Name:
Email Address:
Please save your exam with a filename *lastnamefirstnameGB2019.doc*
Email to ronlasky@aol.com

You must work alone!

Copy and Paste appropriate Minitab graphs and output

Date/Time Started:
Date/Time Ended:
Please initial:

1. **This exam is solely a product of my work __JCD__**

In addition to class notes I consulted the following non-living sources:
https://analyse-it.com/docs/user-guide/process-control/shewhart-control-chart-rules
Engs 93 notes and book

I: Introduction to Statistics

1. **A basketball player makes a foul shot 80% of the time.**
   a. **What is the probability that he will make 12 in a row? (2.5pts)**

P(12 in a row) = .8^12 = **.0687**

   b. **What is the probability he will miss 4 in a row? (2.5pts)**

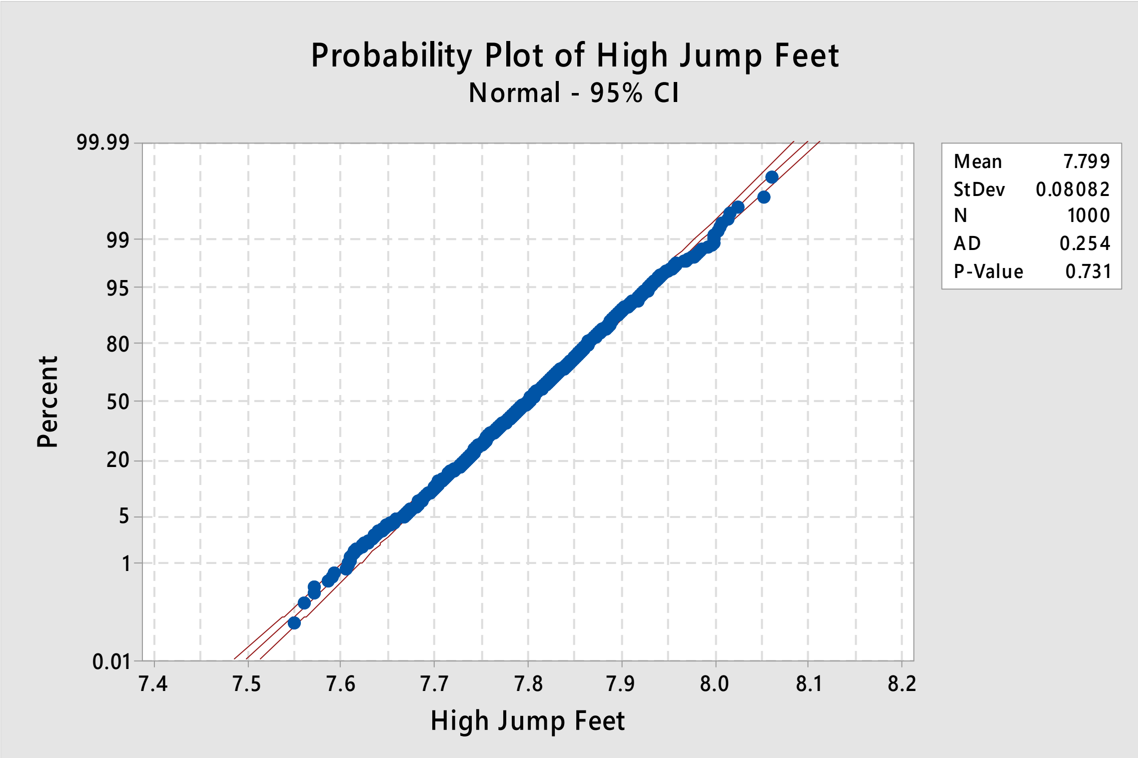
P(miss 4 in a row) = 1-.8^4 = **.5904**

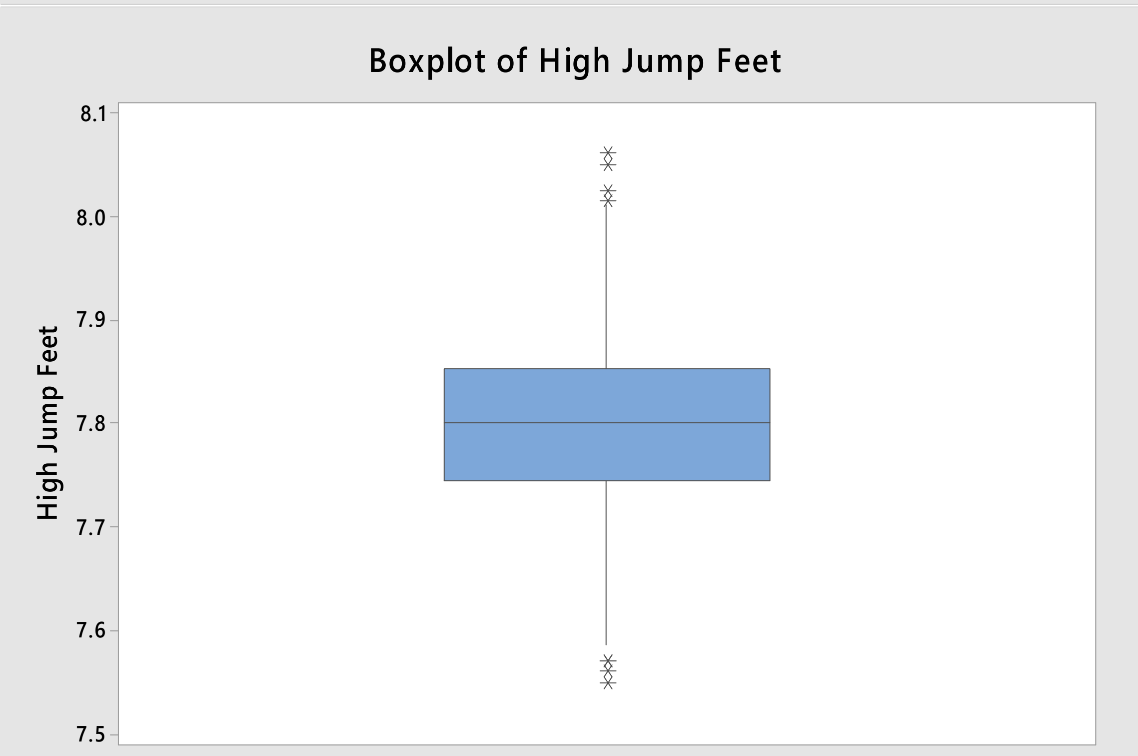
2. **A high jumper, John "Hoppin" Hermann, completes the jumps on the excel worksheet "High Jumps" for his track season. Using your statistical analysis package in Minitab, complete a normal probability and box plot of the data and perform Stat=>Basic Statistics=>Graphical Summay. Paste the results below. Discuss the results in detail. Are the data normal? Discuss the chances of Hoppin Hermann breaking Javier Sotomayor's world record of 8.0383 feet. (15pts) Hint: Only one jump is needed to break the world record.**

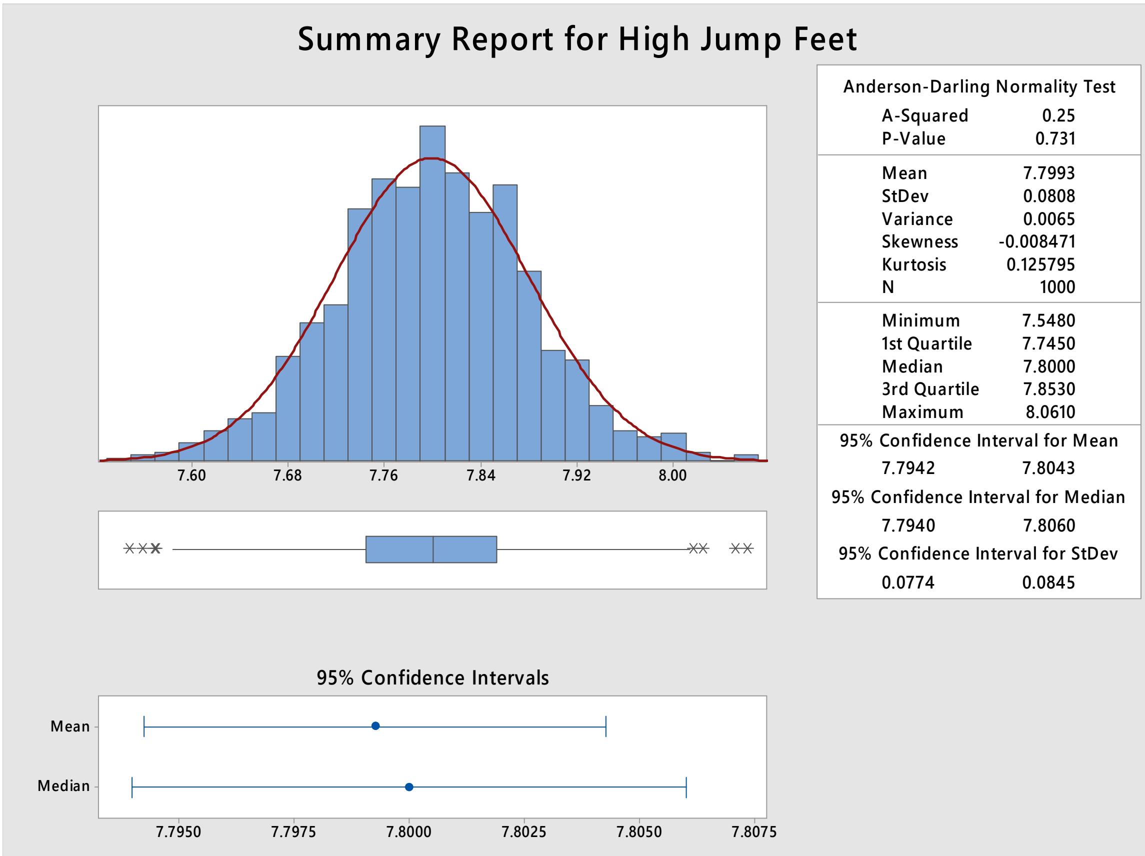
The results indicate that the data is fairly normal. The probability plot shows a linear fit by the data points without tailing further indicating that the data are normal. Further, the box plot reveals that the data has a few outliers. These outliers however do not seem to skew the data as the skewness value is -.008 which is well within the +-0.5 range for a normally distributed plot.

There is very little chance of John breaking the world record. Per the chart below, he has less than a 1% chance of beating the world record. 0.15% chance of beating the world record to be exact. This is can be confirmed by looking at the normal diminution plot for the jumping. 8.0383 feet is on the far right of the graph meaning there is a very low probability that he can jump higher than this

Mean	7.7993
StDev	0.0808
Record	8.0383
z score	2.957921
prob of making it	0.1549%


Probability Plot of High Jump Feet
Normal - 95% CI
Percent
99.99
99
95
80
50
20
5
1
0.01
7.4
7.5
7.6
7.7
7.8
7.9
8.0
8.1
8.2
High Jump Feet
Mean 7.799
StDev 0.08082
N 1000
AD 0.254
P-Value 0.731


Boxplot of High Jump Feet
High Jump Feet
8.1
8.0
7.9
7.8
7.7
7.6
7.5


Summary Report for High Jump Feet
Anderson-Darling Normality Test
A-Squared 0.25
P-Value 0.731
Mean 7.7993
StDev 0.0808
Variance 0.0065
Skewness -0.008471
Kurtosis 0.125795
N 1000
Minimum 7.5480
1st Quartile 7.7450
Median 7.8000
3rd Quartile 7.8530
Maximum 8.0610
95% Confidence Interval for Mean
7.7942 7.8043
95% Confidence Interval for Median
7.7940 7.8060
95% Confidence Interval for StDev
0.0774 0.0845
7.60
7.68
7.76
7.84
7.92
8.00
95% Confidence Intervals
Mean
Median
7.7950
7.7975
7.8000
7.8025
7.8050
7.8075

II: DMAIC:

While visiting the MIT Mousetrap Company as a consultant you are approached by the Quality Control Supervisor, Wes Jones. Mr. Jones has noticed that some (3 per 100) of the new humane catch-n-release traps are below specification (door shuts before mouse has entered) and has approached you to assist in fixing this expensive problem (MIT sells millions of these C-n-Rs each year).

a) DMAIC -- define each letter of the acronym (D,M,A,I, and C) and write 1-2 sentences related to the above scenario, i.e. talk about the steps you would recommend taking for each part of the process and discuss what resources you might use to complete that task. (15)

Define: In order to properly address this problem, there needs to be a specific scope of the problem (is it in the whole factory or just one portion); a proper team needs to be developed (will likely need mechanical and manufacturing engineers); and proper resources will need to be obtained (time on machines and prototyping equipment). Secondly, target metrics need to be determined (what are the specified limits of when the door can close); background information (such as the mean and standard deviation of when the door closes and how many traps are outside of the bounds); and the input, process, and output need to be defined (materials for mouse trap, the manufacturing process of mousetraps, and finalized mousetrap performance respectively).

Measure: This step requires the mousetrap company to find the variability of the mousetraps meaning they have to develop a process of measuring when the mousetraps shut too early. This will allow them to validate if the trap is below specification and will serve as a baseline moving forward.

Analyze: This situation can be analyzed through a root cause analysis such as a fishbone diagram of the 5Ys potentially, and the quantification of the waste which is the mousetraps here. A fishbone diagram can analyze what areas in the manufacturing process or environment may cause the defects, and 5Ys can also uncover the root cause of the defects.

Improve: The improve segment of the process is the part when solutions are developed and implemented. These ideas can come from brainstorming, value stream mapping, solution planning, DFMEA/PFMEA relating to the manufacturing process of the mousetraps, and gathering trial data.

Control: The control process includes comparing results from before and with these results determine if they are within the defined specifications. It also includes implementing new procedures, new equipment, and re organizing the space if necessary, to sustain these changes.

b) Discuss more extensively how you might determine possible solutions to the problem in the "I" portion of this problem-solving framework and what tools, techniques, and resources you might use (and how). (10)

The process for improvement is brainstorming, testing solutions, and assessing the outcome of these solutions. For this example, a company brainstorming is the first step in this phase and can be performed after the measure and analyze steps are performed and data from the current machines is gathered and analyzed. This brainstorming step can include a collaborative brainstorming session where engineers and other key players submit their ideas on how to improve the quality of the mousetraps. TRIZ methodology can also be applied by generalizing this problem and find solutions based from this generalized solution that others have performed in industry. Secondly, a future/ideal state map can be creating in order to develop what the ideal process would look like in comparison to the current process. After the top proposed solution is chosen using a decision matrix or other decision-making technique, the best solution will have an initial pilot program. This best solution can use FMEA to determine potential failure points for new designs and processes. For this specific case, measuring the results and performing a SPC study to determine what errors in the process are being committed is a good course of action. This study could potentially show any Shewhart violations or if machines are imprecisely tuned. Pending the validation of these test results, the pilot program can be put into full implementation. Also, a full economic analysis can be performed to determine if the process can cost effectively produce these modified mouse traps.

III: Statistics:

1. Your company makes an uber-bouncy-tennis ball for professional players that bounces an average of 57 inches when dropped from 100 inches (within international tennis regulations) over 900 drops when new. You've been tipped off that your material supplier may have changed the quality of their yellow fuzz product without any warning and you wonder how much of an effect, if any, this will have on the quality and bounciness of your tennis balls. You take a random sampling of n=20 samples. The data you collect (inches of bounce height) are below.

56.39
57.62
56.53
56.78
57.23
56.82
57.21
56.80
56.17
57.66
56.41
56.41
56.25
56.51
56.31
56.34
56.18
56.94
57.02
56.81

1. **Is this new yellow fuzz different from your previous product? Prove by testing the hypothesis $H_0 : \mu = 57.00, \quad H_1 : \mu < 57.00"$ for α = 0.05. Use the T-test statistic. (10)**

$$H_0: \mu = 57.00; H_1: \mu < 57.00$$

$$\alpha = .05$$

$$SEM = \frac{\sigma}{sqrt(n)} = \frac{0.4512}{sqrt(20)} = 0.100$$

$$z = \frac{xbar - x}{SEM} = \frac{56.719 - 57}{0.100} = -2.77$$

$$\boldsymbol{-2.77 < 1.729\ so\ we\ reject\ the\ H_0; they\ achieved\ their\ goal}$$

2. **Double check your answer by finding the confidence bounds on the mean bounce height. Do your results agree? Comments?(10)**

$$xbar - t_{\frac{\alpha}{2},n-1} * SEM < \mu < xbar + t_{\frac{\alpha}{2},n-1} * SEM$$
$$56.719 - 2.093 * \frac{0.4512}{sqrt(20)} < \mu < 56.719 + 2.093 * \frac{0.4512}{sqrt(20)}$$
$$56.508 < \mu < 56.930$$

Yes, the results agree, the new fuzziness has affected the bounce height and we believe it is now less than 57 feet with a 95% confidence.

3. **Assuming that this was a screening experiment, what do you do next and/or what do you tell your boss about both your existing data and your ideas for the future? (5)**

I would tell my boss to call the manufacture and ask them to revert back to the original quality of their fuzziness because it has demonstrated to affect the bounciness of the tennis ball. In the future, we may want to switch manufactures in the future if they continue to have less than needed quality fuzziness.

2. **Vermont invests about $4.5 million/year in anti-smoking efforts. Out of 100,000 VT high school students 17,600 smoke. In New Hampshire no money is spent on anti-smoking campaigns and 20,800 out of 100,000 HS students smoke. Using the Poisson distribution, can Vermont argue that their program has some positive effect? (15)**

$$H_0: \lambda = 20800$$
$$H_1: \lambda < 20800$$
$$\alpha = .05$$

Because lambda>5

$$z = \frac{x - \lambda}{sqrt(\lambda)} = \frac{17600 - 20800}{sqrt(20800)} = -22.188$$

$$\boldsymbol{-22.188 < -1.645\ reject\ H_0; Vermont's\ program\ is\ working}$$

Using this Poisson distribution hypothesis test, Vermont can argue with a 95% confidence that their program is working.

3. **An election poll concluded that two candidates were tied at 50% of polled voters each. The number of people polled was 500. What is the statistical error at a 95% confidence level? Comment on the results. Hint: Use the continuous approximation to the binomial distribution. This type of result will be similar to when polls are reported on the news and the newscaster will say that the error is plus and minus 3%. (15)**

$$p = q = 0.50$$

From .95 on z-table

$$z = 1.96$$
$$n = 500$$

Margin of Error:

$$MOE = z * sqrt\left(\frac{pq}{n}\right) = 1.96 * sqrt\left(\frac{.5 * .5}{500}\right) = \mathbf{0.0438}$$

This Margin of Error of 4.38% indicates that these poll results are inconclusive because either candidate could be leading. They do not tell which candidate has a better position. Until one candidate is approximately 5 percentage points ahead of their opponent in the polls, there cannot be a confident poll winner.

IV: SPC

1.

A. Discuss the differences between special cause and common cause failures or variation, giving at least one example of each. How might you see the difference in your measurements? (5)

A common cause variation is natural and expected in engineering processes. This can be due to wear in machines or other gradual causes. These variations are controllable in the sense that a more accurate machine can be used. An example of this is bolt length in a bolt factory. Although these lengths will accurate, there will still be an allowable tolerance such as +-.1 in. Although they may not be the exact length, they are still in the acceptable length. If improvements are desired, more precise machines must be used. Measuring these may be understood in a normal distribution.

Conversely, a special cause variation comes unexpectedly. It is an aberration in the process, and are comparably rarer than a common cause variation. If one occurs, a root cause analysis must be performed as it may not necessarily be the result of machine variation. Instead, it could be external factors that varied outside of the normal process during a specific operation. Measuring these may come from an extreme outlier in a quality test.

B. Discussion the difference between attribute and variables data. How do they work together in an effective SPC Program? (5)

Variable data is qualitative such a measurements or quantitative testing results. Attribute data however is qualitative such as the functionality of a particular component that customers may interact with making it more important. They operate hand in hand in a SPC because the more variable data is limited, the more attribute data may improve for the consumer for external operations.

C. What is a Pareto Chart? How is it used in a continuous improvement program? (5)

A pareto chart is a statistical tool that presents error causes in descending order. The data is cumulatively added throughout the plot. This plot presents engineers a means to identify what can potentially be the most common causes of errors. It's used by continuous improvement programs to understand where errors in processes are coming from which allows them to improve the process with this newfound understanding.

2. **The USGA announced that they are going to be very "tough" in enforcing the rule that the maximum coefficient of restoration (COR) for golf club drivers be 0.83. (some drivers were measured by them as 0.85, this COR gives a drive 5 yards or so advantage over one that is "in spec." Assume that the lower spec limit is 0.70)**

   The USGA will allow the upper spec limit on any manufacturer's driver to be 0.83 as long as the Cpk is at least 2.0. Ping has developed a very repeatable process for making the driver heads that they believe can achieve a Cpk of 2 with the average COR being 0.828.

a) If this is true what must σ be? (5)

Using the Cp, Cpk, Cpl, and Cpu equations we can isolate sigma. These equations Cpu and Cpl both equal 2.

$$\sigma = \frac{USL - Xbar}{3C_{pu}} = \frac{.83 - .828}{3*2} = \mathbf{.00033}$$

$$\sigma = \frac{Xbar - LSL}{3C_{pl}} = \frac{.828 - .7}{3*2} = .0213$$

The standard deviation is .00033 COR

b) Ping is encouraged as they believe their competitors σ is at least 0.004. If this is true, what COR average must the competitor aim for to have a Cpk = 2. (5)

$$Xbar = USL - 3\sigma C_{pu} = .83 - 3 * .004 * 2 = \mathbf{0.806}$$

c) For every 0.01 loss in COR the driver loses 2.5 yards. How much less yardage will the competitions driver hit a ball on average as compared to Pings? (5)

$$Yards\ lost = (Ping\ mean - Competition\ Mean) * 2.5 * 100$$

$$= (.828 - .806) * 2.5 * 100 = \mathbf{5.5\ Yards}$$

d) Ping manufactures 10,000 drivers. The data are in the spreadsheet in tab "Golf Club COR." Analyze the data. Assume with subgroup size = 1. Did they achieve their goal? Comment on the data Re: normality, etc. Are there Shewhart violations? If so discuss them. State

any assumptions. Copy and paste appropriate data and/or graphs. Use an upper spec of 0.83 and a lower spec of 0.82.(15)

Analyzing the graph, the data appears to be normal from the capability histogram and the normal probability plot. They achieved their goal of normality.

Shewhart Test Failed: 1, 2, 3, 4, 5, 6, 7, 8

Because the 1 test was failed, this tells us there is 1 point outside of the control limits. This indicates a large shift in the process. Meaning there should be a root cause analysis performed to understand this problem considering it happens repeatedly throughout the processes.

Because test 2 was failed, this tells us there is a small sustained shift in the manufacturing process. Because the test 2 was failed in multiple sections of the manufacturing process, it tells us that one shift or process in a particular time was problematic to some extent. Determining the cause of these aberrations is worth exploring for future test.

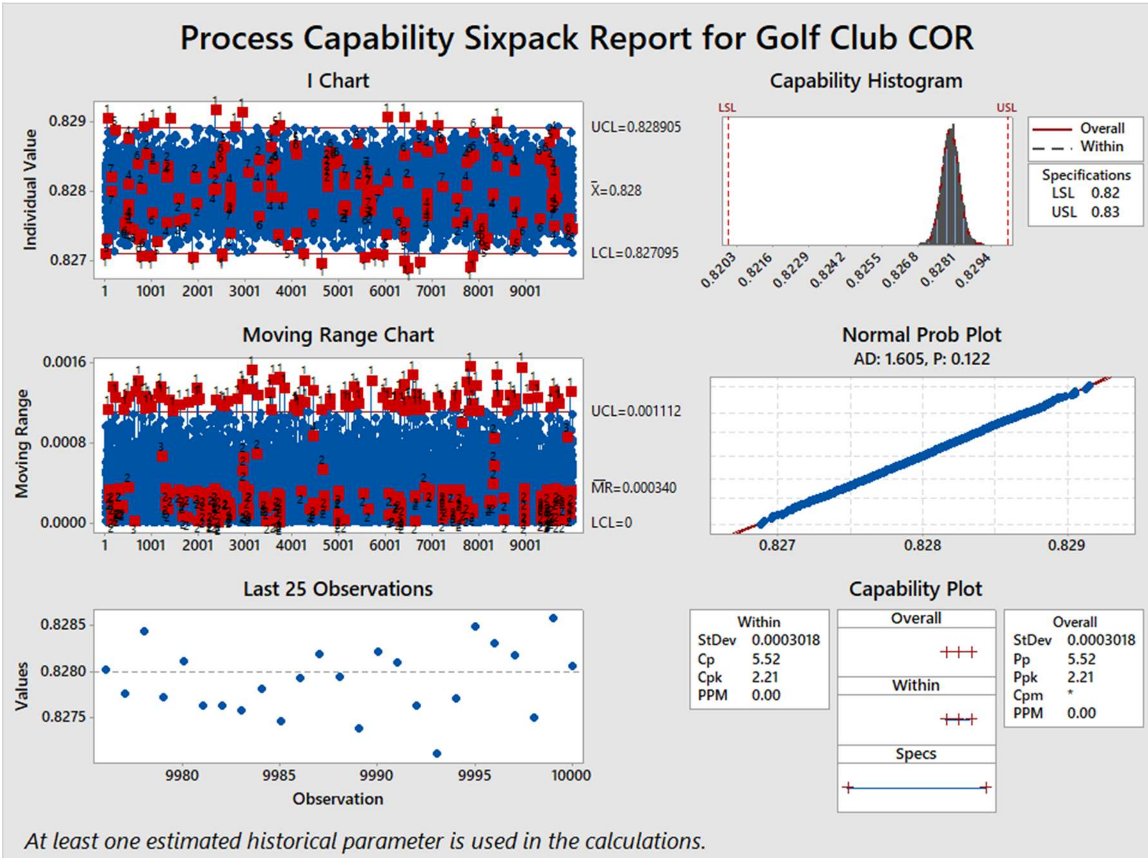
Because test 3 was violated at several points, it means there was a trend up or down in the process. Meaning, there might have been an error in the process that resulted in increasingly worse quality products.

Because test 4 was failed, it indicates there was a systematic variation in the process. This could be something such as environmental changes at one part of the process or machine wear resulting in lower quality parts.

Because test 5 was failed it indicates a medium shift in the process. Because test 6 was failed it indicates a small shift in the process. These shifts could have occurred from environmental variations within the process such as temperature or humidity. It also could have been caused by other external factors.

Because test 7 was failed it shows a stratification in the process. This means that there were 15 consecutive points within one sigma of the center line. This could indicate the machine has been tightly tuned to the very specific range around the center line.

Because test 8 was failed it shows there is a mixture pattern in the process. This mixture pattern indicates that the machine producing them could have an aberration in the manufacturing process that is causing these mixed results in the point.



Process Capability Sixpack Report for Golf Club COR
I Chart
Individual Value
UCL=0.828905
X̄=0.828
LCL=0.827095
Capability Histogram
LSL
USL
Overall
Within
Specifications
LSL 0.82
USL 0.83
Moving Range Chart
Moving Range
UCL=0.001112
M̄R=0.000340
LCL=0
Normal Prob Plot
AD: 1.605, P: 0.122
Last 25 Observations
Values
Observation
Capability Plot
Within
StDev 0.0003018
Cp 5.52
Cpk 2.21
PPM 0.00
Overall
Within
Specs
Overall
StDev 0.0003018
Pp 5.52
Ppk 2.21
Cpm *
PPM 0.00
At least one estimated historical parameter is used in the calculations.

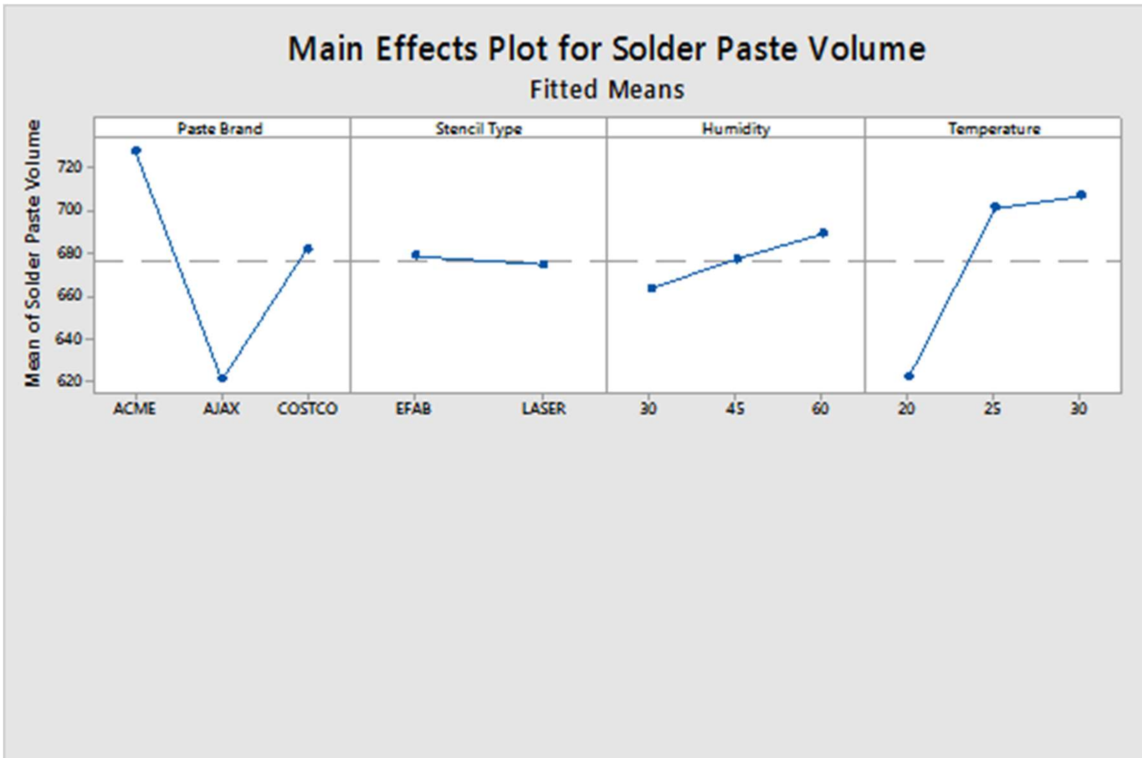
V: DOE

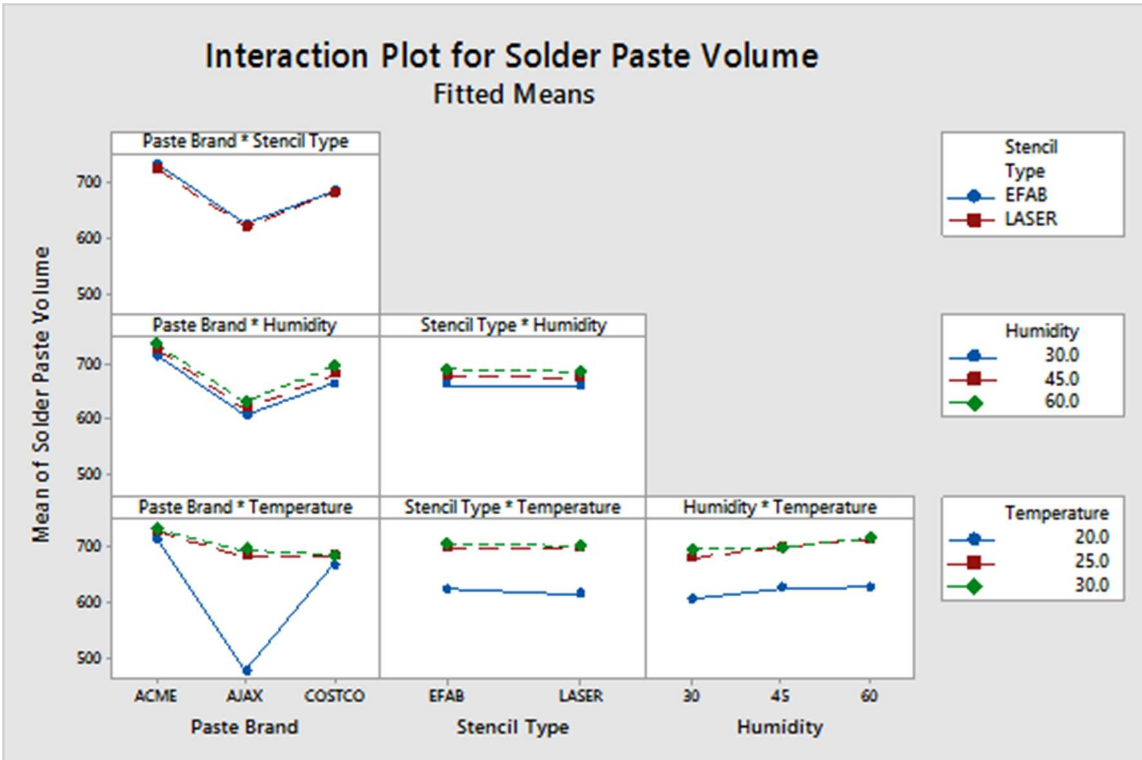
A full factorial experiment is proposed to optimize stencil printing for a 0.3mm process. The assembly will be in Singapore, so management wonders if temperature and humidity control will be needed. The stencil aperture is 6x4x30 mils, +/- 10% of this volume is the proposed spec. The factors are Type 4 paste (1=ACME, 2=AJAX, 3=Kostco), stencil (efab, laser), humidity (30, 45, 60 RH), temperature (20, 25, 30 C). The two replicate data are in the worksheet "Solder Paste DOE." Set up the experiment with the factors in this order and do not randomize runs. Analyze the data, look for interactions and nonlinear effects. Comment on the results. What are your recommendations? There is a rumor in the industry that the AJAX paste does not print well at 20C. What do the data tell you in this regard? Do you propose further experiments, what are they? (40)

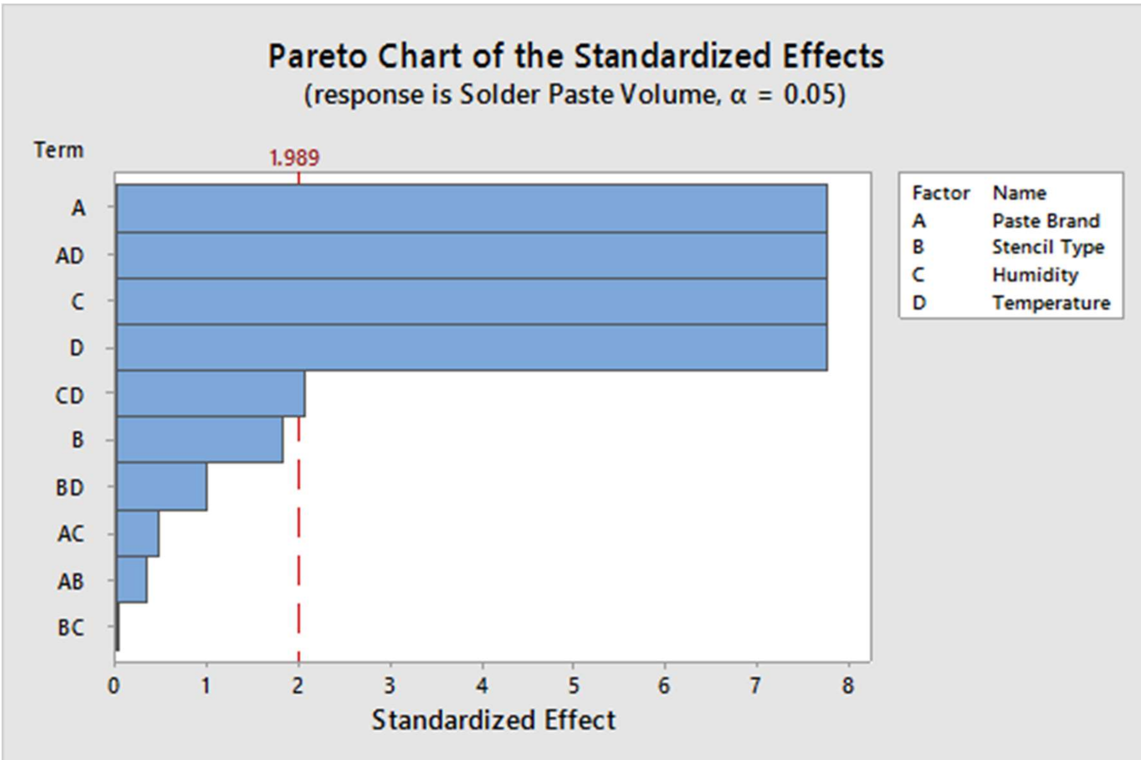
Looking at the main effects plot, my first recommendation is to not use the AJAX brand at all. There paste does not seem to approach the desired 720 cubic mils of solder paste volume that is required from the project. The Costco brand is within the specified volumes however the ACME brand performs significantly better than the other two brands. I recommend using this brand in the future unless outside factors such as cost present a barrier. Secondly, I recommend using whichever stencil type is cheaper between the EFAB and Laser. Neither of these stencil types present clear advantages over one of the other. Potential test should include testing with both stencil in the event that varying paste brand humidity or temperature affects these results. I recommend using a higher humidity. There is a clear trendline with this data that suggest that higher humidity is better of solder paste volume. The same goes for temperature. I recommend using a higher temperature. 30 degC demonstrated higher solder volume with a trendline of higher temperature resulting in higher solder paste volume.

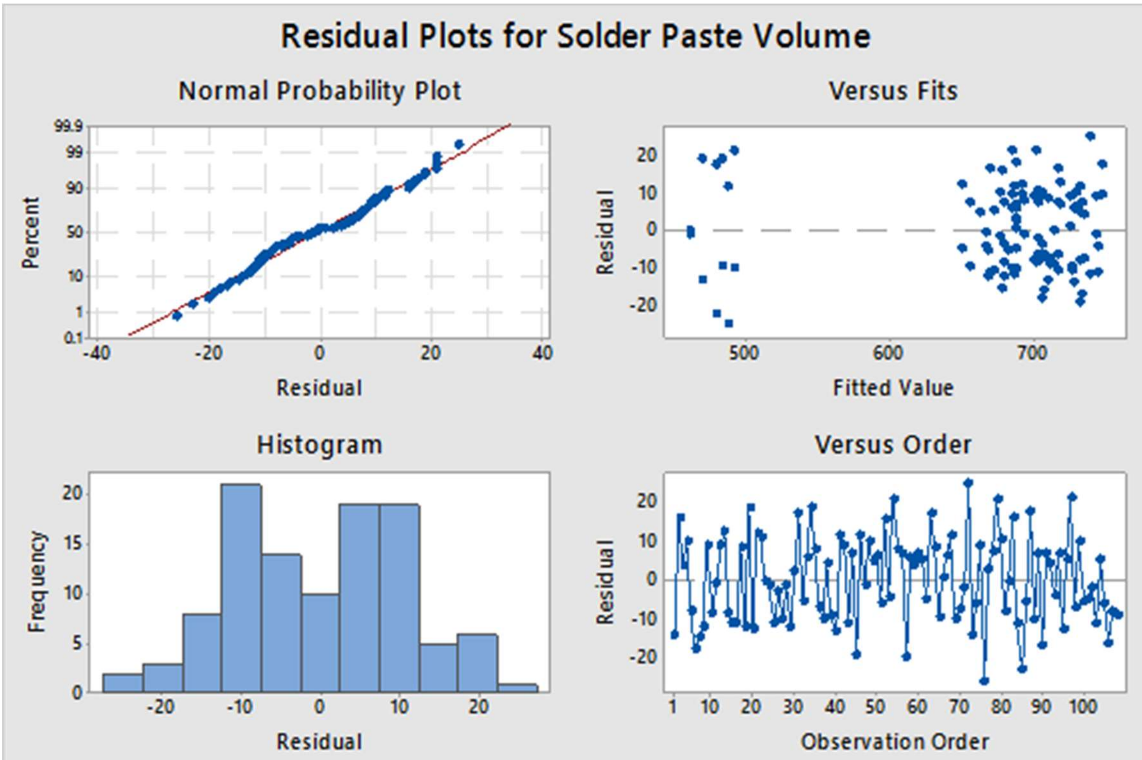
Yes, the data confirms that the AJAX paste does not print well at 20C. Looking at the interaction plot, the Paste Brand and temperature plot demonstrates this. The blue line which represents 20C, shows the lowest solder paste volume in any of the interaction graphs with the AJAX brand paste. The AJAX brand paste does not print well at 20C.

Yes, I propose several further experiments. First, the humidity main effects plot is demonstrating an upwards trend that should be further explored. I recommend using 75, 90, and 100 RH to determine what humidity gives the results closest to 720 cubic mils of solder paste. Extrapolating this plot will allow for a full understanding of which relative humidity gives the solder paste outcome closest to 720 cubic mils. Secondly, I recommend doing the same thing with temperature. Although slightly less pronounced, the temperature plot in the main effects graph is demonstrating an upward trend. I recommend testing at 35, 40, and 45C to better determine at what temperature is the preferred 720 solder paste volume obtained. Throughout all these test, I recommend using the EFAB and laser stencils as neither currently presents a distinctive advantage over the other. These results for the stencils may change as humidity, temperature, and paste brand are modified.




Interaction Plot for Solder Paste Volume
Fitted Means
Paste Brand * Stencil Type
Paste Brand * Humidity
Stencil Type * Humidity
Paste Brand * Temperature
Stencil Type * Temperature
Humidity * Temperature
Mean of Solder Paste Volume
700
600
500
ACME
AJAX
COSTCO
Paste Brand
EFAB
LASER
Stencil Type
30
45
60
Humidity
Stencil Type
EFAB
LASER
Humidity
30.0
45.0
60.0
Temperature
20.0
25.0
30.0


Pareto Chart of the Standardized Effects
(response is Solder Paste Volume, α = 0.05)
Term
1.989
A
AD
C
D
CD
B
BD
AC
AB
BC
0
1
2
3
4
5
6
7
8
Standardized Effect
Factor Name
A Paste Brand
B Stencil Type
C Humidity
D Temperature


Residual Plots for Solder Paste Volume
Normal Probability Plot
Percent
Residual
Versus Fits
Residual
Fitted Value
Histogram
Frequency
Residual
Versus Order
Residual
Observation Order

General Factorial Regression: Solder Paste Volume versus ... mperature

Factor Information

Factor	Levels	Values
Paste Brand	3	ACME, AJAX, COSTCO
Stencil Type	2	EFAB, LASER
Humidity	3	30, 45, 60
Temperature	3	20, 25, 30

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	25	587573	23503	144.38	0.000
Linear	7	378539	54077	332.20	0.000
Paste Brand	2	205625	102813	631.59	0.000
Stencil Type	1	538	538	3.30	0.073
Humidity	2	11666	5833	35.83	0.000
Temperature	2	160709	80355	493.63	0.000
2-Way Interactions	18	209034	11613	71.34	0.000
Paste Brand*Stencil Type	2	103	52	0.32	0.729
Paste Brand*Humidity	4	407	102	0.63	0.645
Paste Brand*Temperature	4	206449	51612	317.06	0.000
Stencil Type*Humidity	2	7	4	0.02	0.977
Stencil Type*Temperature	2	373	186	1.15	0.323
Humidity*Temperature	4	1695	424	2.60	0.042
Error	82	13348	163		
Lack-of-Fit	28	4223	151	0.89	0.620
Pure Error	54	9126	169		
Total	107	600921			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
12.7586	97.78%	97.10%	96.15%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	676.38	1.23	550.93	0.000	
Paste Brand					
ACME	50.87	1.74	29.30	0.000	1.33
AJAX	-55.69	1.74	-32.07	0.000	1.33
Stencil Type					
EFAB	2.23	1.23	1.82	0.073	1.00
Humidity					
30	-13.13	1.74	-7.56	0.000	1.33
45	0.84	1.74	0.49	0.629	1.33
Temperature					
20	-54.46	1.74	-31.37	0.000	1.33
25	24.51	1.74	14.12	0.000	1.33
Paste Brand*Stencil Type					
ACME EFAB	1.24	1.74	0.71	0.477	1.33
AJAX EFAB	-0.09	1.74	-0.05	0.958	1.33
Paste Brand*Humidity					
ACME 30	2.13	2.46	0.87	0.388	1.78
ACME 45	1.07	2.46	0.44	0.663	1.78
AJAX 30	0.69	2.46	0.28	0.781	1.78
AJAX 45	-0.95	2.46	-0.39	0.699	1.78
Paste Brand*Temperature					
ACME 20	43.96	2.46	17.90	0.000	1.78
ACME 25	-20.68	2.46	-8.42	0.000	1.78
AJAX 20	-87.40	2.46	-35.59	0.000	1.78
AJAX 25	41.30	2.46	16.82	0.000	1.78
Stencil Type*Humidity					
EFAB 30	-0.37	1.74	-0.21	0.832	1.33
EFAB 45	0.21	1.74	0.12	0.903	1.33
Stencil Type*Temperature					
EFAB 20	2.13	1.74	1.23	0.223	1.33
EFAB 25	-2.40	1.74	-1.38	0.171	1.33
Humidity*Temperature					
30 20	-1.04	2.46	-0.42	0.674	1.78
30 25	-4.68	2.46	-1.90	0.060	1.78
45 20	4.82	2.46	1.96	0.053	1.78
45 25	0.94	2.46	0.38	0.704	1.78

Regression Equation

Solder Paste Volume = 676.38 + 50.87 Paste Brand_ACME - 55.69 Paste Brand_AJAX
+ 4.81 Paste Brand_COSTCO + 2.23 Stencil Type_EFAB
- 2.23 Stencil Type_LASER - 13.13 Humidity_30 + 0.84 Humidity_45
+ 12.29 Humidity_60 - 54.46 Temperature_20 + 24.51 Temperature_25
+ 29.95 Temperature_30 + 1.24 Paste Brand*Stencil Type_ACME EFAB
- 1.24 Paste Brand*Stencil Type_ACME LASER
- 0.09 Paste Brand*Stencil Type_AJAX EFAB
+ 0.09 Paste Brand*Stencil Type_AJAX LASER
- 1.15 Paste Brand*Stencil Type_COSTCO EFAB
+ 1.15 Paste Brand*Stencil Type_COSTCO LASER
+ 2.13 Paste Brand*Humidity_ACME 30 + 1.07 Paste Brand*Humidity_ACME 45
- 3.20 Paste Brand*Humidity_ACME 60 + 0.69 Paste Brand*Humidity_AJAX 30
- 0.95 Paste Brand*Humidity_AJAX 45 + 0.27 Paste Brand*Humidity_AJAX 60
- 2.81 Paste Brand*Humidity_COSTCO 30
- 0.12 Paste Brand*Humidity_COSTCO 45
+ 2.94 Paste Brand*Humidity_COSTCO 60
+ 43.96 Paste Brand*Temperature_ACME 20
- 20.68 Paste Brand*Temperature_ACME 25
- 23.29 Paste Brand*Temperature_ACME 30
- 87.40 Paste Brand*Temperature_AJAX 20
+ 41.30 Paste Brand*Temperature_AJAX 25
+ 46.10 Paste Brand*Temperature_AJAX 30
+ 43.44 Paste Brand*Temperature_COSTCO 20
- 20.62 Paste Brand*Temperature_COSTCO 25
- 22.81 Paste Brand*Temperature_COSTCO 30
- 0.37 Stencil Type*Humidity_EFAB 30 + 0.21 Stencil Type*Humidity_EFAB
45 + 0.16 Stencil Type*Humidity_EFAB 60
+ 0.37 Stencil Type*Humidity_LASER 30
- 0.21 Stencil Type*Humidity_LASER 45
- 0.16 Stencil Type*Humidity_LASER 60
+ 2.13 Stencil Type*Temperature_EFAB 20
- 2.40 Stencil Type*Temperature_EFAB 25
+ 0.27 Stencil Type*Temperature_EFAB 30
- 2.13 Stencil Type*Temperature_LASER 20
+ 2.40 Stencil Type*Temperature_LASER 25
- 0.27 Stencil Type*Temperature_LASER 30 - 1.04 Humidity*Temperature_30
20 - 4.68 Humidity*Temperature_30 25 + 5.71 Humidity*Temperature_30 30
+ 4.82 Humidity*Temperature_45 20 + 0.94 Humidity*Temperature_45 25
- 5.76 Humidity*Temperature_45 30 - 3.79 Humidity*Temperature_60 20
+ 3.74 Humidity*Temperature_60 25 + 0.05 Humidity*Temperature_60 30

Fits and Diagnostics for Unusual Observations

Obs	Solder Paste Volume	Fit	Resid	Std Resid	
72	764.00	739.15	24.85	2.24	R
76	462.00	488.03	-26.03	-2.34	R
85	456.00	479.06	-23.06	-2.07	R

R Large residual

Effects Pareto for Solder Paste Volume

Residual Plots for Solder Paste Volume

VI: General

Explain Lean, Six Sigma, and the limitation of each as a separate discipline in a way that your 15 year old neighbor would understand. (10)

Lean manufacturing can be best understood as a process methodology in which waste is removed in order to increase productivity thus the value of the resulting product from that specific process. This process doesn't have to be a manufacturing process necessarily. For example, lean has been implemented in the startup process under the term "Lean Startup." This practice looks to reduce time on wasted product development and instead use customer feedback and proper metrics to create a more valuable product. This application of lean and the traditional application have the same goal: reduce waste in order to improve productivity and in turn improve the resulting product whether it be a widget or a startup idea.

Six sigma is a statistical based, data-driven approach that is ultimately a continuous improvement process. The continuous improvement process is looking to eliminate defects in the specific product being manufactured, although it can be used for processes or services. For product processes specifically however, it means that the product's upper and lower limits are 6 standard deviations away from the mean. The standard deviation represents how wide or tight data can deviate from the center of a group of data. For example, if I wanted my football size to be between 10 and 12 inches long, the center of the data should be 11 inches. If we are following six sigma, the standard deviation of the footballs should be 1/6 or .166 inches. This process however is not achieved without applying statistical tools such as DOE, ANOVA, and other tools that helps engineers understand where defects come from and how to reduce them.

VII: Lean

1. You are a Six Sigma practitioner working for a small local shop that sells yard tractors. The company has been losing market share recently, and it has been determined that this is due to poor customer satisfaction with the in-store repair department. You have just been assigned a project to improve the process of repairing tractors returned to store.

1) **What is the most probable primary metric (or key process output variable) for this process? (5)** The quality of the repaired tractors is the key process output variable. This is the primary metric because if the tractor repairs have a higher quality, they will be received higher customer satisfaction which is the ultimate goal. It can be manipulated through various process changes to increase customer satisfaction.
2) **How would you begin to determine possible sources of waste in this process? (Select the best answer) (5)**
   a. Conduct a DOE to determine sources of variation at the factory.
   b. Map the value stream of the repair process.
   c. Run a 2 sample T test on process time before and after improvements.
   d. Look at what has been done in the past when sales have fallen and repeat those actions.
   e. Ask the owner what he would do.
3) **Create a rough process map of the repair process, and identify the NVA, BNVA and VA steps (can be simply "step 1 → step →", no fancy graphics required). Comment on which could be eliminated or reduced. (10)**

Tractor brought in -> BNVA
Tractor inspected -> BNVA
Tractor parts ordered -> VA
Tractor parts held -> NVA
Tractor put into fixing queue -> NVA
Fix tractor -> VA
Second tractor inspection -> NVA
Parts ordered again if necessary -> VA
Fix again if necessary ->
Customer pickup -> BNVA
Customer survey -> BNVA

First, holding the tractor parts can be removed if the shop appropriately times the fixing of the tractor through proper anticipation. These parts my take up valuable space in the shop. Secondly, the queue for fixing tractors can be eliminated or reduced through proper anticipation of how busy the shop will be and also removing tractor rework mentioned later in the process. The tractor rework and part ordering can be eliminated and removed through implementing a more comprehensive inspection process that can anticipate the issues the tractor will have.

Also, it can be reduced by encouraging mechanics to perform all fixes properly the first time through incentive programs potentially.

2. Think of an organization you work with or have worked with. Discuss how 5 S and the 7 mudas could be used to improve the operation. If the organization has implemented these tools, discuss the process and benefits. (20).

The 5S's and 7 mudas were used extensively during my internship with Maclean-Fogg two summers ago. *Seiri and Seiton* were used especially for tooling in the factory. The process for this in the chemical mixing room for example involved first sorting what should and shouldn't be in the chemical mixing room. Various buckets and mops were in the room yet had not function been in the room. After extraneous items were removed from the room, it was then organized and made orderly for easy access to buckets, hoses, and any other equipment chemical room operators would need. Next, *Sieso* was applied to maintain cleanliness in the room. Tape silhouettes were used to show exactly where equipment should be placed. Every item in the room had a specific home, so any chemical room operator knows exactly what equipment should be in the room and where it should be. Lastly, *Seiketsu* was applied to schedule regular cleaning of the chemical room equipment that was very messy. These changes benefitted the factory greatly. Previously, the chemical room was a place of mass confusion causing it to be the chokepoint the factory because all of the resin used for the pultrusion process comes through this room, so the entirety of the operation is dependent on how fast this room can send resin to the machines. These changes were greatly received and allowed for a more reliable chemical room especially in the consistency of the resin that was much more variable before due to the imprecision of the process involved.

The 7 mudas were used on a much larger scale in the factory. Because the factory was experiencing quality issues, the management team decided that implementing lean into the factory would be the best course of action moving forward. With this, the engineers discovered much of the waste discussed in the 7 mudas and the solution towards this was moving towards single piece flow for the factory.

Transportation: the composite beams that were produced in the pultrusion process were made and then transported into holding until where they would wait for final assembly. After final assembly, they were again transported into holding waiting final shipment. Transporting these beams multiple times was altogether wasteful and could be best addressed through implementing single piece flow. Although I didn't stay long enough to see the full single piece flow be implemented, the logistic change where beams were taken directly from the pultrude and into final assembly yielded great results in terms of efficiency and quality in the factory. There was much less confusion from the workers perspective as to which parts should be applied to which beam and why.

Inventory: Because the factory had not implemented single piece flow yet, there was still significant unworked inventory. This inventory took up valuable floor space that could have been used for more machines space for finalized inventory. However, it was being used by unfinished composite beams. Reducing the inventory meant that Maclean-Fogg could now transition into single piece flow. The floor space that the inventory occupied previously prevented the factory from expanding unless a new building was constructed.

Motion: Wasted motion in the final assembly was identified. The assemblers were walking back and forth between their bench and the tool desk to retrieved commonly used tools. This was done because many of the tools are quickly lost on the messy table deck, so they resorted to keeping the tools in one central location. After performing an operator motion analysis, the engineering team determined that 17% of the operator's time was spent going to and from the tool desk. To address this, the factory hung tools from the ceiling following proper OSHA regulations. This was very well received by the assemblers and benefitted the entire process as a whole because it meant that this stage of the production process could process more beams daily.

Waiting: wasted time waiting was also found in the assembler's station. Sometimes assemblers would be overloaded with work and on other days they would have 5 hours' worth of work on an 8 hour day. This waste was due to poor scheduling on the management team side. This poor scheduling meant that these workers were being overworked on some days and under worked on others. This issue was addressed by the engineers through an improved scheduling process that allows for less variability in the beam production process as to reduce the variation in the final assembly. This change resulted in happier workers on the assembler table. Although less quantifiable, it means that their workers are more likely to do a quality job on the beams as they do not feel overworked.

Overproduction: Over production was an issue at the factory due to the long lead time for orders. The factory often made beams that hadn't necessarily been ordered to alleviate long lead times but this meant wasted product. To address this, the team implemented quicker switch over processes for the composite beams. The biggest example of this was the new CNC drill that could process several beams per minute, reducing the overall drilling and production time. This change resulted in shorter lead times and less waste for the factory.

Over-processing: The factory did not necessarily have waste from over-processing. Although there was a CNC drill, different form the one mentioned in overproduction, that was extremely time consuming, this drill was faster than any other option in the market and was needed for complicated drill patterns with several different bit sizes.

Defects: Defect waste was a major problem in the factory primarily from the drilling in the composite beams. When the drill bits became dull, they resulted in composite beams that needed to be reworked or potentially thrown away. Because testing is expensive, engineers could only test a few drill bits. The team determined that if 1 drill bit was dull, it was best to sharpen the rest assuming they had comparable use. This implementation meant that drill operators no longer had to guess if they can and cannot use a certain drill bit. This change resulted in less rework in the final assembly and also less wasted composite beams.