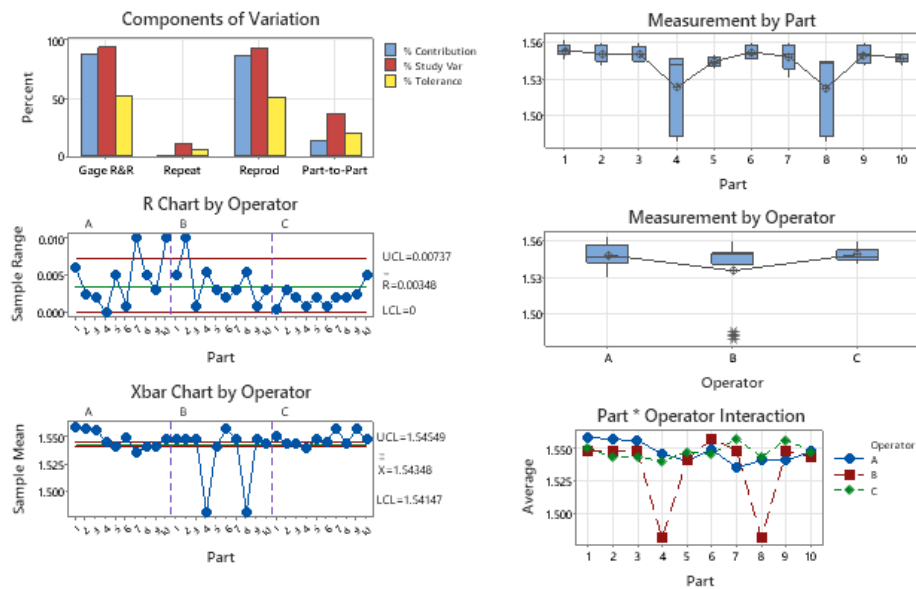


Figure 3. Length Gage R&R for the plastic part

Gage R&R (ANOVA) Report for Measurement

Gage name:
Date of study:

Reported by:
Tolerance:
Misc:

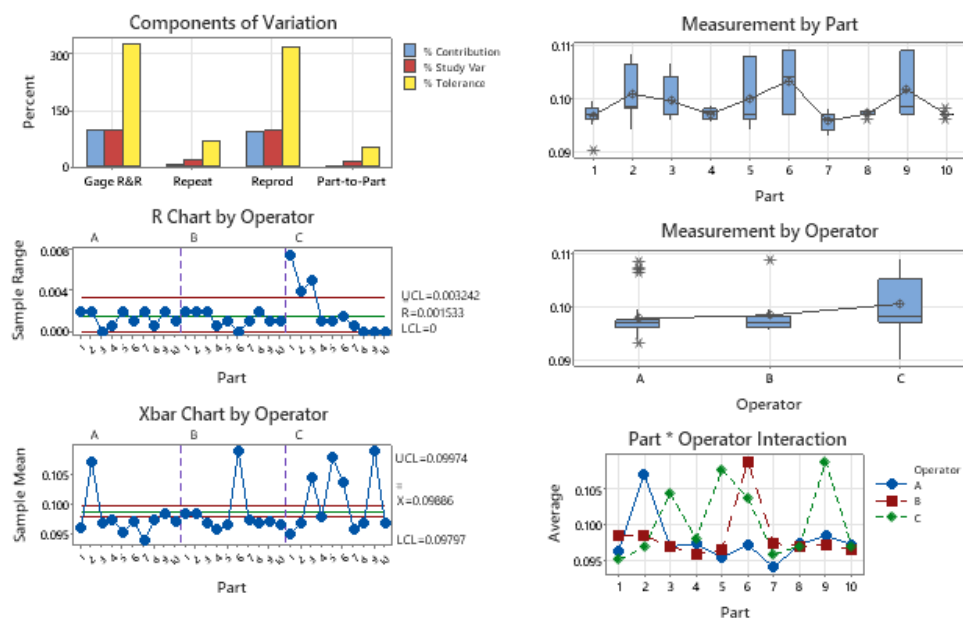


Figure 4. Thickness GR&R for the plastic part

Measurement and Process Capability

For part 2 of the Plastic Part study 19 parts were measured 5 times each for both length and thickness. Figure 5 below shows the Process Capability Sixpack for the length data while Figure 6 shows the Process Capability Sixpack for the thickness data. The specification limits for the length of the part still remain 1.56 for the USL and 1.54 for the LSL while the thickness remains the same with a USL of 0.104 and a LSL of 0.096. The Xbar Charts for both the length and thickness measurements have many averages outside of the UCL and LCL limits. The R Chart for both data sets has multiple ranges outside of the acceptable limits as well, with both data sets having ranges above the range UCL. The Capability Histogram for both data sets shows the data is not capable with multiple data points outside of the LSL and USL. The AD (1.623) and P value (<0.005) for the length data set is showing the data is not normal. For the thickness data set the AD (6.824) and P value (<0.005) is also showing the data is not normal. The Cp (1.20) versus Cpk (0.78) value is has a large difference from each other showing the process is not centered for the length data set. The Cp (0.63) versus Cpk (0.32) value for the thickness measurements also has a large difference meaning the thickness data is also not centered. The Cp (1.20) of the length measurements shows that Ppk could improve if studied as the Cpk (0.78) is higher than the Ppk (0.27). The Cp (0.63) of the thickness measurements is higher than the Pp (0.30) and the Cpk (0.32) compared to the Ppk (0.15) shows that the process could be improved with current conditions. The Cpk and Ppk values for both measurement sets are unacceptably low and well below 1 which means the process is not a 3-sigma process and not in control.

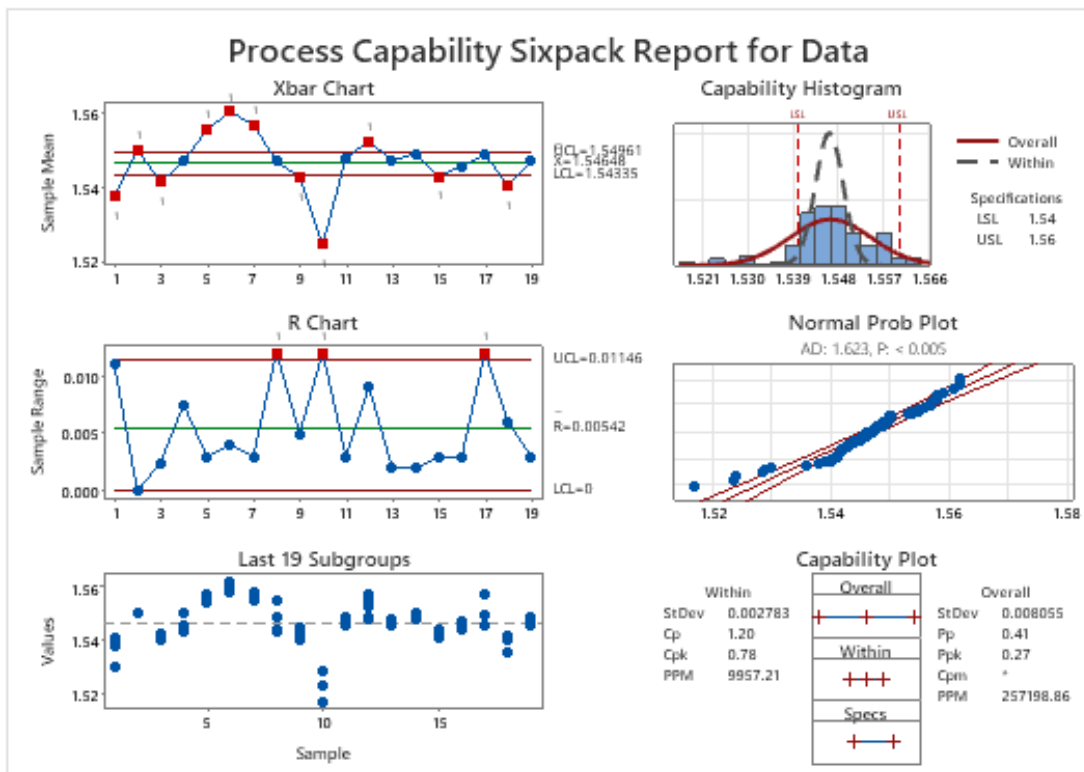


Figure 5. Six Pack analysis for length measurements

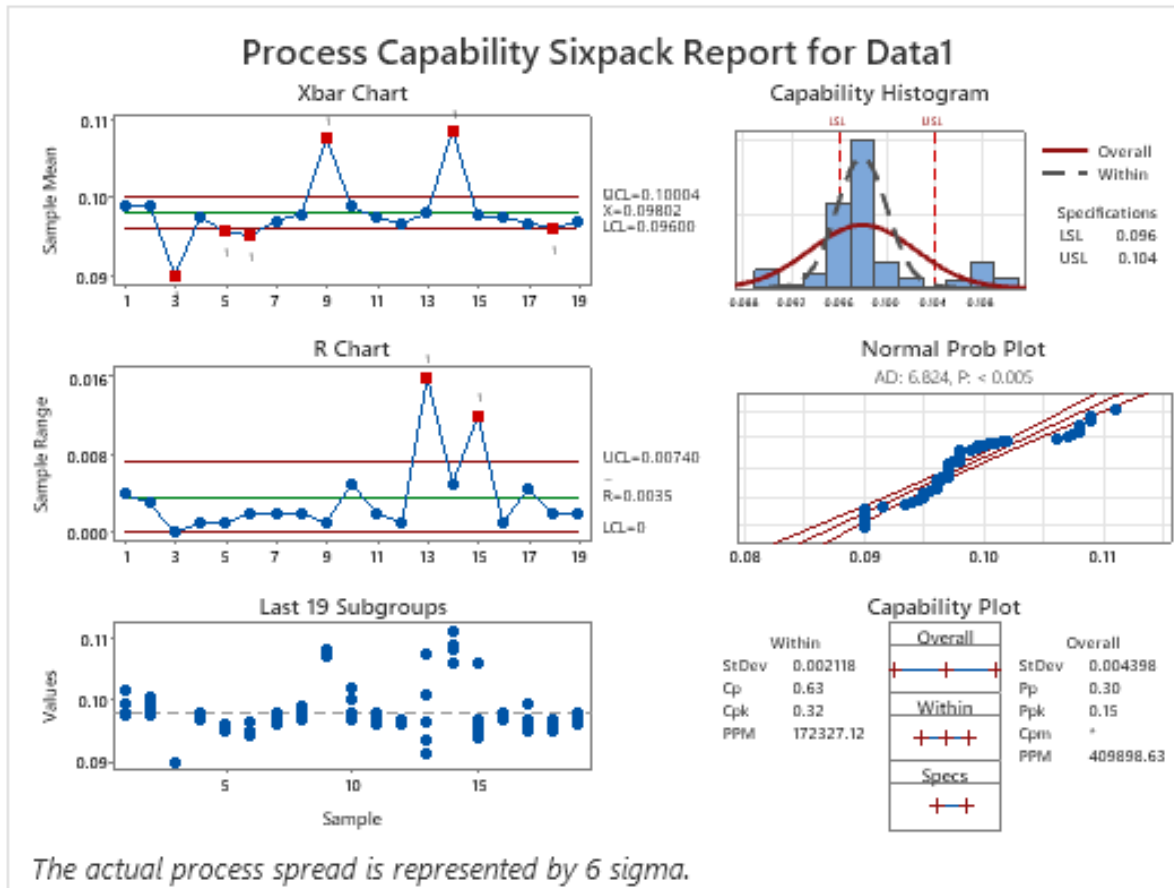


Figure 6. Six Pack Analysis for thickness measurements

To improve the process to a 3-sigma or 6-sigma process the specification limits would need to increase to the numbers shown below in Table 7. The limits are referring to increasing above a Cpk value of 1 and 2 respectively.

Table 7. Specification Limits for the plastic part for a 3-sigma and 6-sigma process

	Upper Specification Limit (in.)	Lower Specification Limit (in.)
Length (3-sigma)	1.56	1.52
Thickness (3-sigma)	0.109	0.091
Length (6-sigma)	1.57	1.51
Thickness (6-sigma)	0.114	0.085

To improve the process, I would suggest investigating if the operator(s) are trained and measuring the parts properly. Second, I would investigate if the measurement equipment is capable of measuring the process. After that I would investigate specific parts with large ranges to see if the part has a flatness specification that could be out of specification causing for large changes in an operator's measurements; if this is the case an investigation into the manufacturing process needs to be conducted. Also, if possible, the engineering specification limits should be increased in both directions to create a 3-sigma or higher process to reduce scrap for the company.