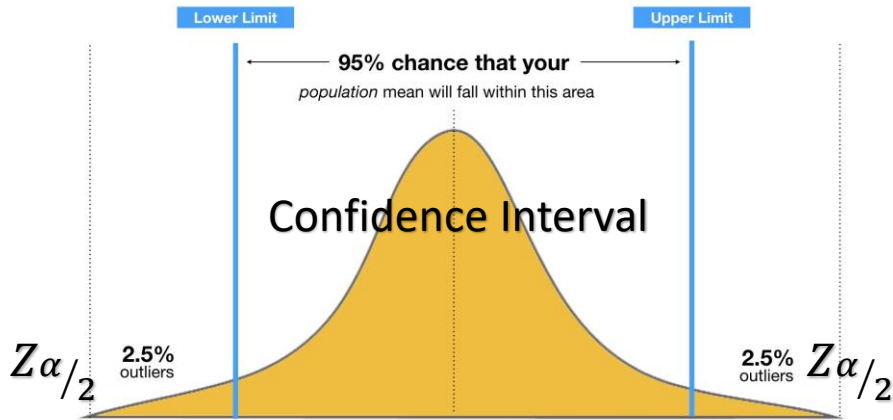
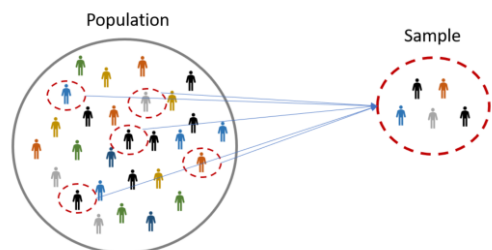




Statistics Cheat sheets



Attribute Agreement Analysis Cheat Sheet

Significance and Basic Definitions

Every time someone makes a decision, it is critical that the decision-maker would select the same choice again and that others would reach the same conclusion. Attribute agreement analysis measures whether or not several people making a judgment or assessment of the same item would have a high level of agreement among themselves by evaluating the repeatability, reproducibility, and overall accuracy of the appraisers.

This type of analysis can be applied to discrete (nominal or ordinal) data:

- Nominal data assigns names to each data point without placing it in order (i.e. Pass, Fail)
- Ordinal data groups data according to some sort of ranking system (i.e. scale of 1 to 10).



Benefits of an Attribute Agreement Analysis:

- Helps to characterize the quality of the data
- Determines the area of non-agreement
- Helps in calibrating appraisers, judges, or assessors for a higher level of agreement

Appraiser – The person who is making the decision.

Expert – The main SME that creates the standard to compare the appraisers' answers to (optional).

Repeatability – Variation in the assessment when it is repeated on the same part, by the same operator.

Reproducibility – Variation in the assessment when it is repeated on the same part, by a different operator.

Excel Set-Up

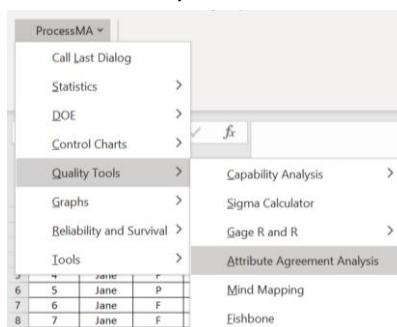
ProcessMA is very particular about how the data is entered. Be sure that column labels are in row 1 and data begins in row 2. Also ensure that there is no data below the table (i.e. sum or average).

- 1) Create columns for the sample, appraiser, result, and standard (optional).

	A	B	C	D
1	Sample	Appraiser	Expert	Answers
2	1	Jane	P	P
3	2	Jane	P	P
4	3	Jane	P	P
5	4	Jane	F	F
6	5	Jane	P	P
7	6	Jane	F	P
8	7	Jane	F	F
9	8	Jane	F	F
10	9	Jane	P	P
11	10	Jane	F	F
12	1	Tim	P	F

13	2	Tim	P	P
14	3	Tim	P	P
15	4	Tim	F	F
16	5	Tim	P	P
17	6	Tim	F	F
18	7	Tim	F	F
19	8	Tim	F	F
20	9	Tim	P	P
21	10	Tim	F	F
22	1	Will	P	P
23	2	Will	P	P

- 2) Navigate to “Add-Ins” – “ProcessMA” – “Quality Tools” – “Attribute Agreement Analysis”.



Box Plots Cheat Sheet

Significance and Basic Definitions

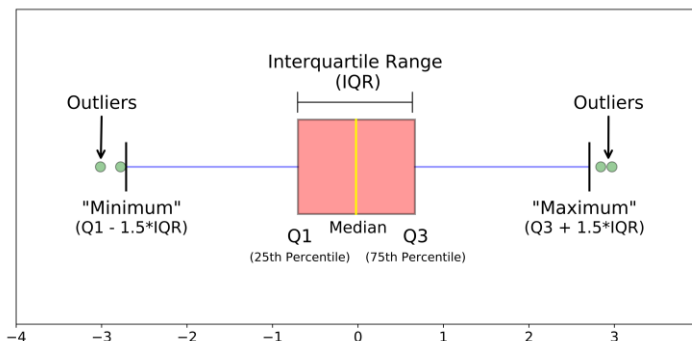
A boxplot, also known as a box and whisker chart, is a standardized and visual way to display the distribution of data based on a five-number summary. It is useful for datasets that require more than just the measures of central tendency (mean, median, and mode) to indicate if data is skewed and to help identify potential outliers. Boxplots are also extremely useful when comparing datasets.

The five-number summary includes:

1. **Minimum:** Calculated value ($Q1 - 1.5 \cdot IQR$)
2. **First Quartile (Q1):** The middle number between the smallest value and the median
3. **Median (Q2):** The middle value of the dataset
4. **Third Quartile (Q3):** The middle value between the median and the highest value
5. **Maximum:** Calculated value ($Q1 + 1.5 \cdot IQR$)

The **Interquartile Range (IQR)** is the range of Q1 to Q3, aka the 25th to the 75th percentile

'Whiskers' extend outwards to indicate the highest and lowest values excluding any outliers



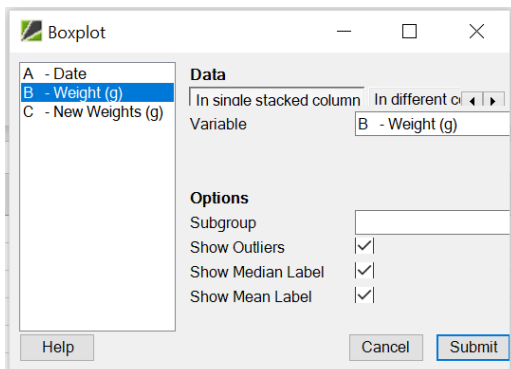
Outliers, represented by a dot, are outside the IQR by more than $1.5 \cdot IQR$

Excel Set-Up

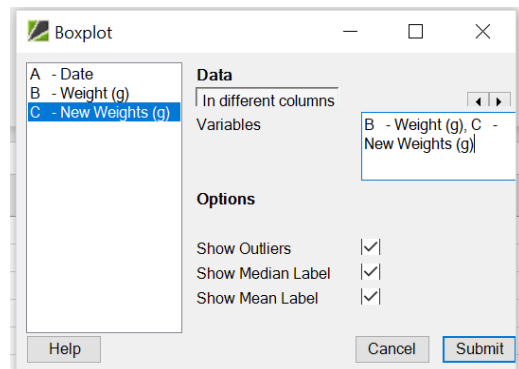
ProcessMA is very particular about how the data is entered. Be sure that column labels are in row 1 and data begins in row 2. Also ensure that there is no data below the table (i.e. sum or average).

- 1) Create a column for the data that is being analyzed.
- 2) Navigate to "Add-Ins" – "ProcessMA" – "Graphs" – "Boxplots".
- 3) For a **single dataset**, select the data for Variable by double clicking on the lettered options from the column headers. For **multiple datasets**, click the 'In different columns' tab and then select the data for Variables by double clicking on the lettered options from the column headers. Also click the checkboxes to show the outliers, median label, and mean label.

Single



Double

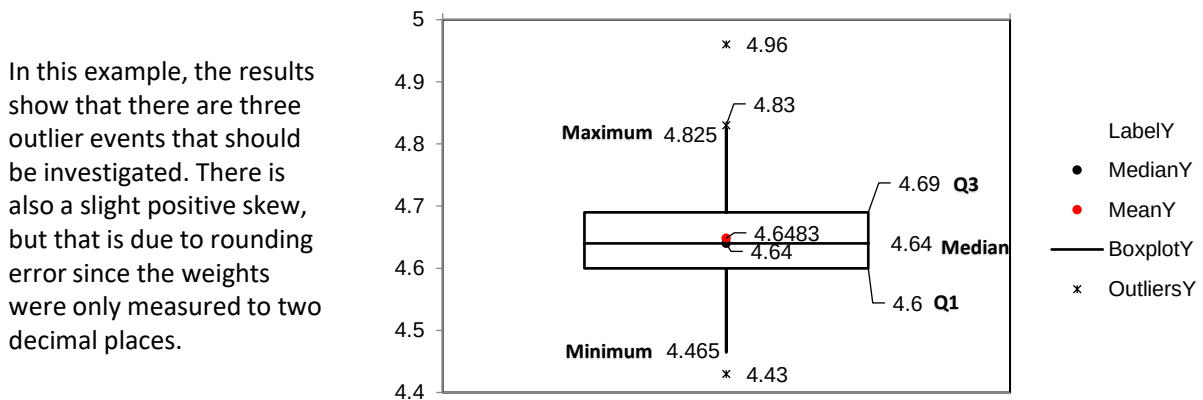


- 4) Press "Submit". The Attribute Agreement Analysis will open in a new tab.

Results and Interpretation

The result of the Boxplot will appear in the following format with five-number summary previously discussed. The graph can be manipulated in the same manner as a regular Excel graph to include data labels a legend, etc.:

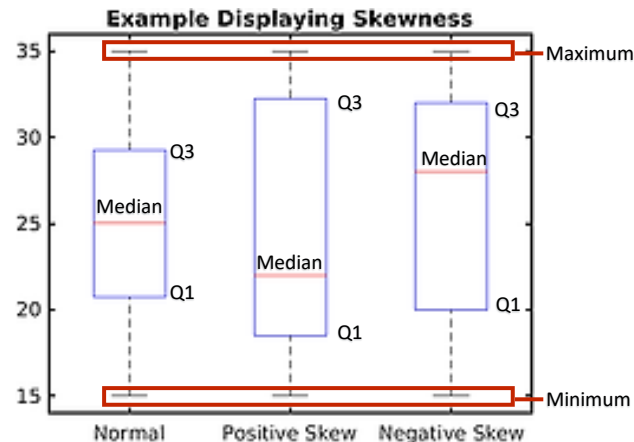
Boxplot - Weight (g)



The graph can be used to interpret if the data is skewed if one of the boxes is larger than the other. Skewed data indicates that the data may be non-normal.

A **Positive or Right Skew** means that the mean is greater than the median, and is to the right of the peak in a distribution curve.

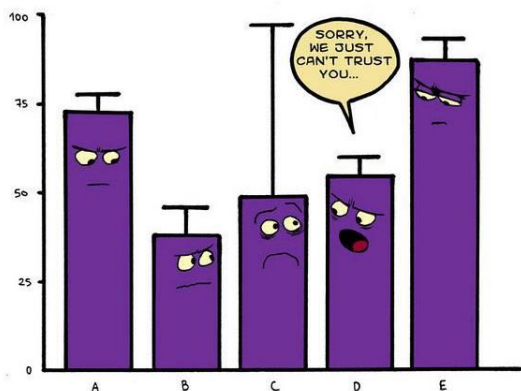
A **Negative or Left Skew** means that the mean is less than the median, and is to the left of the peak in a distribution curve.



Outliers can strongly impact the results. Try to identify the cause of any outliers and consider removing values associated with abnormal 'special cause' events, then repeat the analysis.

When comparing **groups** of data, take special consideration of the median and spread of the datasets:

Different **medians (Q2)** of the datasets indicate there is likely to be a difference between the groups, especially when the median of a dataset is outside of the IQR of another dataset.



The length of the '**whiskers**' can also be used to show the variability in the data, as longer whiskers denote higher variability which is less desirable in most cases. Skewed data will also have whiskers of different lengths; left skewed has a longer left whisker and vice-versa.

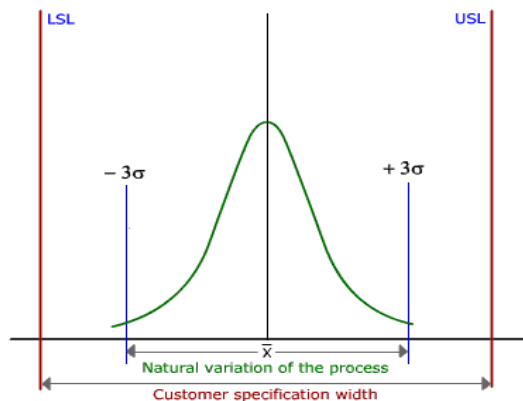
Capability Analysis Cheat Sheet

Significance and Basic Definitions

A Capability Analysis helps to determine how well a process meets a set of specification limits, or how well a process performs.

Important definitions include:

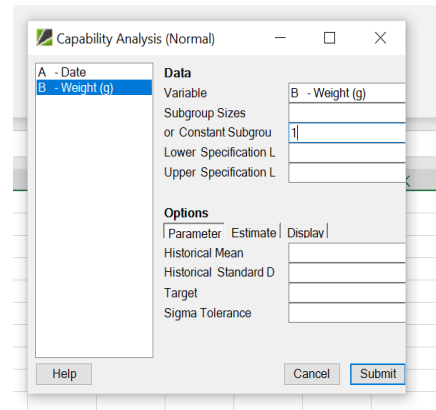
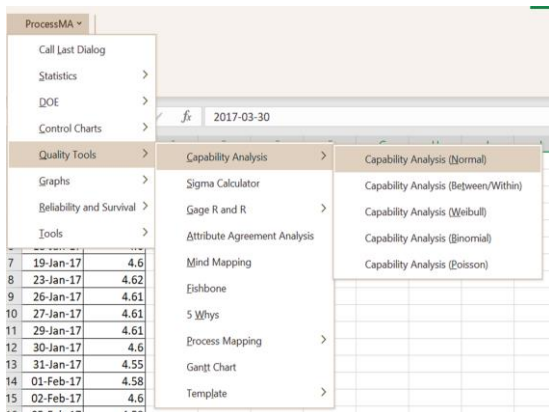
- **Process Capability (C_p)**: the potential of meeting the upper and lower specification limits
- **Process Capability Index (C_{pk})**: the capability of achieving an output within certain specifications
- **Process Performance (P_p)**: the actual performance of a system meeting the upper and lower limits
- **Process Performance Index (P_{pk})**: the performance of achieving an output within specifications



Excel Set-Up

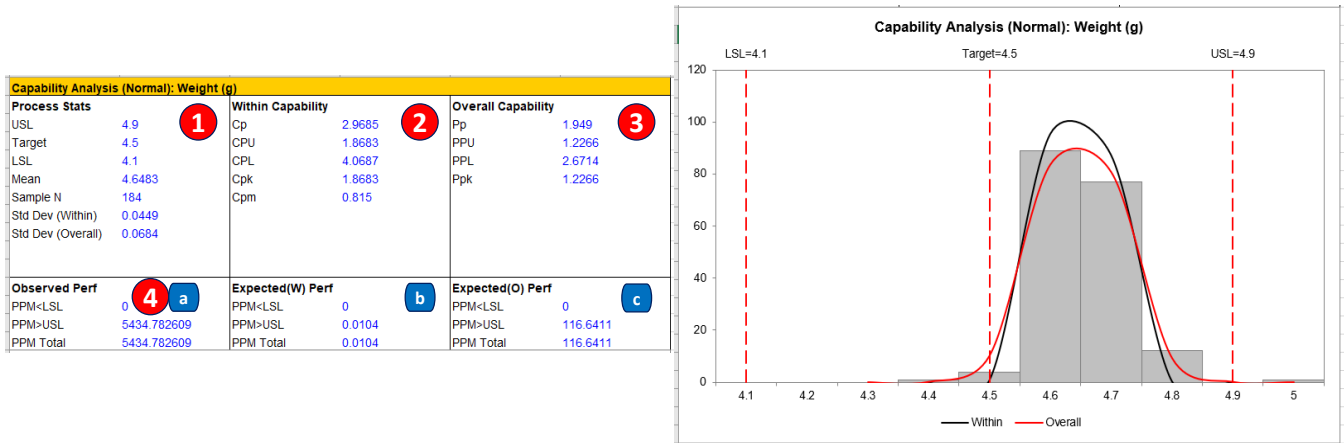
Before doing a capability analysis, check that your data is normally distributed and statistically in control. These can be checked using a normality test and a control chart in ProcessMA ("Statistics" – "Normality Test", and "Control Charts" – "Variable Control Charts for Individuals" – "I-MR")

- 1) Create columns for the **measurement(s)**. Row 1 is the title and the data begins in Row 2.
- 2) "Add-Ins" – "ProcessMA" – "Quality Tools" – "Capability Analysis" – "Capability Analysis (Normal)".
- 3) Select the appropriate variable. Leave 'Subgroup Sizes' blank and 1 for 'Constant Subgroup Size'. Enter the 'Lower Specification Limit' and 'Upper Specification Limit'. If there is a target value, it can be entered for 'Target'.



Results and Interpretation

The result of the Capability Analysis will appear in the following format with several components, each conveying different types of information. The components include:



1 Process Stats:

Std Dev (Within): variation within the subgroup from common cause or inherent sources.

Std Dev (Overall): long term variability including common and special cause sources.

- A substantial difference between within and overall may indicate the process is not stable or has additional sources of variation

2 Within Capability: The level of performance the process could obtain in the **short-term** if all sources of variation are eliminated.

C_p : variation within the subgroup from common cause or inherent sources.

CPU/CPL : How close the mean is to the UCL/LCL

C_{pk} : The lesser of CPU and CPL

C_{pm} : Overall capability index that measures whether the process meets specification and is on target (target value must be entered).

- C_p , C_{pk} , and $C_{pm} \geq 1.33$ is preferred. If C_p , C_{pk} , or $C_{pm} < 1$, the process is not capable of meeting the specification
- The difference between C_p and C_{pk} indicates how far the average of the process is from the target. If $C_p > C_{pk}$ the process is off center. When $C_p = C_{pk}$, the process is centered at the midpoint of the specification limits

3 Overall Capability: Represents the level of performance the process could obtain in the **long-term** if all sources of variation are eliminated.

P_p : variation within the population from common cause or inherent sources.

PPU/PPL : How close the mean is to the UCL/LCL

P_{pk} : The lesser of PPU and PPL

- Same rules as C_p and C_{pk} apply to P_p and P_{pk}
- If C_p and C_{pk} are much greater than (33%+) P_p and P_{pk} , the process may not be suitable for a capability analysis and a control chart should be used instead

4 a, b, and c Performance: Parts per million outside the limits.

- Preferred to have as few PPM outside of the limits as possible, indicating there are no nonconforming units (PPM Total = 0)

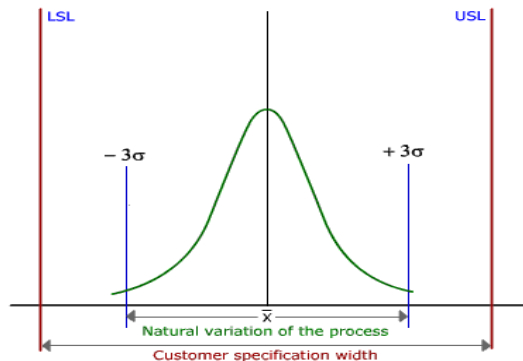
Capability Analysis Cheat Sheet

Significance and Basic Definitions

A Capability Analysis helps to determine how well a process meets a set of specification limits, or how well a process performs.

Important definitions include:

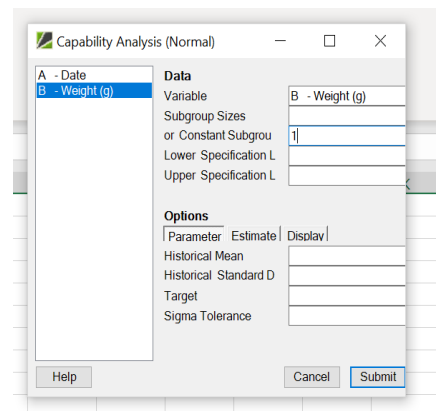
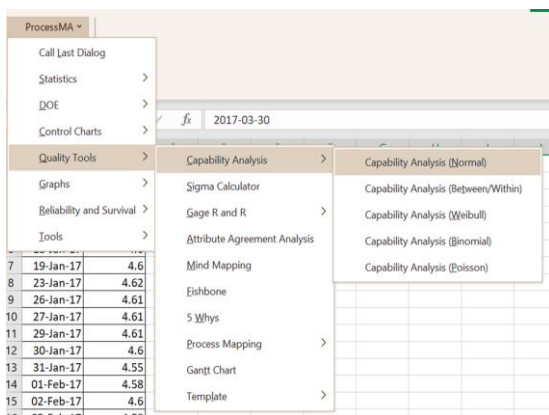
- **Process Capability (C_p)**: the potential a system has of meeting both the upper and lower specification limits
- **Process Capability Index (C_{pk})**: the capability a process has of achieving an output within certain specifications
- **Process Performance (P_p)**: the actual performance of a system meeting both the upper and lower specification limits
- **Process Performance Index (P_{pk})**: the actual performance of a system achieving an output within certain specifications



Excel Set-Up

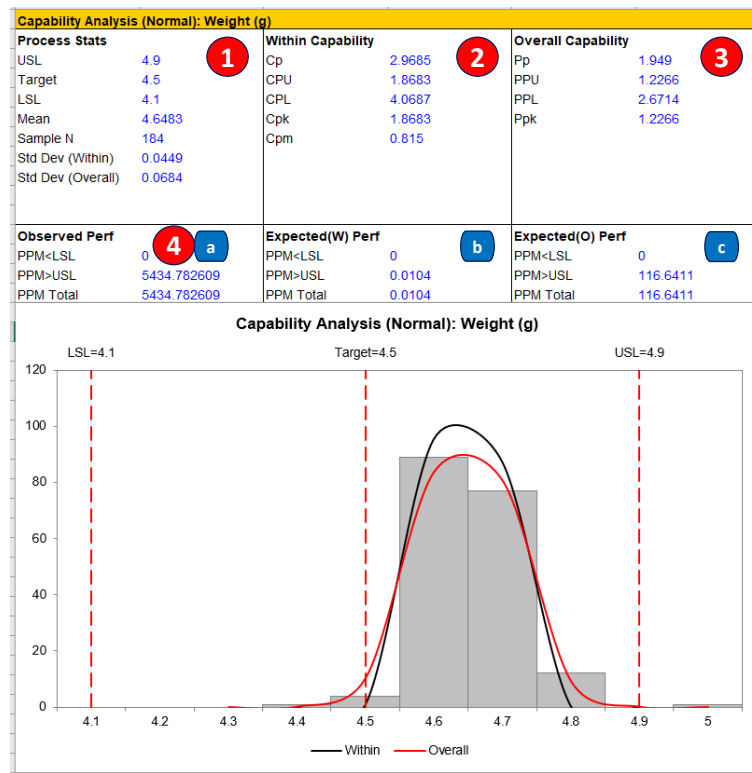
Before doing a capability analysis, check that your data is normally distributed and statistically in control. These can be checked using a normality test and a control chart in ProcessMA ("Statistics" – "Normality Test", and "Control Charts" – "Variable Control Charts for Individuals" – "I-MR")

- 1) Create columns for the **measurement(s)**. Row 1 is the title and the data begins in Row 2.
- 2) Navigate to "Add-Ins" – "ProcessMA" – "Quality Tools" – "Capability Analysis" – "Capability Analysis (Normal)".
- 3) Select the appropriate variable for analysis. Leave 'Subgroup Sizes' blank and 1 for 'Constant Subgroup Size'. Enter the 'Lower Specification Limit' and 'Upper Specification Limit'. If there is a target value, it can be entered for 'Target'.
- 4) Press 'Submit'.



Results

The result of the Capability Analysis will appear in the following format with several components, each conveying different types of information. The components include:



- 1 Process Stats:**

Std Dev (Within): variation within the subgroup from common cause or inherent sources.

Std Dev (Overall): long term variability including common and special cause sources.
- 2 Within Capability:** Represents the level of performance the process could obtain in the **short-term** if all sources of variation are eliminated.

C_p : variation within the subgroup from common cause or inherent sources.

CPU : How close the mean is to the UCL

CPL : How close the mean is to the LSL

C_{pk} : The lesser of CPU and CPL

C_{pm} : Overall capability index that measures whether the process meets specification and is on target (target value must be entered). The target is not centered
- 3 Overall Capability:** Represents the level of performance the process could obtain in the **long-term** if all sources of variation are eliminated.

P_p : variation within the population from common cause or inherent sources.

PPU : How close the mean is to the UCL

PPL : How close the mean is to the LSL

P_{pk} : The lesser of PPU and PPL
- 4**
 - a Observed Performance:** Parts per million outside the limits calculated using only the sample data.
 - b Expected(W) Perf:** Estimated nonconforming units using the **within** capability standard deviation.
 - c Expected(O) Perf:** Estimated nonconforming units using the **overall** capability standard deviation.

Interpretation

1 Process Stats:

- A substantial difference between the within standard deviation and the overall standard deviation may indicate the process is not stable or has additional sources of variation
- Larger values of between standard deviation indicates greater variation between subgroups, while larger values of within indicate greater variation in the subgroup

2 Within Capability:

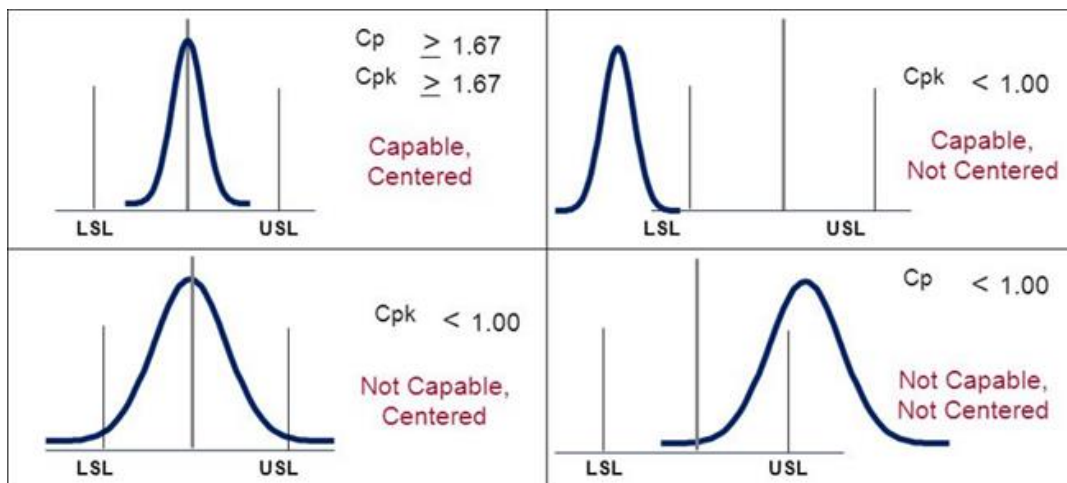
- $C_p \geq 1.33$ is preferred. If $C_p < 1$, the process is not capable of meeting the specification
- $C_{pk} \geq 1.33$ is preferred, the greater the number the better. If $C_{pk} < 1$, the process is not capable of meeting the specification
- The difference between C_p and C_{pk} indicates how far the average of the process is from the target. If $C_p > C_{pk}$ the process is off center. When $C_p = C_{pk}$, the process is centered at the midpoint of the specification limits
- $C_{pm} \geq 1.33$ is preferred. If $C_{pm} < 1$, the process is not capable of meeting the specification

3 Overall Capability:

- Same rules as C_p and C_{pk} apply to P_p and P_{pk}
- If C_p and C_{pk} are much greater than (33%+) P_p and P_{pk} , the process may not be suitable for a capability analysis and a control chart should be used instead

4 a, b, and c Performance:

- Preferred to have as few PPM outside of the limits as possible, indicating there are no nonconforming units (PPM Total = 0)



Control Chart Cheat Sheet

Significance and Basic Definitions

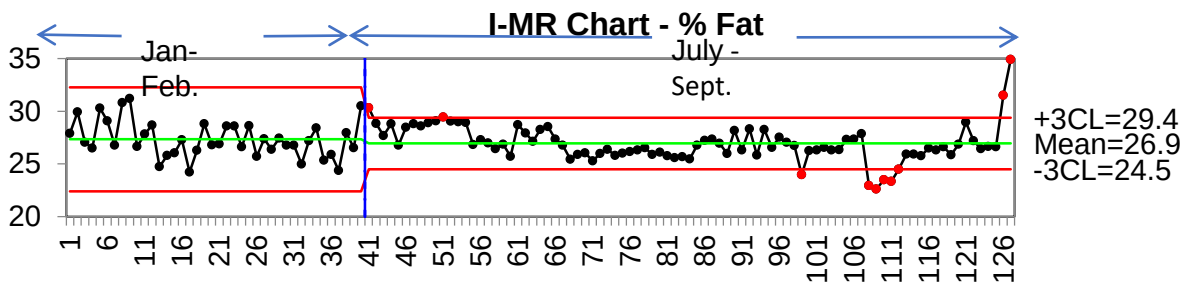
Control Charts help to:

- Detect unknown changes in a process
- Evaluate planned changes
- Communicate the effect of changes

Important definitions include:

- **Mean** – the average of the values.
- **Standard Deviation** – quantification of how far measurements for a group are spread out from the average (mean), or expected value.
- **Common Cause Variation** – inherent to the process, is likely not controllable or easy to control.
- **Special Cause Variation** – an assignable reason is causing variation that likely can be controlled.

In the example below, a new, more accurate testing method was introduced in February. We can clearly communicate that the Upper and Lower Control Limits are noticeably tighter. Aside from a few outliers, there is more control of the process. Consistent monitoring allows us to quickly detect results outside of the spec limits and allows further investigation of the outlying events. When cause for the outlier is determined the process may be able to be controlled even more, creating tighter specs and fewer losses.



Excel Set-Up

ProcessMA is very particular about how the data is entered. Be sure that **column labels are in row 1** and **data begins in row 2**. Also ensure that there is no data below the table (i.e. sum or average).

The most commonly used Control Chart is the I-MR, it plots individual data points and the differences between each successive point.

Navigate to "Add-Ins" – "ProcessMA" – "Control Charts" – "Variables Charts for Individuals" – "I-MR".

A pop up will open to set up the data for the test. The test requires a Variable, next select the Limit tab and set the upper and lower limit tab

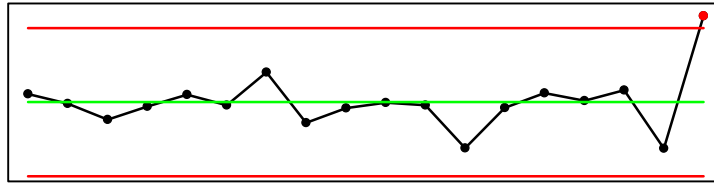
When interpreting Control Charts, the below Rules consider 3 Zones between the Upper and Lower Control Limits – A, B and C.

UCL	Zone A	CL+3 σ
	Zone B	CL+2 σ
	Zone C	CL+1 σ
CL	Zone C	CL-1 σ
	Zone B	CL-2 σ
	Zone A	CL-3 σ

Results

Rule 1

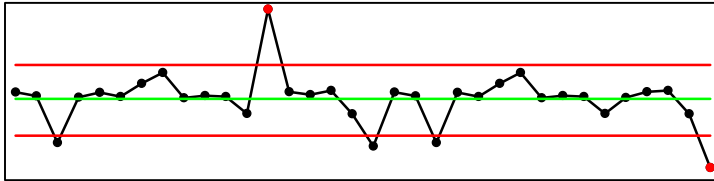
One point outside Zone A.



Assignable cause.

Rule 2

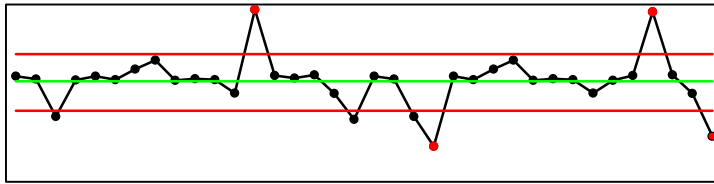
2-3 points outside Zone A.



Assignable cause.

Rule 3

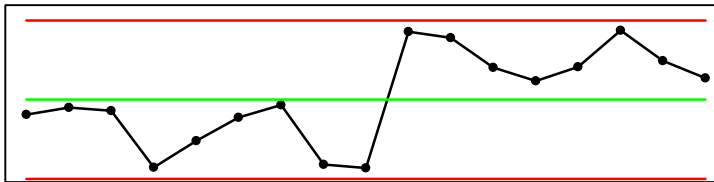
4-5 points outside Zone A or B



Assignable cause.

Rule 4

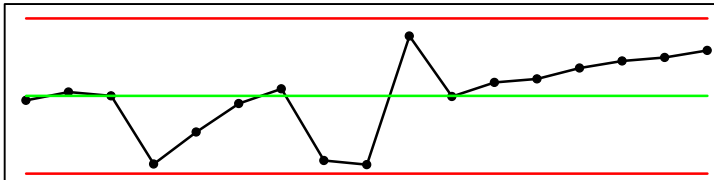
8 consecutive points on the same side of center line.



Change in the process.

Rule 5

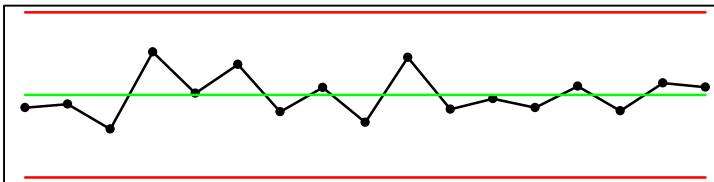
6 points trending upwards or downwards.



Indicates a trend to investigate

Rule 6

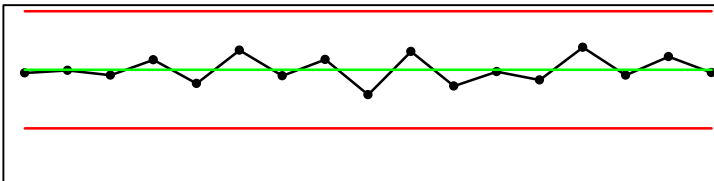
14 consecutive points alternating up and down



Indicates a mix of 2 processes.

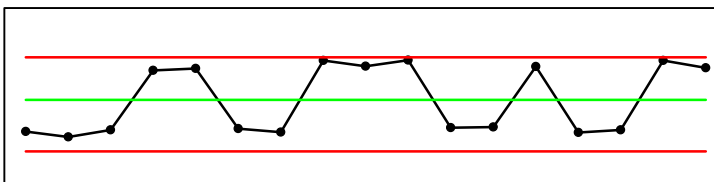
Rule 7

Points group around the center line, little variation.



Indicates sampling error or wrong control limits or real improvement.

Rule 8 Points hug each side of the mean, none in Zone C



Mix of different populations or cycle effect

Gage R&R Cheat Sheet

Significance and Basic Definitions

Gage R&R Studies help to investigate:

- The magnitude of measurement system variability in comparison to process variability
- The amount of variation between different operators
- Whether a measurement system is capable of discriminating between products

Important definitions include:

- **Repeatability:** variation from the measurement instrument
- **Reproducibility:** variation from the operators
- **Overall Gage R&R:** the combined effect of Repeatability and Reproducibility
- **Part-to-Part Variability:** Variation of the parts from each other
- **Number of Distinct Categories:** The number of groups that the measurement tool can distinguish

A typical study involves **3 operators** measuring **10 products**, **3 times** each. The minimum recommended testing includes 3 operators measuring 5 products at least 2 times each. It is important that the samples are taken across all major sources of process variation and are tested randomly.

Excel Set-Up

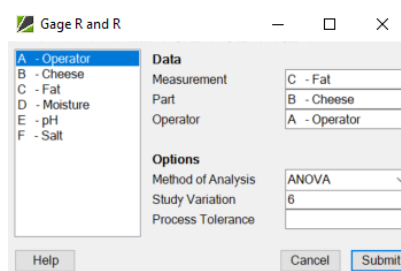
ProcessMA is very particular about how the data is entered. Be sure that **column labels are in row 1** and **data begins in row 2**. Also ensure that there is no data below the table (i.e. sum or average).

- 1) Create columns for **Operators** and **Products**. You can use letters, numbers, or names.
- 2) Create a column for **measurement(s)**.



Operator	Cheese	Fat	Moisture	pH	Salt
1	1	12.21	53.13	5.17	1.310
1	1	12.71	52.12	5.14	1.336
1	1	11.98	52.73	5.30	1.713
2	1	12.30	53.14	5.39	1.554
2	1	11.83	53.46	5.53	1.779
2	1	11.98	53.04	5.48	1.716
3	1	12.42	53.50	5.26	1.760
3	1	13.11	53.25	5.37	1.790

- 3) Navigate to “Add-Ins” – “ProcessMA” – “Quality Tools” – “Gage R&R” – “Gage R&R”.
- 4) Select the data for Measurement, Part/Product, and Operator by double clicking on the lettered options from the column headers. Leave the ‘Options’ as ANOVA for Method of Analysis, 6 for Study Variation, and leave Process Tolerance blank.



- 5) Press “Submit”. The Gage R&R will open in a new tab.
- 6) Repeat the steps for any other measurement values that data has been collected (i.e. moisture, pH, salt content, etc.). Each measurement will have a separate Gage R&R so the results will need to be compared separately to find trends in sources of variance.

Results

ANOVA Table: Provides a statistical analysis of the variance in the selected data.

Gage R&R (Crossed): Fat					
ANOVA					
Source	DoF	SS	MS	F	P Value
Part	6	505.377	84.2295	1010.5326	0
Operator	2	0.386	0.193	2.3155	0.1411
Operator*Part	12	1.0002	0.0834	2.3918	0.0185
Repeatability	42	1.4637	0.0348		
Total	62	508.2269			

Source	Varcomp	%Varcomp	StdDev(SD)	StudyVar(6*SD)	%StudyVar
Total Gage R&R	0.0562	0.60%	0.2371	1.4223	6.03%
Repeatability	0.0348	0.37%	0.1867	1.1201	4.53%
Reproducibility	0.0214	0.23%	0.1462	0.8775	3.50%
Operator	0.0052	0.06%	0.0723	0.4336	1.73%
Operator*Part	0.0162	0.17%	0.1272	0.7829	3.13%
Part-to-Part	9.3496	93.40%	3.0577	18.3462	73.70%
Total Variation	9.4058	100%	3.0669	18.4013	100%

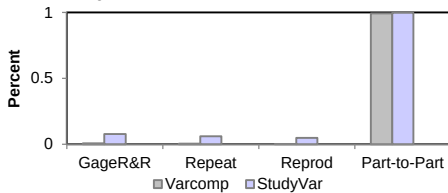
#Dist Category: 16

a Total Gage R&R: Concludes if the measurement system is acceptable.

% R&R	Decision
Less than 10%	Acceptable measurement system
10% – 30%	Acceptable depending on application
More than 30%	Not an acceptable measurement system

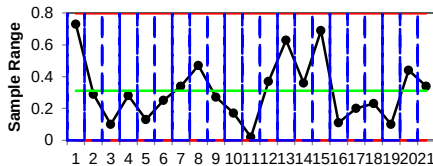
b # Distinct Categories: Ideal to have more categories than products you are trying to differentiate between.

Components of Variation: Shows how much each category contributes to the overall variation.



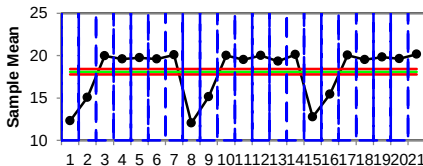
- Want to see high Part-to-Part variability, Low Gage R&R, Low Repeatability, and Low Reducibility
- High Gage R&R (>30%) indicates variability is coming from the measurement system itself which is not ideal

R Chart by Operator: Represents if your operators are repeatable.



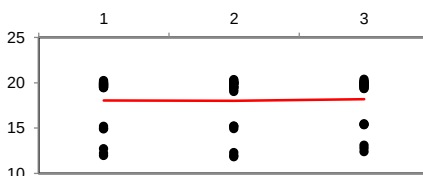
- Values should be low and within the control limits denoted by the red lines
- Values outside the control limits indicate high test-retest error which is undesirable

X-bar Chart by Operator: Shows the average for each part by Operator to show the part-to-part variability.



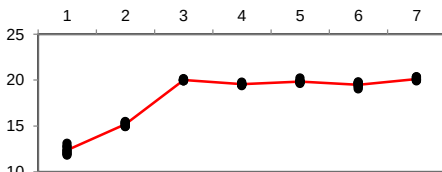
- Most values should fall out of the control limits to confirm high part-to-part variability
- Pattern should be similar for each operator to show reproducibility

By Operator: Depicts reproducibility, if operators are able to achieve the same result.



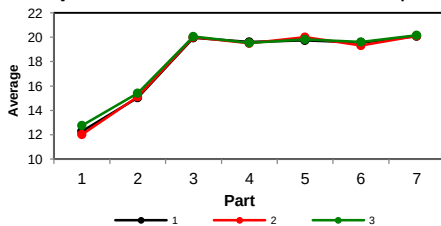
- The spread of the points and trendline depicts if the operators are achieving similar results
- Horizontal line is good, operators getting similar results
- Slanted line means operator's results are different

By Part: Displays the variability between parts.



- Plot should not be horizontal – a horizontal line means all samples are of a similar measured value and should cover the full range of possible measurements

Operator*Part Interactions: Depicts the interaction between Operator and the part.



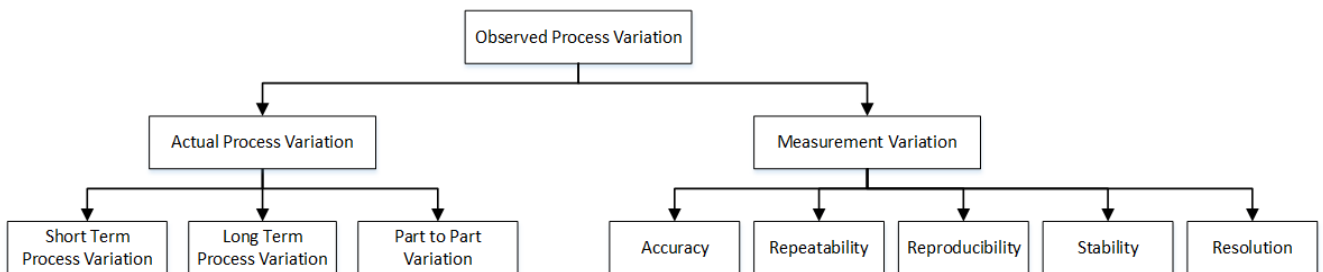
- Lines should overlap to show that the interaction between operator and part is low (results don't change due to operator variance)

Gage R&R Cheat Sheet

Significance and Basic Definitions

Variation exists in every manufacturing process; it is important to monitor, and in some cases, try to reduce the variation in order to maintain statistical control of the process. Gage R&R (Gage Repeatability & Reproducibility) is a methodology used to determine the source and amount of variability in measurement data. Variability can be introduced by factors such as differences in test methods, operators, measurement instrumentation, and products.

Understanding how to analyze the results of a Gage R&R strengthens the analyst's ability to determine the source and scope of measurement error and variation. By determining where the variation in the measurement system takes place, appropriate action can be taken to improve the quality of the data. This test can measure the precision of a system but further analysis is required when investigating the accuracy.



Gage R&R Studies help to investigate:

- The magnitude of measurement system variability in comparison to process variability.
- The amount of variation between different operators.
- Whether a measurement system can discriminate between products.

Gage – The measurement system that the analyses is aimed at validating.

Repeatability – Variation in the measurement when it is repeated on the same part, by the same operator.

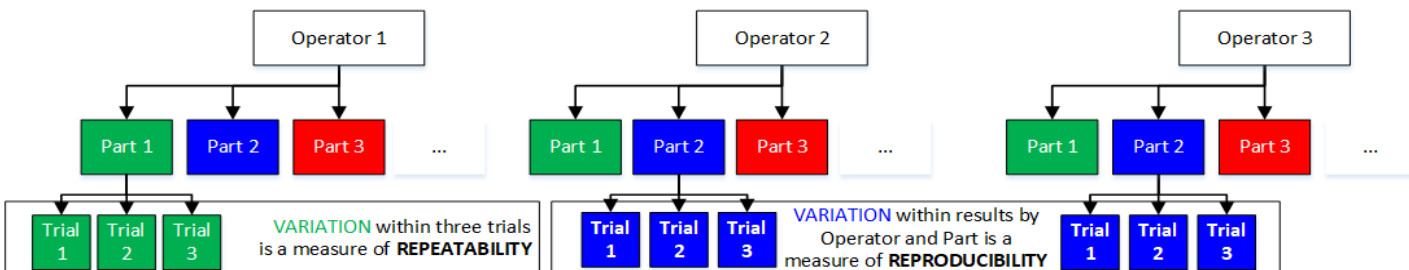
Reproducibility – Variation in the measurement when it is repeated on the same part, by a different operator.

Total Gage R&R – The amount of variation that can be attributed to the measurement system itself.

Part-to-Part Variability – Variation of the parts from each other.

Number of Distinct Categories – The number of categories that the measurement tool can distinguish.

Interaction – Interference between the operator and parts during the part set up and/or measurement.



A study should involve 3 operators measuring 10 products at least 3 times each.

The minimum recommended testing includes 3 operators measuring 5 products at least 2 times each. It is important that the samples are taken across all major sources of process variation, as well as tested randomly to ensure the study produces meaningful results.

The composition must represent 80% of the total specification range.

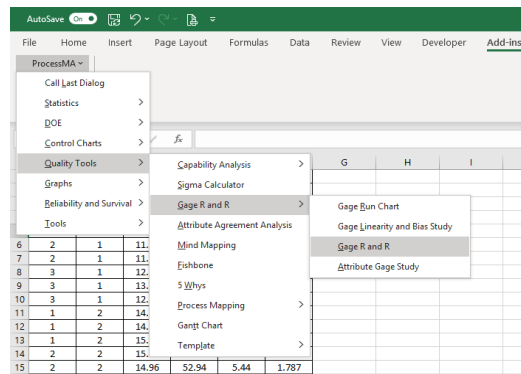
Excel Set-Up

ProcessMA is very particular about how the data is entered. Be sure that column labels are in row 1 and data begins in row 2. Also ensure that there is no data below the table (i.e. sum or average).

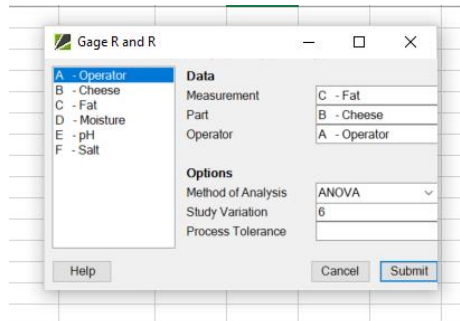
- 1) Create columns for Operators and Parts. You can use letters, numbers, or names.
- 2) Create a column for measurements.

	A	B	C	D	E	F
1	Operator	Cheese	Fat	Moisture	pH	Salt
2	1	1	12.21	53.13	5.17	1.310
3	1	1	12.71	52.12	5.14	1.336
4	1	1	11.98	52.73	5.30	1.713
5	2	1	12.30	53.14	5.39	1.554
6	2	1	11.83	53.46	5.53	1.779
7	2	1	11.98	53.04	5.48	1.716
8	3	1	12.42	53.50	5.26	1.760
9	3	1	13.11	53.25	5.37	1.790
10	3	1	12.79	53.25	5.37	1.560
11	1	2	14.92	51.49	5.18	1.594
12	1	2	14.99	51.62	5.16	1.507
13	1	2	15.21	51.08	5.11	1.501
14	2	2	15.18	52.90	5.38	1.727
15	2	2	14.96	52.94	5.44	1.787
16	2	2	15.23	51.21	5.35	1.678
17	3	2	15.37	52.57	5.23	1.670
18	3	2	15.48	52.84	5.28	1.700
19	3	2	15.42	51.78	5.30	1.780
20	1	3	19.93	47.54	5.10	1.347
21	1	3	19.92	49.02	5.13	1.347
22	1	3	20.02	49.34	5.24	1.708
23	2	3	20.09	49.86	5.30	1.503
24	2	3	19.92	49.42	5.31	1.591
25	2	3	20.01	49.19	5.24	1.532
26	3	3	20.17	50.48	5.34	1.790
27	3	3	20.00	50.05	5.24	1.620
28	3	3	19.97	49.80	5.26	1.580
29	1	4	19.48	50.27	5.47	1.8022
30	1	4	19.76	51.41	5.53	1.821
31	1	4	19.57	50.99	5.48	1.5688
32	2	4	19.5	50.73	5.62	1.6973
33	2	4	19.52	52	5.59	1.7836
34	2	4	19.52	49.93	5.97	1.6758
35	3	4	19.62	52.1	5.25	2.03
36	3	4	19.39	51.47	5.24	1.96
37	3	4	19.58	51.36	5.32	1.99
38	1	5	19.65	51.95	5.43	1.7973
39	1	5	19.78	52.5	5.5	1.6292

- 3) Navigate to “Add-Ins” – “ProcessMA” – “Quality Tools” – “Gage R&R” – “Gage R&R”.



- 4) Select the data for Measurement, Part (Product), and Operator by double clicking on the lettered options from the column headers. Leave the 'Options' as ANOVA for Method of Analysis, 6 for Study Variation, and leave Process Tolerance blank*.



- 5) Press “Submit”. The Gage R&R will open in a new tab.
- 6) Repeat the steps for any other measurement values that data has been collected (i.e. moisture, pH, salt content, etc.). Each measurement will have a separate Gage R&R so the results will need to be compared separately to find trends in sources of variance.

Results

The result of the Gage R&R will appear in the following format with several components, each conveying different types of information. The components include:

- 1 **ANOVA Table:** Provides a statistical analysis of the variance in the selected data. Two values are of importance when interpreting the results:

a **Total Gage R&R:** Amount of total variation of the measurement system. The resulting value concludes if the measurement system is acceptable.

Total Gage R&R – %StudyVar	Decision
Less than 10%	Acceptable measurement system
10% – 30%	Acceptable depending on application
More than 30%	Not an acceptable measurement system

b **# Distinct Categories:** Represents the number of groups that the measurement system can discern from the analyzed data. It is ideal to have more categories than products you are trying to differentiate between. Less categories than parts indicates the system can't tell the difference between parts, this is undesirable.

Gage R&R (Crossed): Fat					
ANOVA					
Source	DoF	SS	MS	F	P Value
Part	6	505.377	84.2295	1010.5326	0
Operator	2	0.386	0.193	2.3155	0.1411
Operator*Part	12	1.0002	0.0834	2.3918	0.0185
Repeatability	42	1.4637	0.0348		
Total	62	508.2269			
Source	Varcomp	%Varcomp	StdDev(SD)	StudyVar(6*SD)	%StudyVar
Total Gage R&R	0.0562	0.60%	0.2371	1.4229	7.73%
Repeatability	0.0348	0.37%	0.1867	1.1201	6.09%
Reproducibility	0.0214	0.23%	0.1462	0.8775	4.77%
Operator	0.0052	0.06%	0.0723	0.4336	2.36%
Operator*Part	0.0162	0.17%	0.1272	0.7629	4.15%
Part-to-Part	3.3496	99.40%	3.0577	18.3462	99.70%
Total Variation	3.4058	100%	3.0669	18.4013	100%
#Dist Category	18				

- 2 **Components of Variation:** A breakdown of the variation into categories based on how much each contributes to the overall variation.

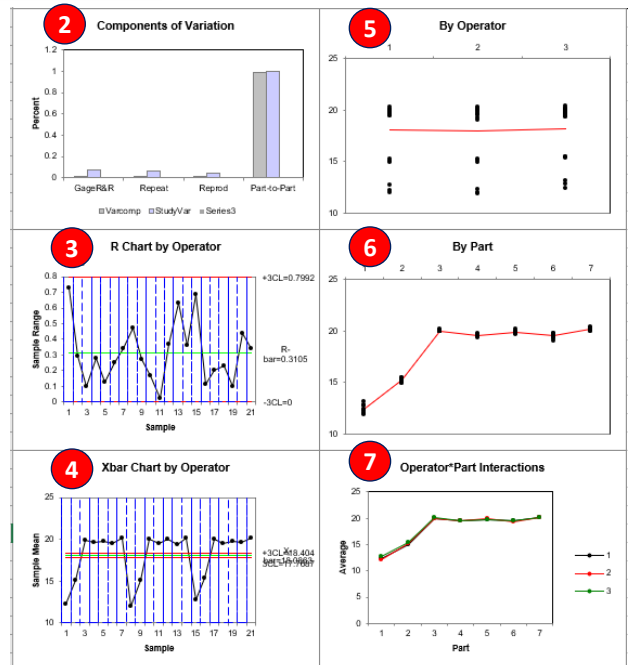
- 3 **R Chart by Operator:** Represents if your operators are repeatable.

- 4 **Xbar Chart by Operator:** Shows the average for each part by Operator to show the part-to-part variability.

- 5 **By Operator:** Depicts reproducibility, if operators can achieve the same result.

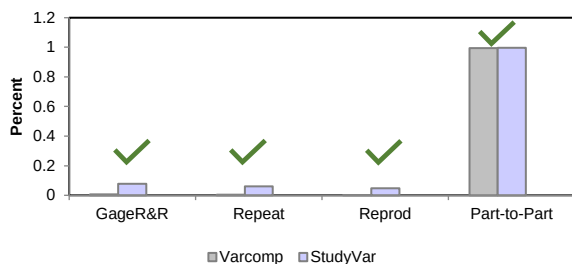
- 6 **By Part:** Displays the variability between parts.

- 7 **Operator*Part Interactions:** Depicts the interaction between Operator and the part.



2

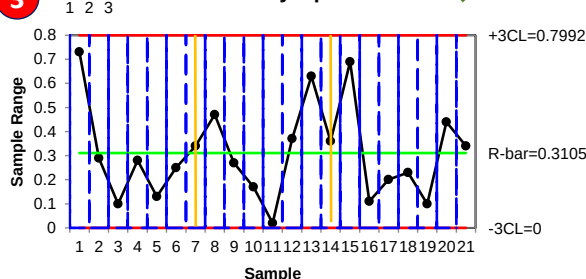
Components of Variation



- ✓ Want to see high Part-to-Part variability, Low Gage R&R, Low Repeatability, and Low Reducibility
- ✓ High Part-to-Part variability indicates most of the variation comes from the difference between parts which is ideal
- ✗ High Gage R&R (>30%) indicates variability is coming from the measurement system itself which is not ideal

3

R Chart by Operator



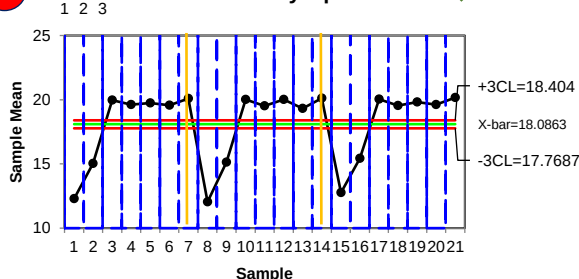
Each data point is the range for each operator (max – min)

- ✓ Values should be low and within the control limits denoted by the red lines
- ✗ Values outside the control limits indicate high test-retest error

Note: The sample range is divided by operator (i.e. Sample 1-7 is Operator 1, 8-14 is Operator 2, and 15-21 is Operator 3)

4

Xbar Chart by Operator



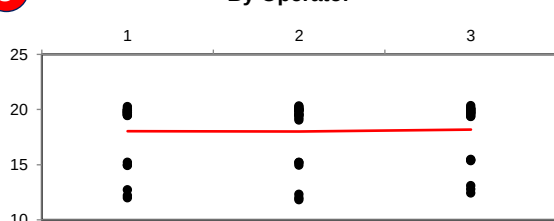
Each data point is the average for each operator showing part-to-part variability

- ✓ Most values should fall out of the control limits to confirm high part-to-part variability
- ✓ Pattern should be similar for each operator to show reproducibility

Note: The sample range is divided by operator (i.e. Sample 1-7 is Operator 1, 8-14 is Operator 2, and 15-21 is Operator 3)

5

By Operator

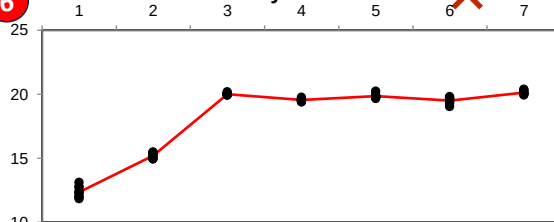


The spread of the points and trendline depicts if the operators are achieving similar results

- ✓ Horizontal line is good, operators getting similar results
- ✗ Slanted line means operator's results are different

6

By Part

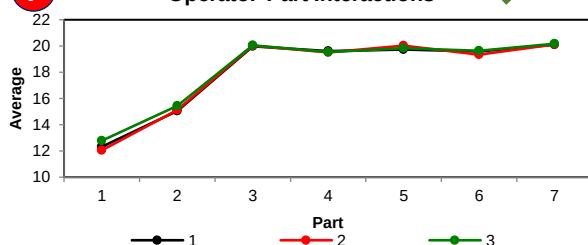


The result for each part for each operator is plotted and shows any within-part variability. The average for each part is used to plot the part-to-part variability

- ✗ Plot should not be horizontal – a horizontal line means all samples are of a similar measured value and instead should include the full variation of the process

7

Operator*Part Interactions



The similarity of the lines show whether there has been an interaction between the operator and a part.

- ✓ Lines should overlap to show that the interaction between operator and part is low.

★ Should always see a pattern in the shape of these 3 graphs

Introduction to Statistics

General Significance and Definitions

Statistics is the science of learning from data that has three key parts. First, statistics is a way to describe the data, specifically what is the center of data and the range or span of it. Second, it is a way to use the data to make predictions or decisions about what is unknown such as future outcomes. Third, statistics provides a means to predict the chance that the anticipated results are correct. In order to identify the correct trends, proper methods must be used to collect the data, apply the correct analyses, and effectively convey the results.

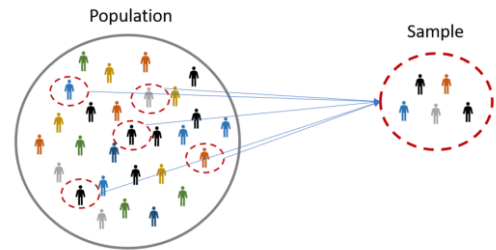
Data Collection

Analysis

Communicate Results

Population – Includes all of the elements from a set of data that are intended to generalize the results (i.e. food processing facilities in US).

Sample – A subset of the data from the population (i.e. XYZ company food processing facilities in US).



Name	Definition	Symbol	
		Population	Sample
Sample Size	Number of data points	N	n
Range	Difference between largest and smallest value	R	r
Mean	Average of all data points	μ	$\bar{x}$
Deviation	Difference between each data point and the mean	D	d
Variance	Measurement of the spread between numbers in a data set	σ^2	s^2
Standard Deviation	Measurement of the dispersion of a data set relative to the mean	σ	S

Standard Deviation and Variance can be calculated using the following equations:

$$\text{Variance } (\sigma^2) = \frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n}$$

$$\text{Standard Deviation } (\sigma) = \sqrt{\sigma^2}$$

Type I Error (α) – The amount of error that is acceptable (typically 0.05 which is 5%). This might vary depending on the situation and the willingness to be wrong, and is important in determining the correct sample size and confidence interval. This concept is further discussed in Hypothesis Testing.

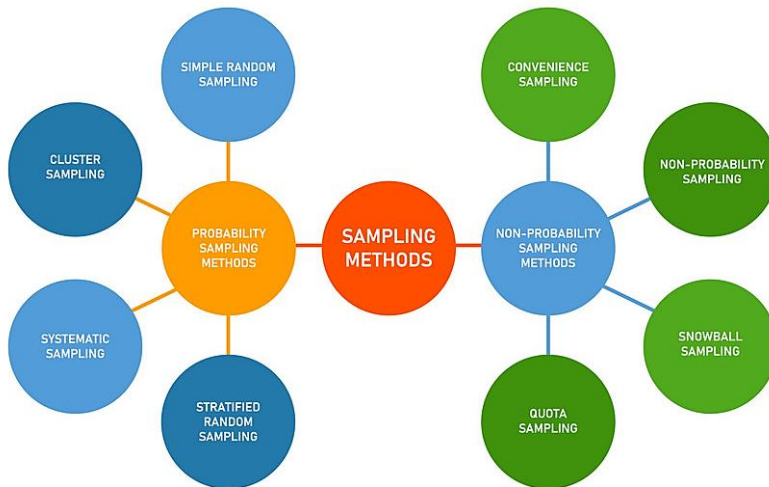
Some basic concepts that are important in statistics and are further described in this package are:

- Sampling
- Normality
- Confidence Intervals

Sampling

In most cases it is typical to deal with a sample instead of a population. In order to get accurate results, it is important that an adequate amount of sample data is collected in the correct way to fully capture the overall process.

It is important that the samples that are collected are unbiased. There are numerous different types of sampling that can be used. Some of these methods include:



Probability Sampling (Optimal):

- Used when complete population data is available
- Data samples can be randomly selected to get proportional data
- Results can be generalized to the population

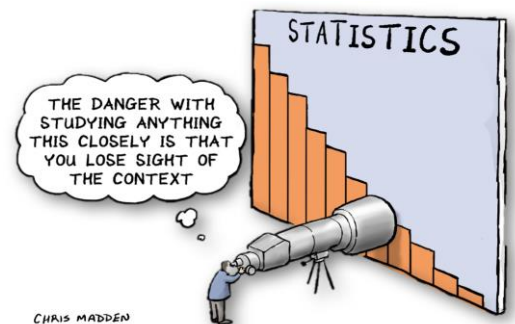
Non-Probability Sampling:

- Used when an exhaustive population list isn't available
- Relies on the subjective judgement of the investigator
- Can't generalize the results to an entire population with a high level of confidence

- **Simple Random Sampling:** All chances are equal, i.e. names from a hat.
- **Cluster Sampling:** The whole population is subdivided into clusters, or groups, and random samples are then collected from each group.
- **Systematic/Interval Sampling:** Select first unit at random and the rest at predetermined intervals.
- **Stratified Random Sampling:** Randomly selected at all levels, i.e. location, day, shift, operator, etc.

It is also important that an adequate number of samples are collected so that the proper conclusion can be drawn. Some factors that impact the sample size include:

- **Required Confidence Interval:** How much risk can be taken?
- **Amount of Inherent Variation in the Measured Variable:** involves the standard deviation of the population.
- **Maximum Allowable Error:** Allowable error based on industry requirements.



The following equation is used to calculate sample size:

$$\text{Sample Size } (n) = \left(\frac{Z_{\alpha/2} * \sigma}{E} \right)^2$$

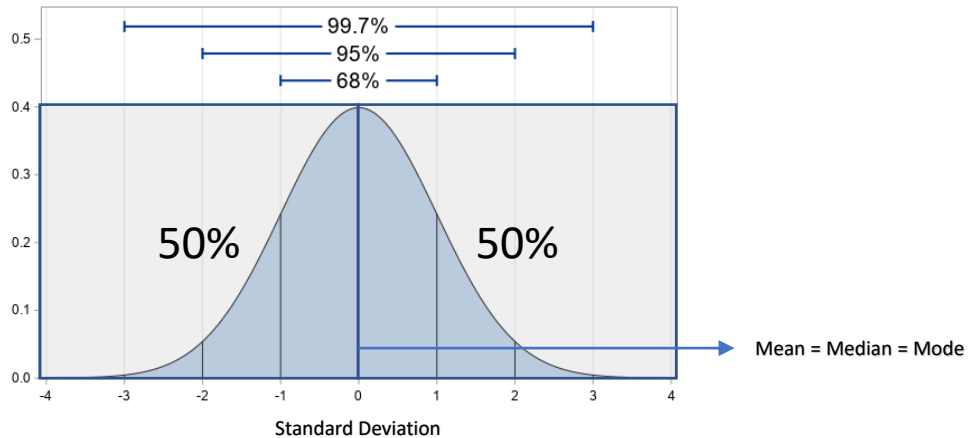
$Z_{\alpha/2}$ = Z-value of acceptable risk level
 σ = Estimate of population standard deviation
E = Maximum allowable error (same units as parameter being measured)

- The smaller the confidence interval that is required, the larger the sample size will be
- The larger the inherent variation (standard deviation), the larger the sample size
- The sample size is independent of population size – a 100x increase in population results in very little change in the sample size. However, reducing the confidence interval by half results in the sample size doubling

Normality

For data to be considered “normal,” it must be drawn from a population that has a normal distribution. A normal distribution has:

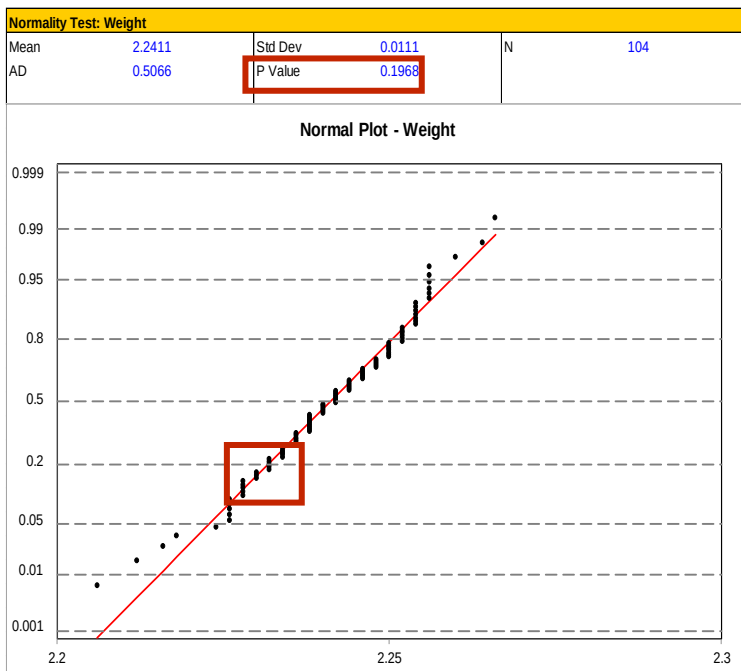
- Mean = Median = Mode
- Symmetry about the center
- 50% of values less than and greater than the mean
- 68% of values are within 1 standard deviation of the mean
- 95% of values are within 2 standard deviations of the mean
- 99.7% of values are within 3 standard deviations of the mean



To conduct a normality test in ProcessMA, navigate to ProcessMA/Statistics/Normality Test. Select the variable that is being investigated, then click ‘Submit’.

The result for the **P-Value** can be used to determine if the data is normal. If the result is greater than 0.05 (α), the data is normal.

Also, if the data is perfectly normal, the points on the plot will form a straight line.



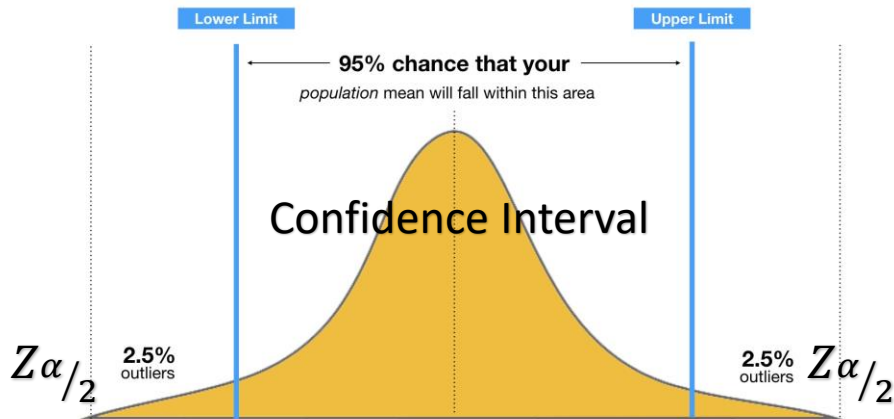
In this example, the results show a P-value of 0.1968. This value is > 0.05 , so we can conclude that the data is normal.

The data also forms a straight line, indicating that it is normal. However, the line is not perfectly straight as it has a slight ‘S’ shape with the highest and lowest values trailing off of the trendline.

Rounding error can be seen in the data as there are consistent gaps between the points. This will be seen if the measurement tool rounds the results (tolerance of ± 0.02).

Confidence Intervals

A Confidence Interval (CI) is a range of values defined with a specified probability within which the actual value of the parameter is expected to fall. In simpler terms, it is a range of values that the true value is expected to lie in. There is still a possibility that the true value lies outside of the confidence interval – this is associated with the acceptable level of error (α).



The width of the confidence interval is dependent on 3 factors:

1. Level of acceptable risk
2. Sample size
3. Amount of variation in the population (standard deviation)

The following equation is used to calculate the confidence interval:

$$\text{Confidence Interval} = \bar{x} \pm Z_{\alpha/2} \left(\frac{\sigma}{\sqrt{n}} \right)$$

Where:

$\bar{x}$ = Sample mean

$Z_{\alpha/2}$ = Z-value of associated risk level

σ = Standard deviation

n = Sample size

Process Mapping Cheat Sheet

Significance and General Procedure

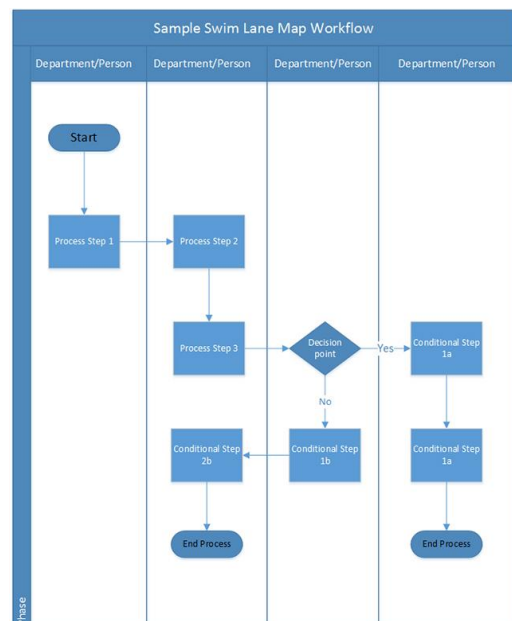
A process map helps to visually describe the flow of work by showing the series of events that are required to produce the end result. It shows who and what is involved in a process and can be used to identify improvement areas within processes including bottlenecks, repetition, and other non-value added steps. The actions that should be followed when creating a process map are:

- 1) Identify the process that is to be mapped
- 2) Determine the beginning and end of the process
- 3) Brainstorm the activities that are involved. It is important to decide what level of detail is going to be used
- 4) Establish the sequence of the steps in the process
- 5) Build the process map with basic flowchart symbols (if necessary)
- 6) Review and finalize the process map with all stakeholders

Process Map Symbols			
	Terminator (Start/End)		Inspection
	Process Steps		Storage
	Decision (Yes/No)		Delay
	Connector		Input or Output
	Document		Move/Transport
	Subprocess		

Different types of process maps may be used depending on the type of process that is being mapped and the situation that requires it to be outlined. Some of the different types include:

- **SIPOC:** identifies key stakeholders as well as the process at a high level
- **High Level Process Map:** provides a simple overview of the process, useful for communicating to leadership or others who don't require details
- **Detailed Process Map:** outlines every part of a process to get a thorough understanding, and makes it easy to identify non-value added tasks
- **Swimlane Map:** separates steps into channels according to who is responsible for the activity. This is valuable when there is a need to clearly identify the responsible party
- **Value Stream Map:** shows a top-down overview of a process with additional details that are used to recognize delays, restraints, and excess inventory that unproductively ties up resources



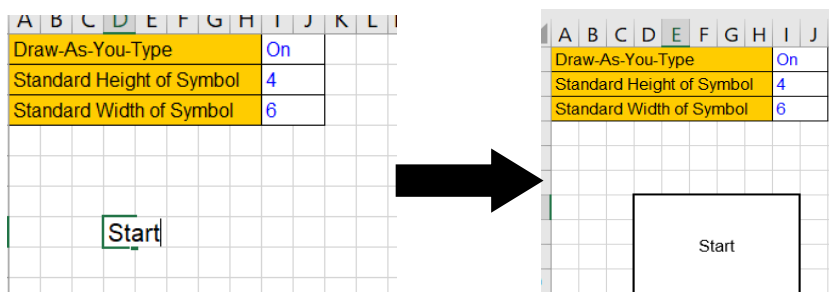
Note: It is not recommended to start building a process map using a software system. They can simply be drawn on a piece of paper or on a white board as a flow chart to start, then the final version can be created using the appropriate symbols. The most important thing is that the process is fully captured and can be used to increase understanding and potentially improve the process

When creating a process map in a group setting, it can be useful to map out a process using sticky notes (one sticky note per step) so that the activities can be easily rearranged as information gets added.

Excel Set-Up

Simple process maps can be created in ProcessMA.

- 1) Navigate to “Add-Ins” – “ProcessMA” – “Quality Tools” – “Process Mapping” – “New Map”. This will open a new sheet that will create a process step with the text that is entered into any cell.



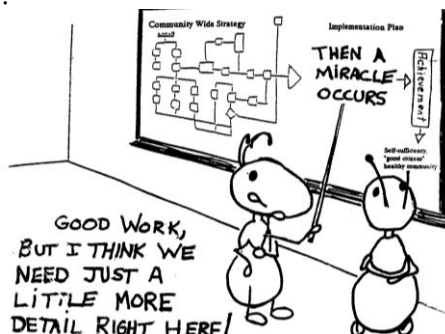
- a) The size of the block can be changed by adjusting the ‘Standard Height’ and ‘Standard Width’ options
 - b) To stop the sheet from creating process step boxes as you type, turn “Draw-As-You-Type” off using the drop down menu
- 2) Navigate to “Add-Ins” – “ProcessMA” – “Quality Tools” – “Process Mapping” – “Toolbar”. This will open a side menu to add different symbols to the process map. To add these symbols, select a cell in the area for the symbol to go, then click on the symbol in the menu
 - 3) Complete the process map as required with the appropriate symbols and connections
 - 4) To create a swimlane map, create the outline of the swimlanes with the borders tool

Note: Other software programs can be used for process mapping such as Microsoft Visio, or any other online tool

Next Steps

After the process map has been completed, it is helpful to ask some questions:

- Is the process being completed how it should be?
- Will team members follow the mapped process?
- Is the team in agreement with the flow of the process map?
- Is anything redundant?
- Are any steps missing?



Regression Analysis

Significance and Basic Definitions

Regression Analyses help to understand if there is a relationship between variables. The findings indicate the direction and strength of the relationship. By applying Regression analyses to our datasets we are able to better predict future events based on past events and optimize our process by determining what value or setting of our independent variable will achieve a desired value of the dependent.

Important definitions include:

- **Dependent variable** – the factor we are trying to understand / predict (Variable).
- **Independent variable** – the factors that may influence the dependent variable (Predictor).
- **Residual** – the difference between the observed result and the predicted value (fitted line/best fit line).
- **R²** – The percentage of variation that is explained by the independent variables.
- **Regression** – the relationship between the mean of a dependent variable and independent variables. There are two types of Regression analysis, linear and multiple.
 - Linear – considers **one** independent variable that could influence the dependent.
 - Multiple – considers **more than one** independent variable that could influence the dependent.

Assumptions

There are 4 assumptions for Regression Analysis:

1. **Normality** – the values of Y are normally distributed.
2. **Homoscedasticity** – the variation around the line of regression is constant, points are spread relatively evenly.
3. **Independence** – the error is independent for each X value; the residual difference between observed and predicted values.
4. **Linearity** – the relationship between variables is linear.

Excel Set-Up

ProcessMA is very particular about how the data is entered. Be sure that **column labels are in row 1** and **data begins in row 2**. Also ensure that there is no data below the table (i.e. sum or average).

This example uses data comparing In house and Maxxam Fat testing. This example uses **Linear** Regression as there is only 1 independent variable that influences the dependent.

With multiple independent variables, follow the same pathway when running **Multiple** Regression.

Data Selection

For **Linear** Regression navigate to “Add-Ins”–“ProcessMA”–“Statistics”–“Regression” – “Regression (Single Predictor)” .

For **Multiple** Regression Navigate to “Add-Ins”–“ProcessMA”–“Statistics”–“Regression” – “Regression (Multiple Predictors)” .

The screenshot shows the 'Regression (Single Predictor)' dialog box. On the left, a list of variables includes 'B - Fat In House', 'C - Fat Maxxam', 'D - Difference (In House -', 'E - Moisture In House', 'F - Moisture Maxxam', and 'G - Difference (In House -'. In the 'Data' section, 'Variable' is set to 'B - Fat In House' and 'Predictor' is set to 'C - Fat Maxxam'. Under 'Options', the 'Model' is set to 'Linear'. Several checkboxes are checked: 'Plot Residual', 'Plot Fitted Line', 'Show Confidence Bands', and 'Show Prediction Bands'. The 'Confidence Level' is set to '0.95'. At the bottom, there are 'Help', 'Cancel', and 'Submit' buttons.

Results and Interpretation

Regression Analysis: Fat In House

Regression Eqn $3.1029 + 0.8076 \text{Fat Maxxam}$
 S 0.5061
 R-Sq 0.6774
 R-Sq(adj) 0.6559

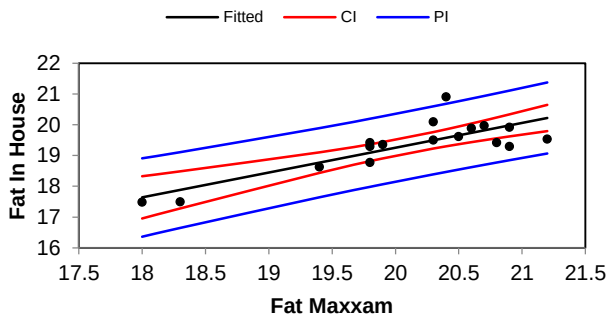
Predictor	Coef	SECoef	T	P Value
Constant	3.1029	2.894	1.0722	0.3006
Fat Maxxam	0.8076	0.1439	5.6123	0

ANOVA					
Source	DoF	SS	MS	F	P Value
Regression	1	8.0667	8.0667	31.498	0
Residual Error	15	3.8415	0.2561		
Total	16	11.9082			

The R^2 value shows that **65.59%** of the variation can be explained by our variables.

A p-value of **0.3006** is > 0.05 . This shows that there is not a strong statistical relationship between our variables.

Fitted Line Plot - Fat In House

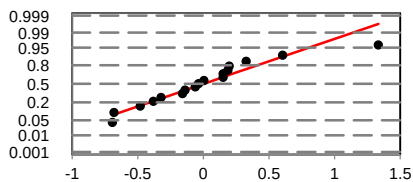


The **Fitted** line is the line of best fit. **Residuals** are measured as the distance from this line to the data point.

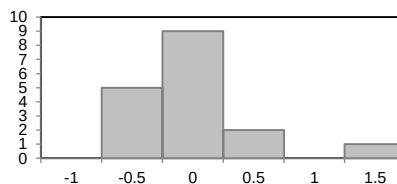
The **Confidence Interval** identifies where 95% of population values would fall if the survey was repeated with new observations from the population.

The **Prediction Interval** identifies where 95% of future values are expected to fall.

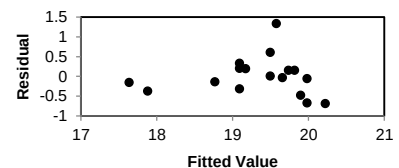
Normal Plot



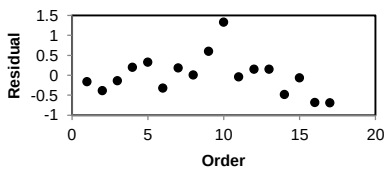
Histogram



Residuals VS Fitted Values



Residuals VS Order



Normality

The values on the Normal Plot must fall in a straight line. The Histogram should follow a bell shaped distribution.

Homoscedasticity

The Residual VS Fitted Values should show no pattern. It measures the distance of data points from the fitted line. A V shape indicates variance dependent on predicted values.

Independence

The Residual VS Order chart should show no pattern, a increasing or decreasing pattern suggests time influenced the results.

Linearity

The Fitted Line Plot should show a linear pattern.

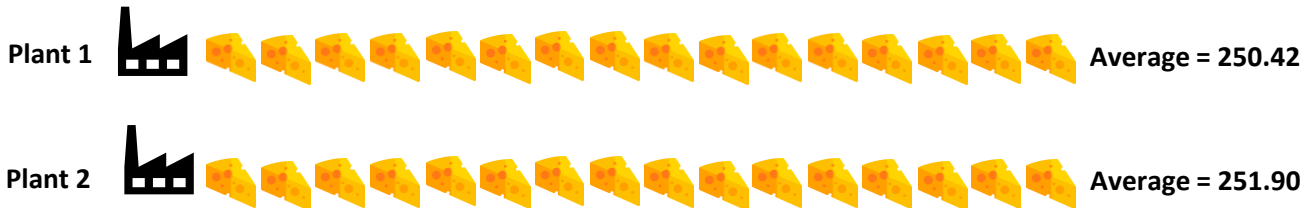
Findings

In an ideal scenario we would see a high R^2 value and low p-value to indicate a high amount of variation is explained by our independent variable and the relationship is statistically significant. A low R^2 value and high p-value shows a low amount of variation is explained by our independent variable and the relationship is not statistically significant. The example compares an internal and external method looking to achieve the same result, they **should** have a strong correlation. This could mean our internal method needs to be reviewed. When this occurs think – what other variables am I missing that could influence the results? What can I add to my research to better understand the situation?

T-Tests

Significance and Basic Definitions

T-Tests help to understand if the difference between variables is statistically significant. The test compare the average values of data sets and determine if they came from the same population. It is useful in understanding the overall variation, as an example let's look at weights of the same product from two different pieces of equipment.

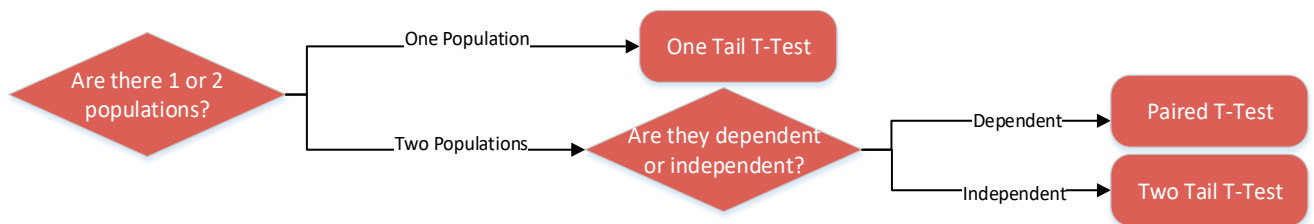


There are three different types of T-Tests to consider when analyzing your datasets – One Tail T-Test, Two-Tail T-Test and a Paired T-Test. Selecting the type of test to use is determined by the number of populations being examined and whether the variables are dependent or independent.

Important definitions include:

- **Alpha Risk** – the risk that a null hypothesis will be rejected when it is actually true. Meaning we wrongfully conclude that there is no relationship between the means.
- **Dependent variable** – the factor we are trying to understand / predict.
- **Independent variable** – the factors that may influence the dependent variable.
- **Directional** – Observing the change in one specific direction (less than, greater than)
- **Non-Directional** – Observing the change in any direction (less than and greater than)

Determining Which Test to Use



	One Tail T-Test	Two Tail T-Test	Paired T-Test
Purpose	Tests the difference between the sample & the population mean.	Tests the difference between the averages of two populations & the population mean.	Tests the difference between dependent samples & the population mean.
Direction	Measures in a single direction, greater or lesser than.	Measures in both directions, identifies any difference.	
Dependency	Independent Population	Independent Populations	Dependent Populations
Variance	N/A	Variances may not be equal	Variances are equal

Excel Set-Up

ProcessMA is very particular about how the data is entered. Be sure that **column labels are in row 1** and **data begins in row 2**. Also ensure that there is no data below the table (i.e. sum or average).

For a One-Tail Test navigate to “Add-Ins” – “ProcessMA” – “Statistics” – “Basic Statistics” – “1-Sample T”

For a Two-Tail Test navigate to “Add-Ins” – “ProcessMA” – “Statistics” – “Basic Statistics” – “2-Sample T”

For a Paired Test navigate to “Add-Ins” – “ProcessMA” – “Statistics” – “Basic Statistics” – “Paired T”.

A pop up will open to set up the data for the T-Test test. Each type of test requires a Variable, The Two-Tail and Paired Tests require a second Variable to be selected as it compares two datasets with our dependent variable. Select the data for Variables and Factors by double clicking on the lettered options from the column headers. Do not change the Confidence Interval, a 0.95 identifies where 95% of population values should fall if the survey was repeated with new observations from the population.

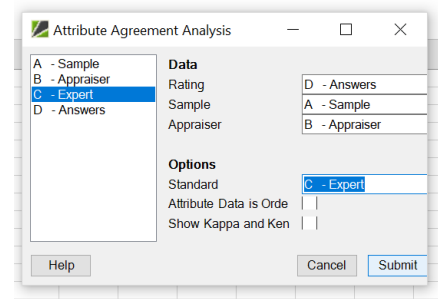
The example comparing product weights of separate plants requires a Paired T-Test to understand the relationship of the weight data.

Results and Interpretation

The low p-value (<0.05), this indicates that there is a significant difference between the means of Plant 1 and Plant 2.

Paired t Test: Plant 1 vs Plant 2					
Sample	Plant 1	Plant 2	Diff	95% Lower Bound	-2.132
N	16	16	16	95% Upper Bound	-0.8493
Mean	250.4156	251.9062	-1.4906	Test of diff	=0 vs <>0
Std Dev	0.3405	1.1991	1.2036	DoF	15
SE Mean	0.0851	0.2998	0.3009	T	-4.9537
				P Value	0.0002

- 3) Select the data for Rating, Sample, and Appraiser by double clicking on the lettered options from the column headers. Select the data for Standard if it is available. Press "Submit". The Attribute Agreement Analysis will open in a new tab.



Results and Interpretation

The result of the Attribute Agreement Analysis will appear in the following format with several components, each conveying different types of information. The components include:

Attribute Agreement Analysis: Answers					
Appraiser vs STD					
Assessment					
Appraiser	# Inspected	# Matched	Percent	95% CI - Lower	95% CI - Upper
Jane	30	27	90%	73.47%	97.89%
Jim	30	29	96.67%	82.78%	99.92%
Kate	30	28	93.33%	77.93%	99.18%
Sally	30	28	93.33%	77.93%	99.18%
Tim	30	28	93.33%	77.93%	99.18%
Will	30	30	100%	90.50%	100%
Between Appraiser					
Assessment					
	# Inspected	# Matched	Percent	95% CI - Lower	95% CI - Upper
	30	21	70%	50.60%	85.27%
All Appraiser vs STD					
Assessment					
	# Inspected	# Matched	Percent	95% CI - Lower	95% CI - Upper
	30	21	70%	50.60%	85.27%

All appraisers evaluated 30 items, of which 27-30 answers matched the experts (or 90-100%). Using this information, we can say with 95% confidence that there is 73.89 – 100% likelihood that the appraiser **will make the correct evaluation** (depending on the appraiser).

Of the 30 items evaluated, the answers for 21 of the items matched (or 70%). From this we can say with 95% confidence that there is a 50.60-85.27% chance that the appraisers **will agree on an answer**.

Of the 30 items evaluated, the answers for 21 of the items agreed with the standard (or 70%). Now we can say with 95% confidence that there is a 50.60-85.27% chance that the appraisers answers **will match the standard**.

For all components, it is desirable to have the percent as well as the upper and lower limits be as close to 100% as possible. The upper and lower limits dictate the likelihood for each category based on a 95% confidence interval. The acceptable lower limit or percentage would be dictated based on the situation and the risks associated with the appraisers making the incorrect conclusion.

- 1 **Appraiser vs STD:** Because there is a known standard for each sample, you can evaluate the accuracy and consistency of each of the appraiser's ratings.
- 2 **Between Appraiser:** Shows the number of samples that appraisers all agree on.
- 3 **All Appraisers vs STD:** Because there is a known standard for each sample, you can evaluate the accuracy of all the appraisers' ratings.

After identifying where the measurement system is weak one option is to make do with what you have and manage the risk, and the other is to take appropriate action:

- Implement training for appraisers
- Design visual aids to assist with the appraisal process
- Explore options for measurement 'tools' that would permit less subjective assessments