Objectives

- Create and interpret graphs in JMP

Creating Graphs in JMP

Several key graphical tools will be used throughout the DMAIC process. They include:

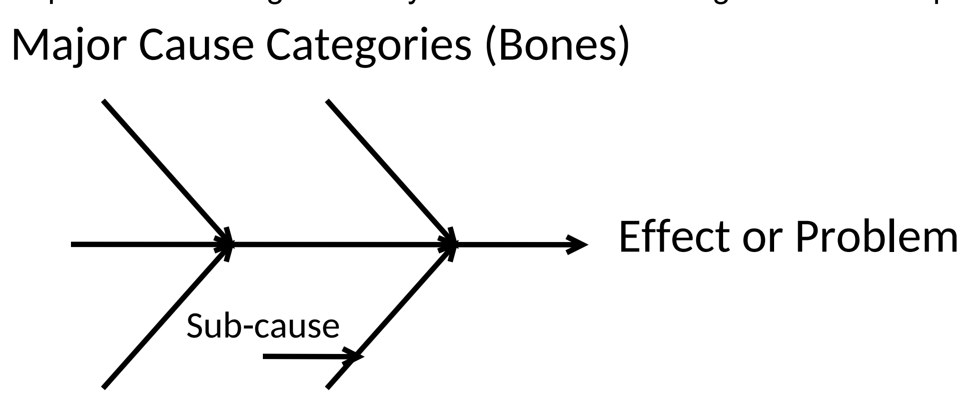
- Cause and Effect Diagrams
- Run Charts
- Histograms
- Pareto Plots
- Box Plots
- Scatter Plots

The versatility and simplicity of these tools are sometimes all that is required in a Green Belt project.

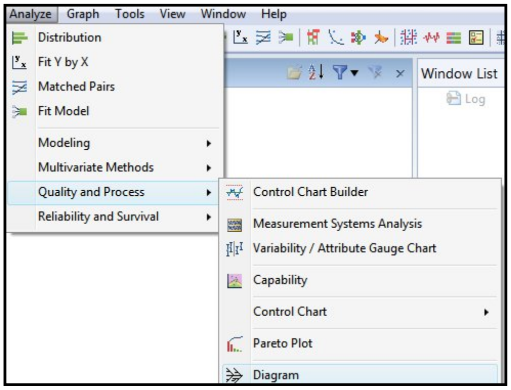
Cause and Effect Diagrams

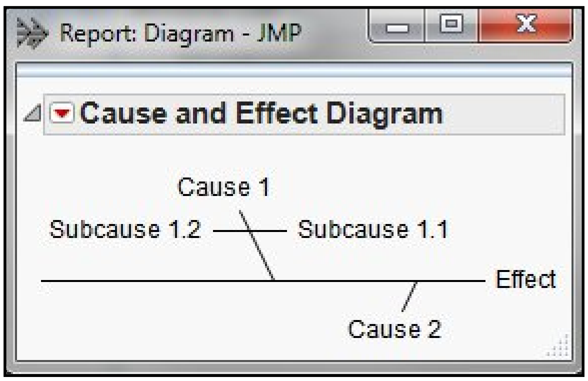
A Cause and Effect diagram is used in several phases of a Lean Six Sigma project to help teams organize ideas of all the possible causes that relate to the problem being investigated. Traditionally, the "Effect" or the problem is stated on the right hand side of the cause and effect diagram. The major "Causes" or bones are connected to the backbone of the chart. Sub-causes are then connected to the major causes.

The traditional major causes in manufacturing are Machine, Methods, Materials and People. These categories may be modified or changed to meet a specific problem.



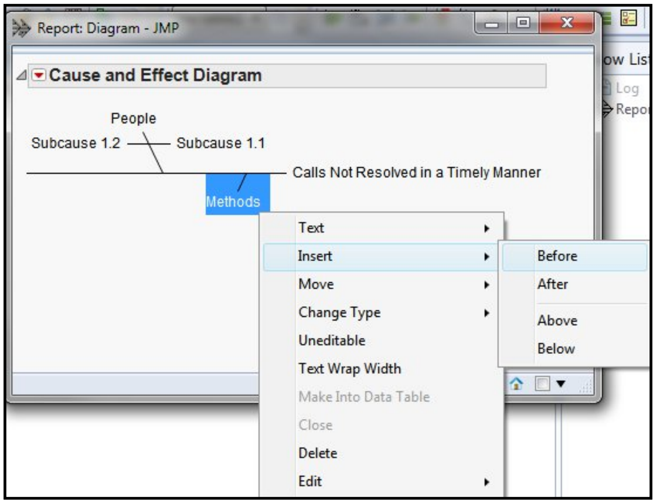
1. Close all open data tables. Save any changes made to **Call Center.JMP**.
2. Select **Analyze → Quality and Process → Diagram**.



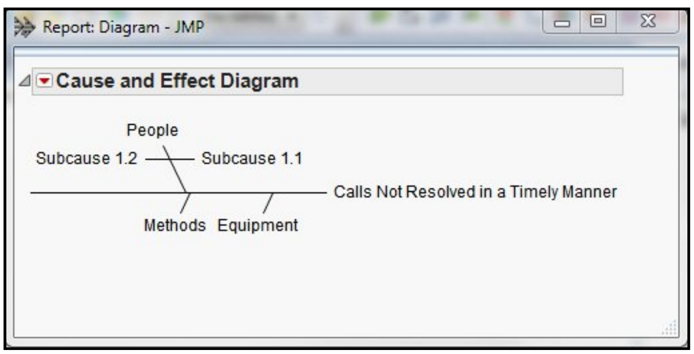


Generally, the problem under investigation becomes the Effect and the team brainstorms to create a list of potential Causes and Sub-Causes that are creating the problem.

3. Click on **Effect**. It will be highlighted. Type **Calls Not Resolved in a Timely Manner**.
4. Click on **Cause 1**. Type **People**.
5. Click on **Cause 2**. Type **Methods**.
6. Position the mouse so that **Methods** has a gray box around it.
7. Right click and select **Insert** → **Before**.

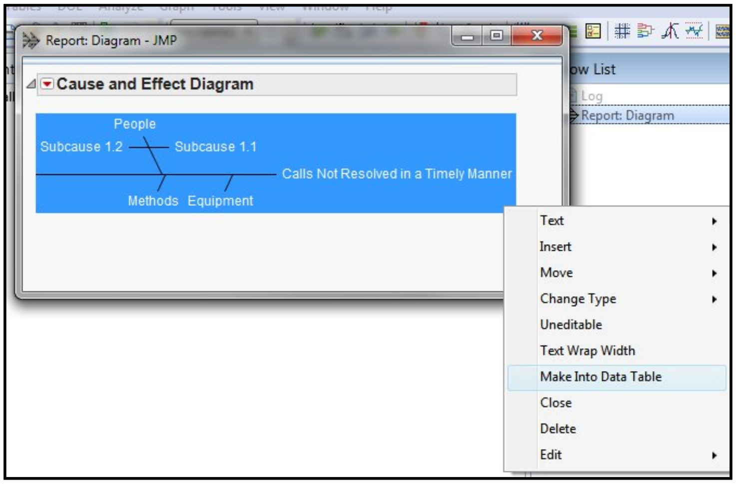


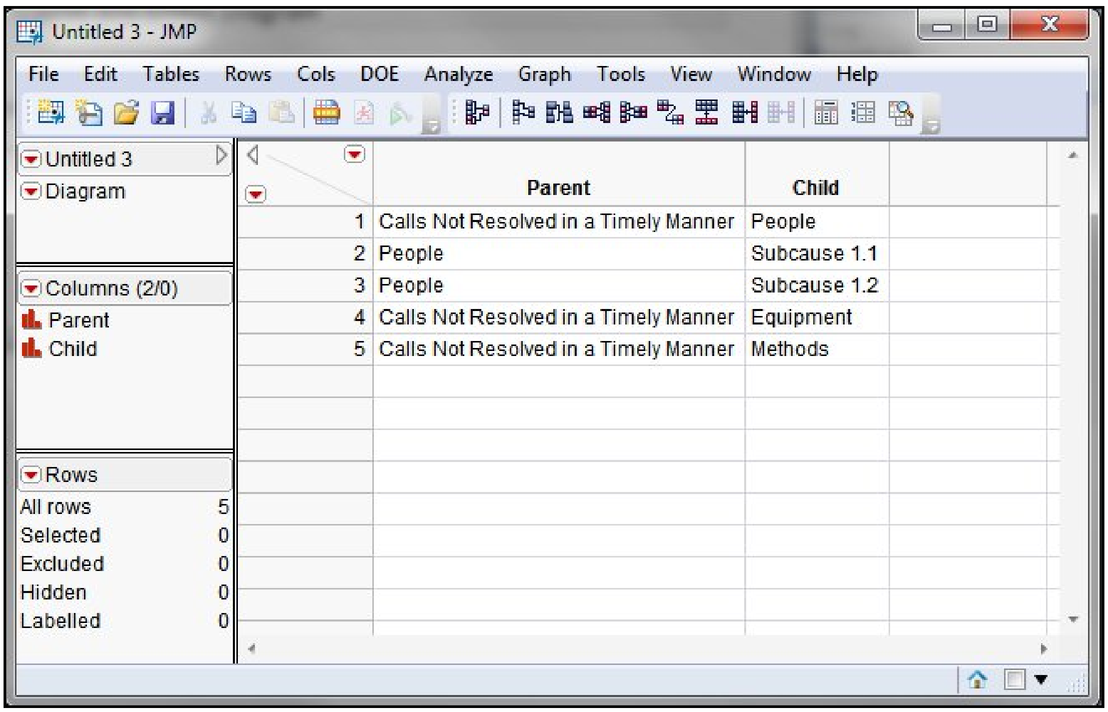
8. Type **Equipment**.
9. Select **OK**.



Once completed, the Cause and Effect diagram may be saved as a data table that may be edited by the team during subsequent meetings.

10. Position the mouse so that a gray box surrounds the entire Cause and Effect Diagram.
11. Right click and select **Make Into Data Table**.





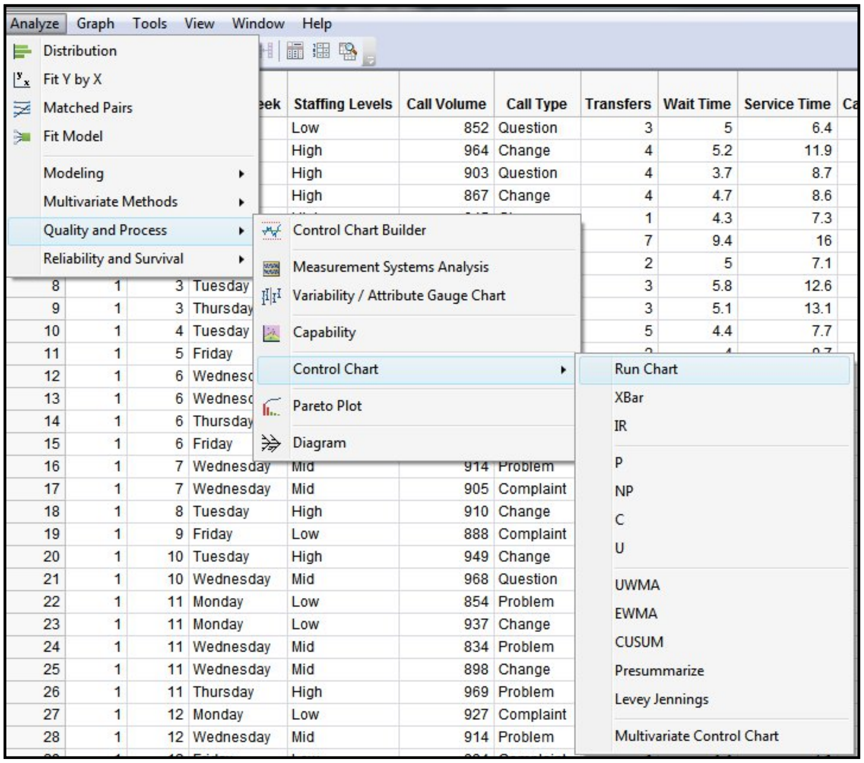
	Parent	Child
1	Calls Not Resolved in a Timely Manner	People
2	People	Subcause 1.1
3	People	Subcause 1.2
4	Calls Not Resolved in a Timely Manner	Equipment
5	Calls Not Resolved in a Timely Manner	Methods

12. Close and do not save the data table.

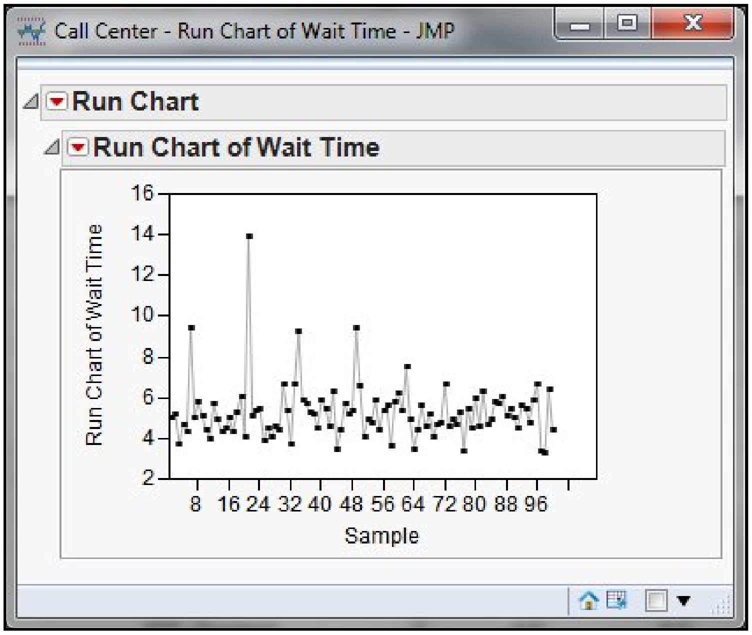
Run Charts

A Run Chart is used throughout a Six Sigma project to track the value of a measurement, such as the Project Metric across time. Teams may use the Run Chart to assess trends or cycles in the data.

1. Open **Call Center.JMP**.
2. Select **Analyze** → Quality and Process → **Legacy Control Charts** → **Run Chart**.

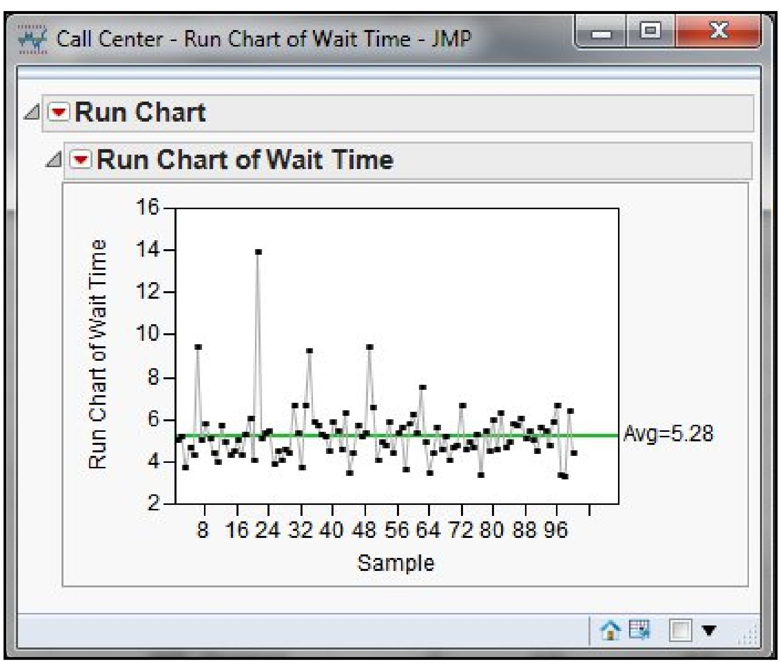


3. Select **Wait Time** → **Process**
4. Select **OK**.



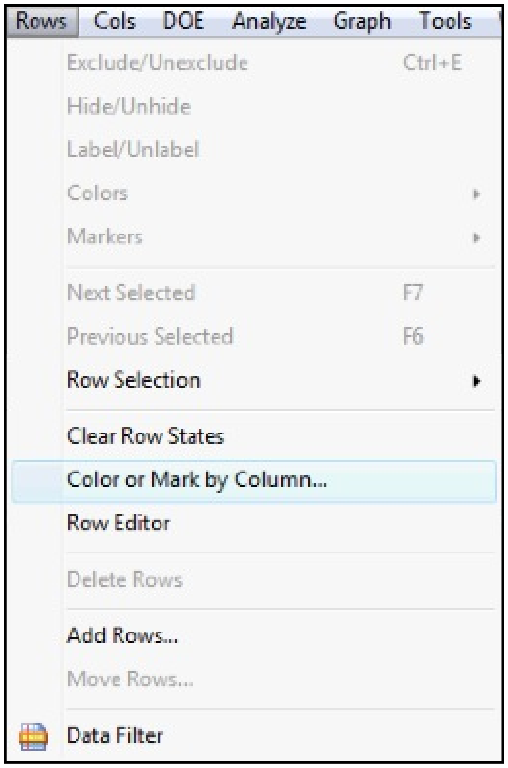
While there are several peaks in Wait Time, there does not appear to be an overall upward trend in Wait Time during the three quarters data was collected. A reference line may also be added to show the average wait time.

5. Click the red triangle next to **Run Chart of Wait Time**.
6. Select **Show Center Line**.

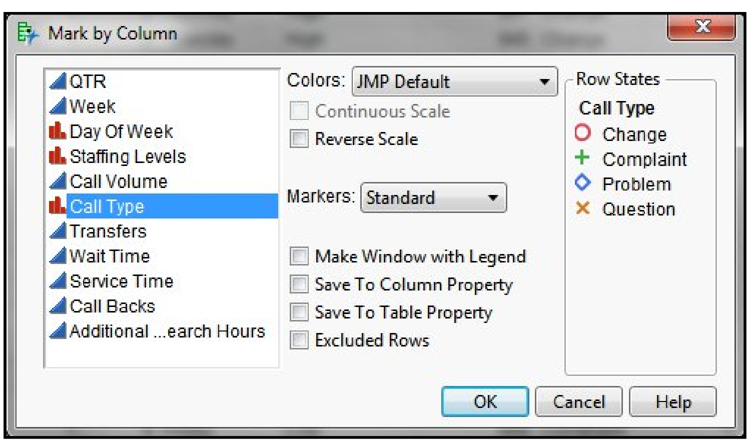


Additional JMP features may be used to highlight information on the chart.

7. Navigate to the **Call Center** data table.
8. Select **Rows** → **Color or Mark by Column…**.

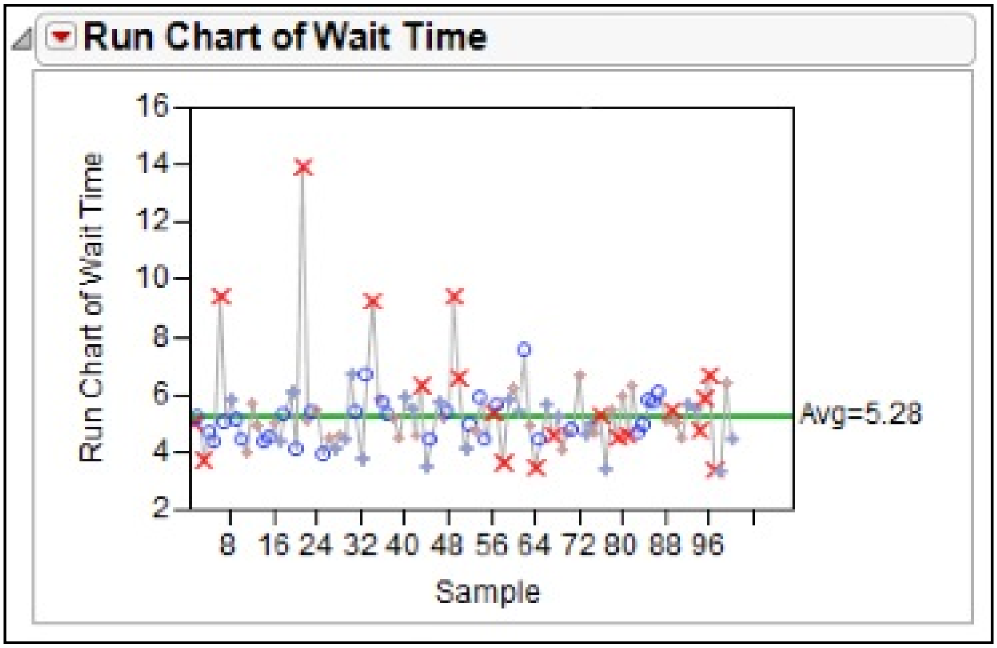


9. Select **Call Type**.
10. Under **Markers**, select **Standard**.

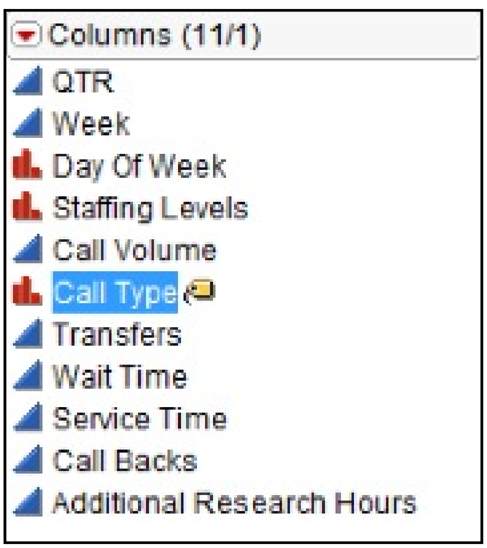


11. Select **OK**.

12. Select **Window** → **Call Center** – **Run Chart of Wait Time**.

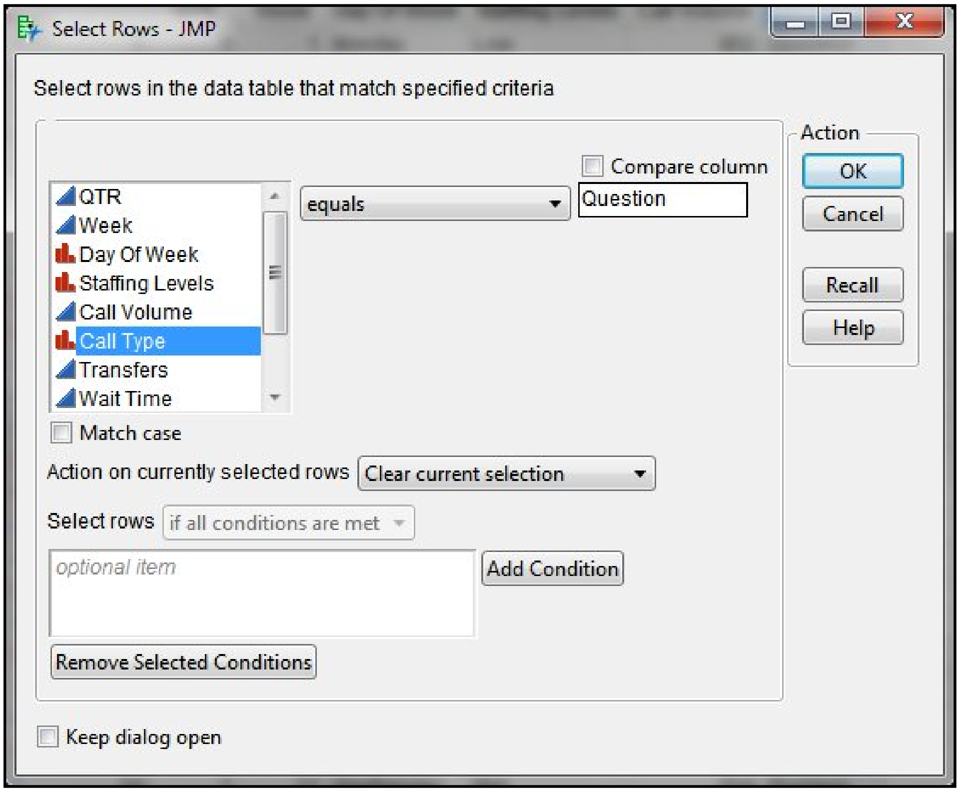


13. Navigate to the data table.
14. Select the **Call Type** column.
15. Select **Cols** → **Label/Unlabel**.

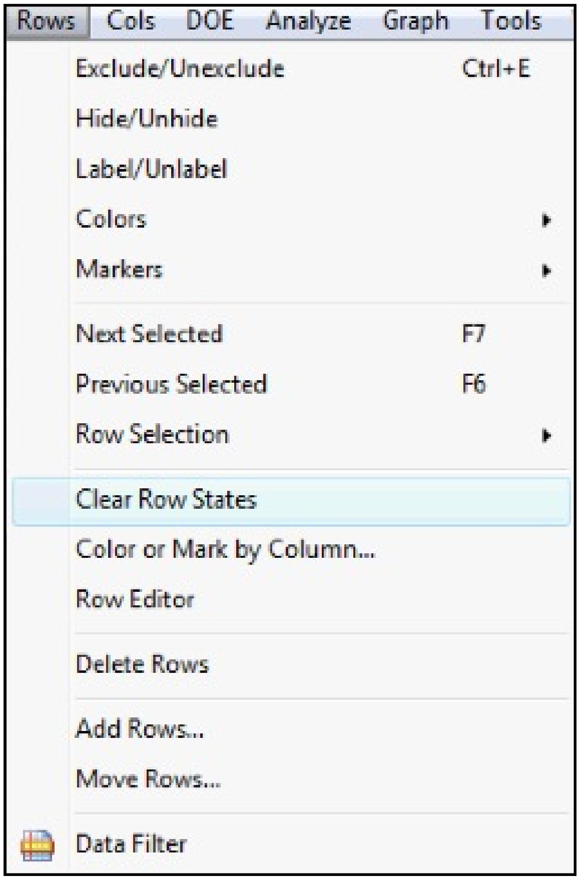


16. Make sure the **Call Type** column is not selected.
17. Navigate to the run chart. Note, that if the mouse is moved over a point the value of **Call Type** for that row is displayed.

18. Select **Rows** → **Rows Selection** → **Select Where….**
19. Select **Call Type**.
20. Type **Question** in the text field.



21. Select **OK**.
22. Select **Rows** → **Label/Unlabel**.
23. Navigate back to the data table. Right click **All Rows** → **Select Rows**.
24. Go to **Rows** → **Clear Row States.**

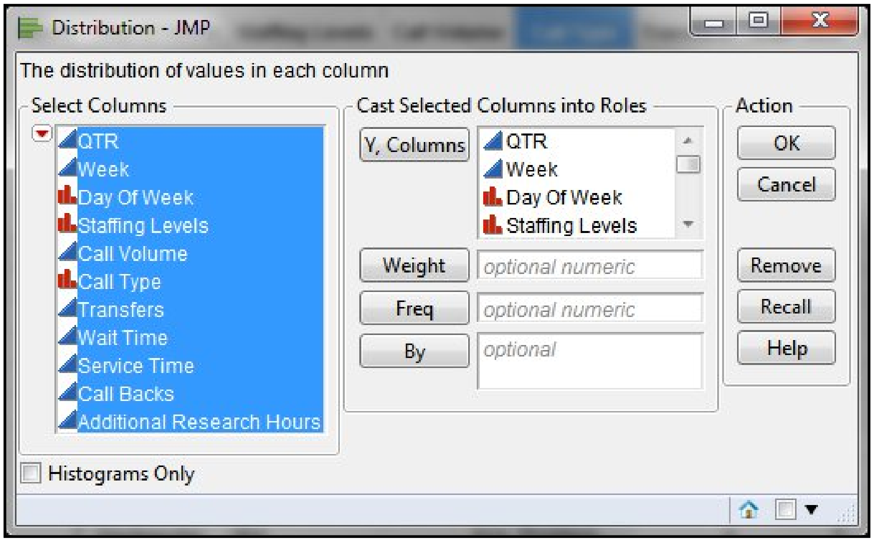


Histograms

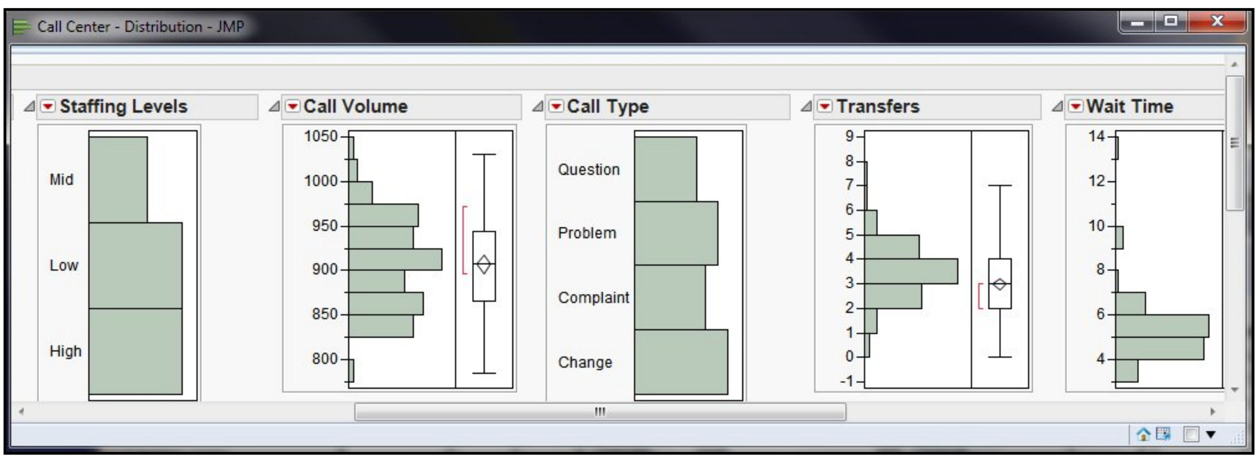
The Histogram is one of the fundamental graphs used in a project. Teams use histograms to visualize the average and standard deviation (spread) of a measurement. The histogram can be used to demonstrate changes in a measurement as a Six Sigma project is carried out.

Making use of JMP's dynamic linking feature, potential relationships between columns can be easily explored using Histograms.

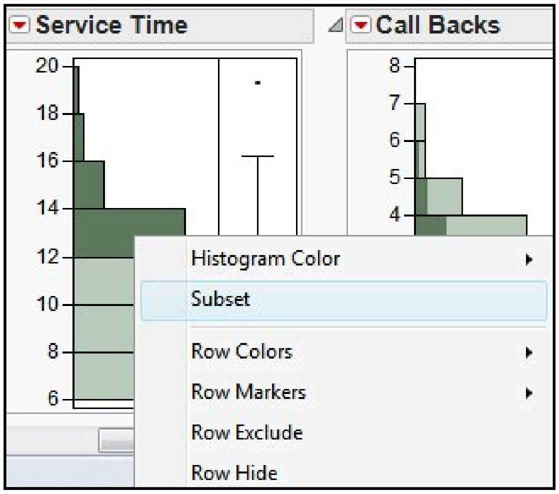
1. Select **Analyze** → **Distributions**.
2. Select **QTR thru Additional Research Hours** → **Y, Columns**.



3. Select **OK**.



4. Scroll right.
5. Select the bars in the Call Type chart to explore relationships between this column, the number of transfers, wait time, service time and the number of additional research hours.
6. Select the 12 – 14 bar in the Service Time histogram. Hold the shift key and select the bars above 14.
7. Right click and select **Subset**.



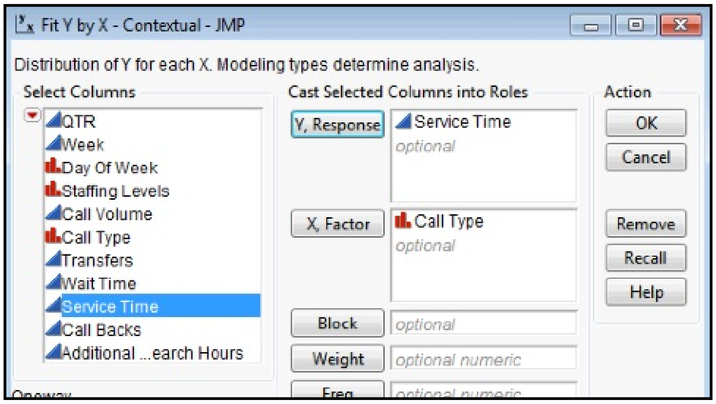
The new table contains the 31 rows where service time exceeds 12 minutes.

8. Save the new table as **Long Service Time**.

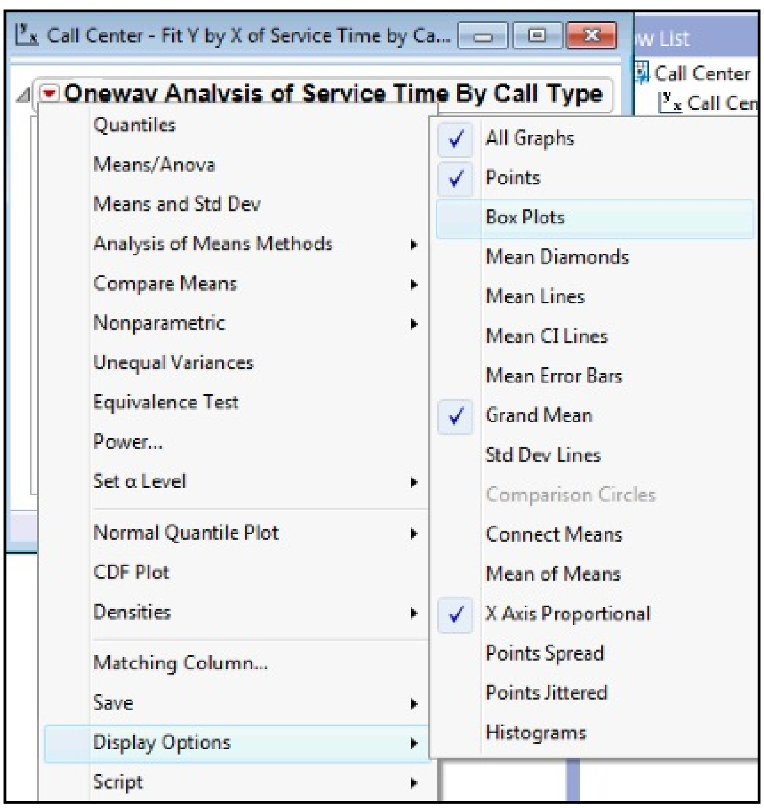
Box Plots

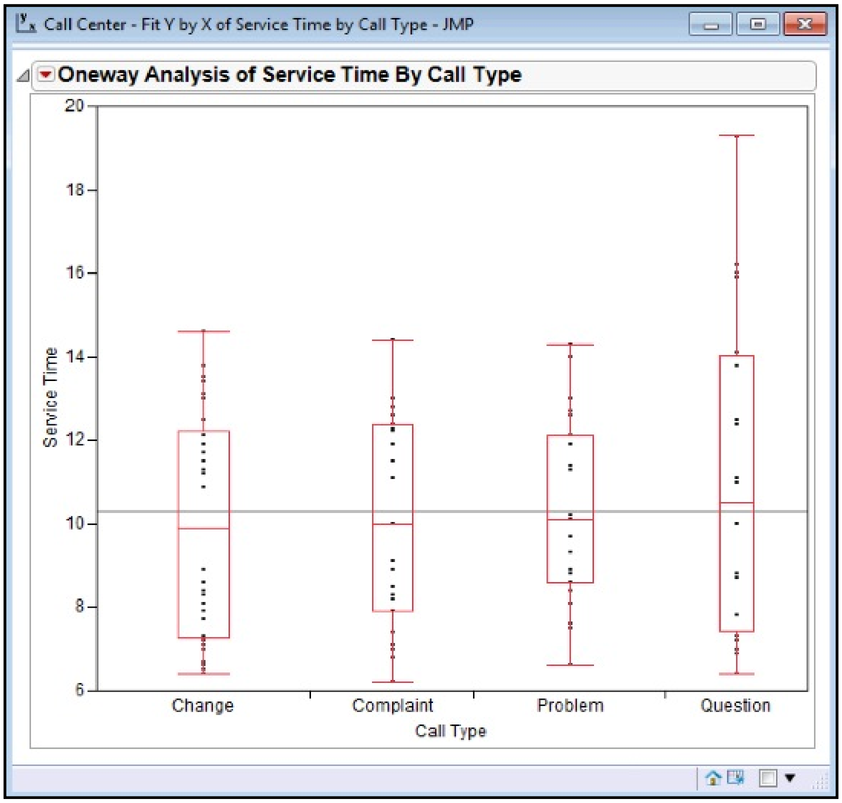
Like the histogram, the Box Plot allows teams to visually assess the distribution of the values of a measurement taken during a project. A single Box Plot can be used to determine the median, the 25th quartile, the 75th quartile, and the spread of a single column of values. Side by side box plots are often used to compare the spread of values based on some attribute. For instance, side by side box plots may be used to compare call volumes across days of the week or might be used in manufacturing to compare yield by machine. The Box Plot is also used to identify potential outliers in the data.

1. Navigate back to the **Call Center.JMP** file.
2. Select **Analyze** → **Fit Y by X**.
3. Select **Service Time** and select **Y, Response**.
4. Select **Call Type** and select **X, Factor**.



5. Select **OK**.
6. Click the red triangle next to. **Oneway Analysis Service Time by Call Type and select Display Options → Box Plots**.





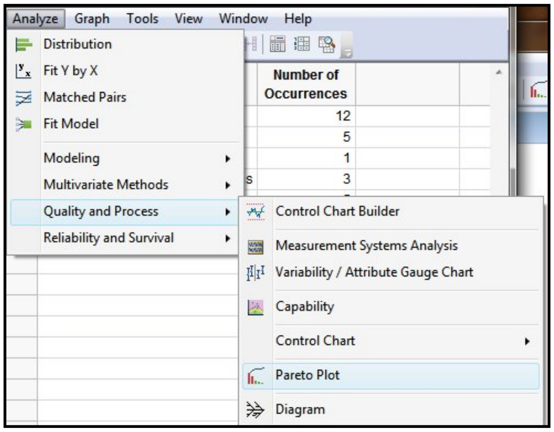
How should the team interpret this output? Could this information be used to investigate root cause?

Pareto Plots

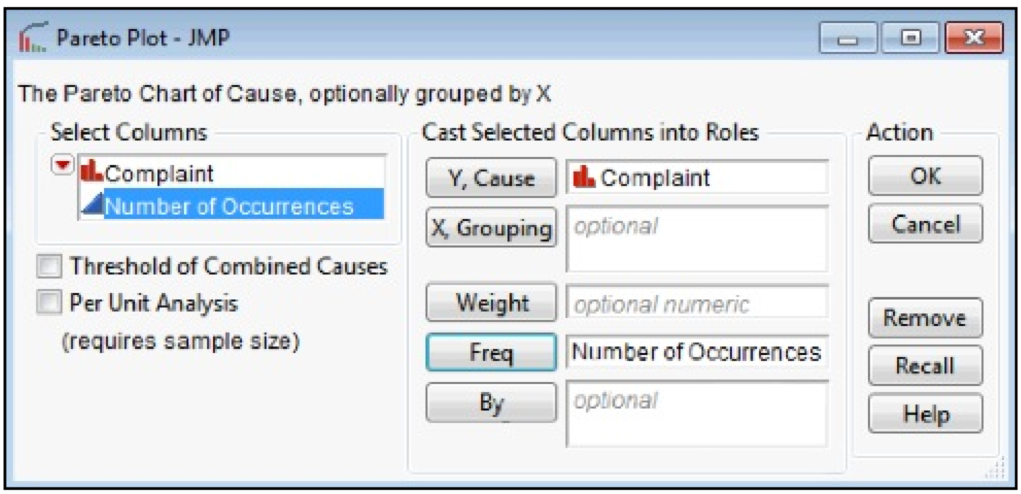
The Pareto Plot is used throughout a Six Sigma project to help teams focus on the most important aspects of a problem. Like the run chart, a Pareto Plot may also be used to monitor progress throughout a project.

The Pareto Plot is based on the Pareto Principle, which paraphrased says 20% of the sources cause 80% of the problems. The Pareto Plot graphically calls out the 20% of the sources the team should be addressing.

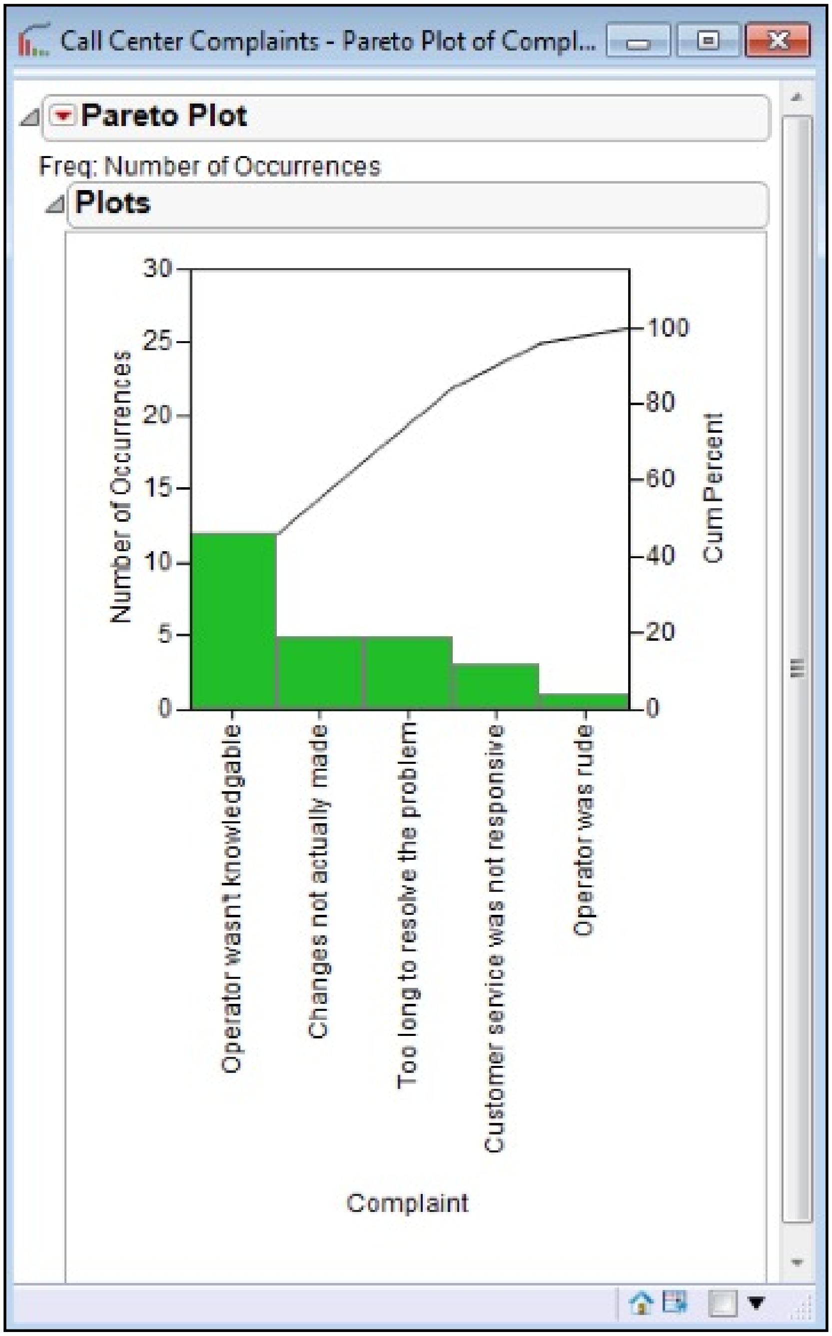
1. Open **Call Center Complaints**.
2. Select **Graph → Quality and Process→ Pareto Plot**.



3. Select **Complaint** → **Y, Cause**.
4. Select **Number of Occurrences** → **Freq**.



5. Select **OK**.



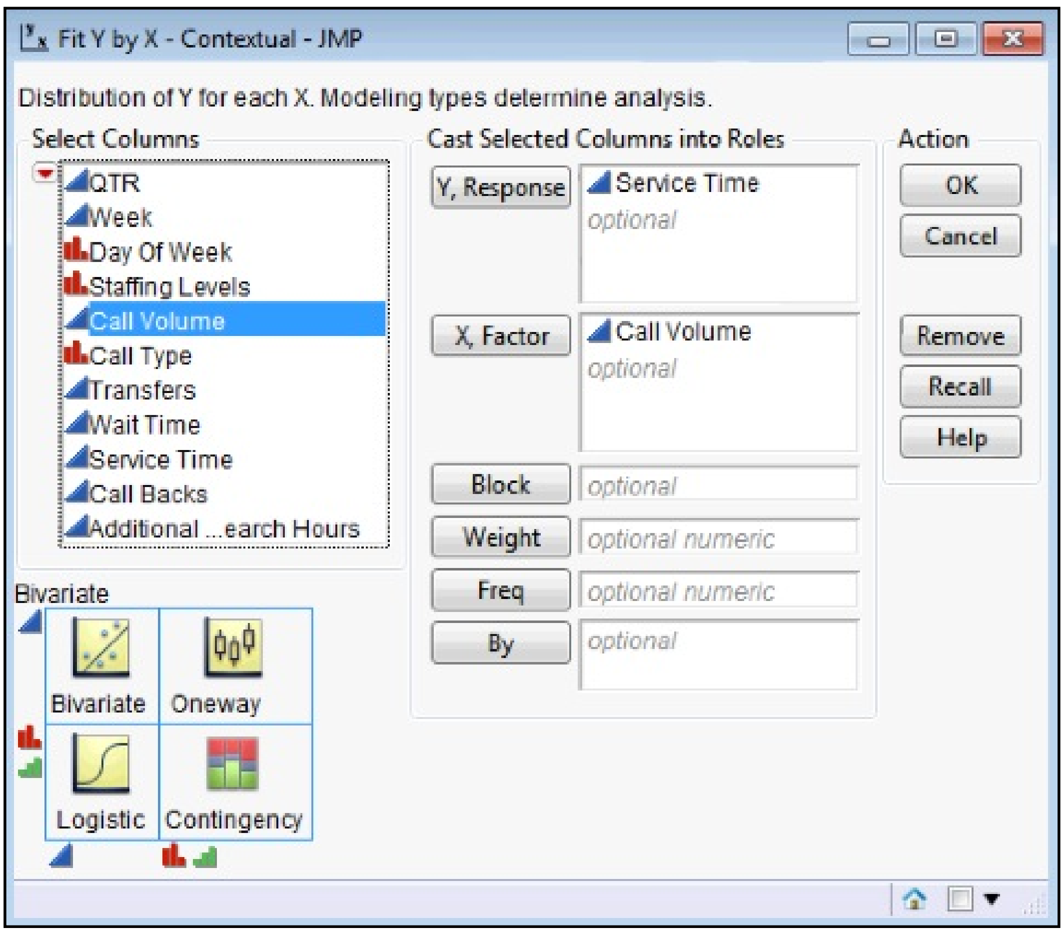
In this situation the team would focus on two categories: Operator wasn't knowledgeable and Changes not actually made.

6. Close the **Pareto Plot**.
7. Close the **Call Center Complaints** data table.

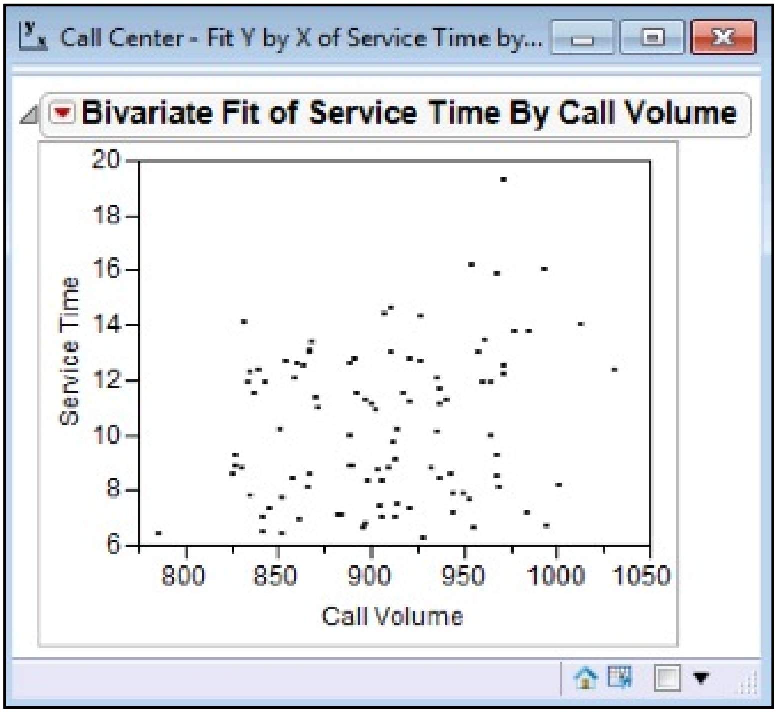
Scatter Plots

Scatter Plots are used to assess whether or not a relationship exists between two variables. Linear and curved (or quadratic) relationships can be detected on a scatter plot. The Scatter Plot is often used during the Analyze phase of a Six Sigma project when the team is trying to determining the root causes of a problem.

1. Navigate to the **Call Center.JMP** data table.
2. Select **Analyze** → **Fit Y by X.**
3. Select **Call Volume** → **X, Factor**.
4. Select **Service Time** → **Y, Response**.



5. Select **OK**.

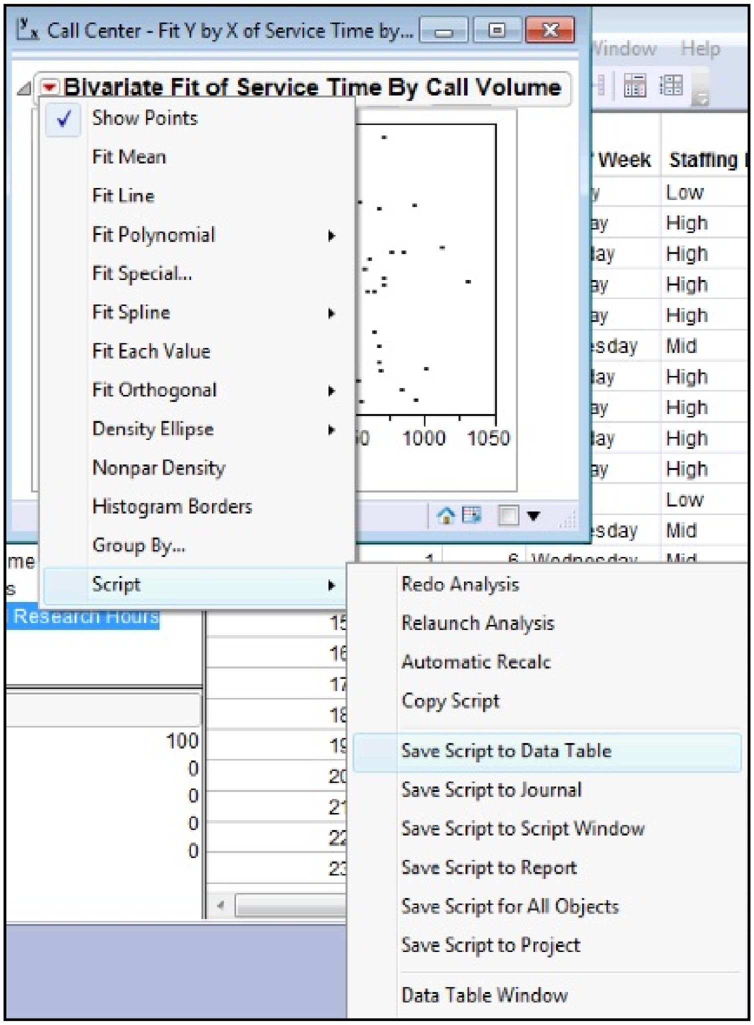


There appears that a positive relationship between Service Time and Call Volume is present. In other words, as Call Volume increases, the Service Time also increases.

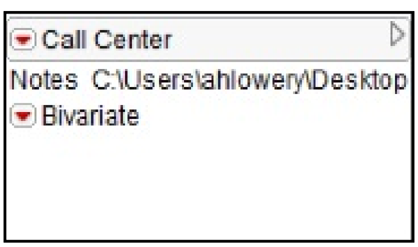
Saving Your Work in JMP

JMP scripts and journals are often used to maintain a record of the analysis generated during a six sigma project.

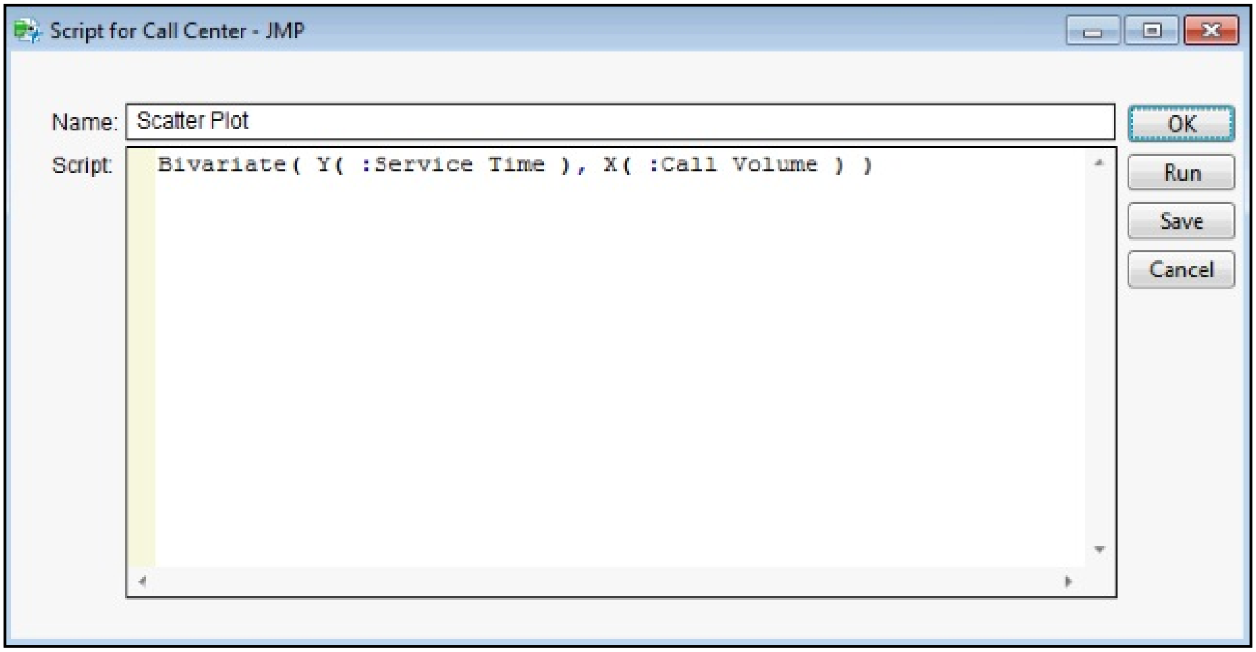
1. Make certain the scatter plot of **Service Time versus Call Volume** is the active window.
2. Click the red triangle next to **Bivariate Fit of Service Time by Call Volume** and select **Script** → **Save Script to Data Table**.



3. Navigate to the data table and examine the Table panel.



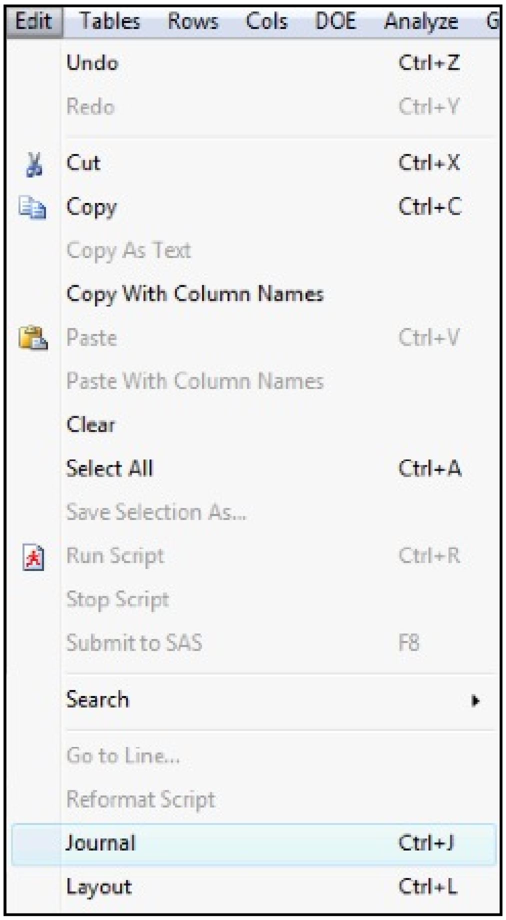
4. To view the script, click the red triangle next to **Bivariate** and select **Edit**.
5. Change the name of the script to **Scatter Plot**.


Script for Call Center - JMP
Name:
Scatter Plot
Script:
Bivariate(Y(:Service Time), X(:Call Volume))
OK
Run
Save
Cancel

6. Select **OK**.

The script is dynamic: if you add or change values in the data table and run the script the output will reflect the changes. Journals may also be used to keep a record of reports created in JMP. Journals are static copies of the output.

1. Select **Window** → **Call Center – Fit Y by X of Service Time by Call Volume**.
2. Select **Edit** → **Journal**.

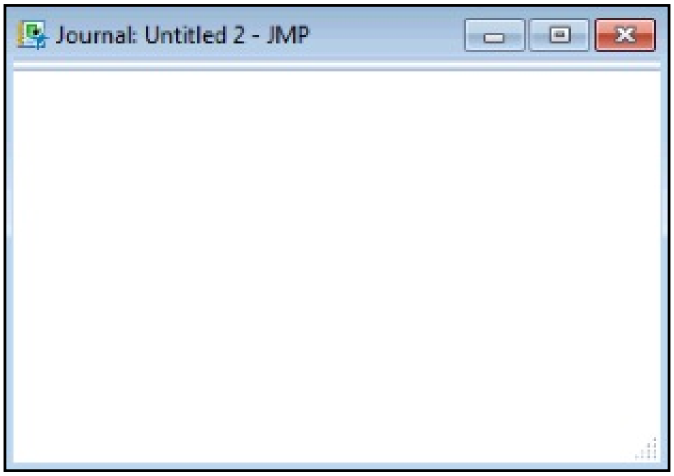


A new window, Journal, opens. Other items may be appended to the Journal window. Navigate to other data tables or output of interest and repeat step 2. A journal may be saved as a .JRN file or as other file types such as .JPG, .DOC, and .HTM.

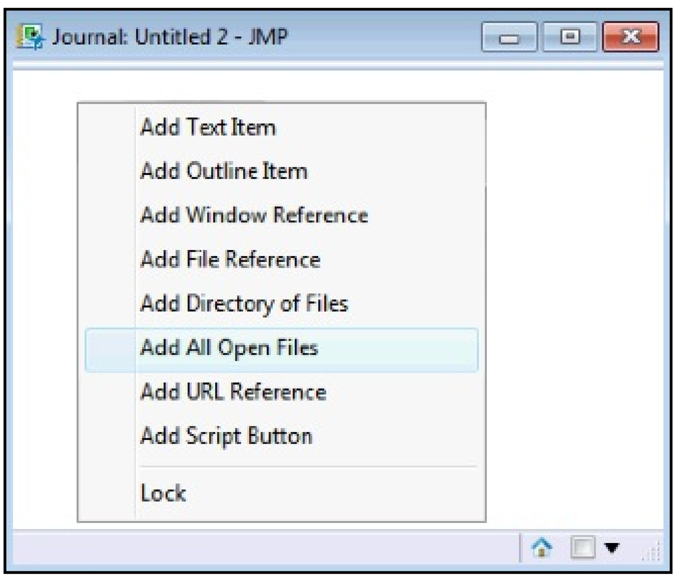
3. Select **File** → **Save**.
4. Change the **Save as Type** to .JPG.
5. Type **Scatter Plot of Times** as the file name.
6. Select **Save**.

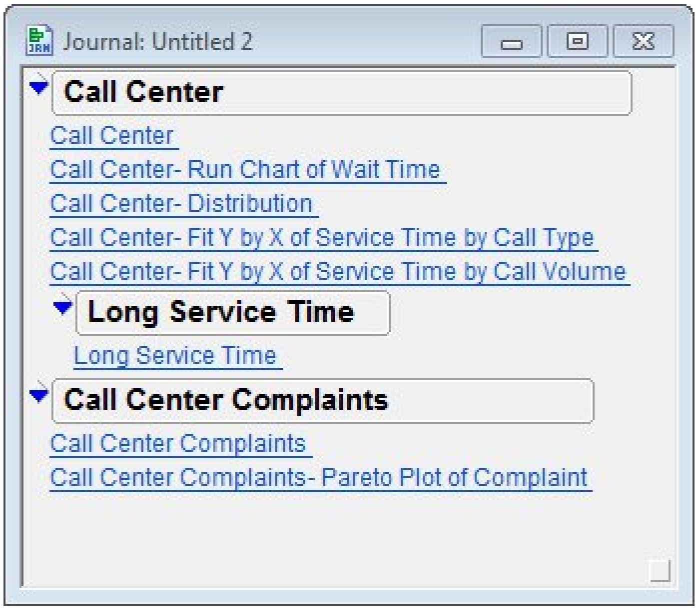
An alternative to saving scripts individually to data tables and to saving some output to a journal file is to create a journal that contains links to all the files and output used during your JMP session.

1. Select **File** → **New** → **Journal**.



2. Right click in the empty Journal and select **Add All Open Files**.




Journal: Untitled 2
Call Center
Call Center
Call Center- Run Chart of Wait Time
Call Center- Distribution
Call Center- Fit Y by X of Service Time by Call Type
Call Center- Fit Y by X of Service Time by Call Volume
Long Service Time
Long Service Time
Call Center Complaints
Call Center Complaints
Call Center Complaints- Pareto Plot of Complaint

THE CONCEPT OF PROCESS

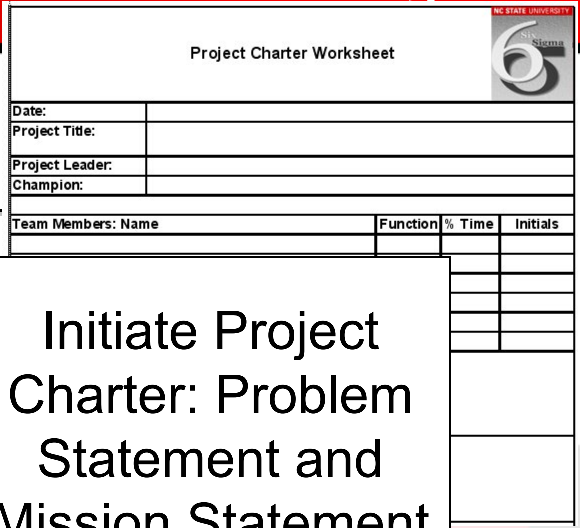
Objectives

- Discuss why it is important to create a process flow map during a Lean Six Sigma project
- Create a SIPOC
- Create a process flow map
- Understand how a swim lane flow map illustrates the complexities of a process

Define Flow

Develop a List of Potential Projects

Evaluate Projects based on Organizational Criteria


Project Charter Worksheet

Date:			
Project Title:			
Project Leader:			
Champion:			
Team Members: Name	Function	% Time	Initials

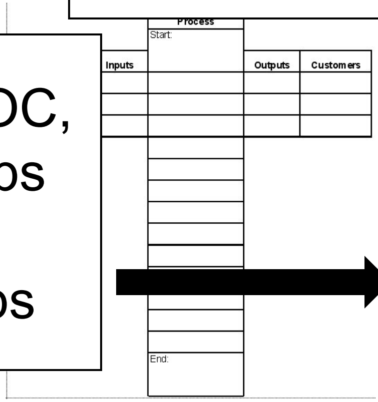
Initiate Project Charter: Problem Statement and Mission Statement

Collect VOC data

Use VOC Data to Develop CTQ Metrics

Complete a Stakeholder Analysis

Develop SIPOC, Process Maps and Value Stream Maps

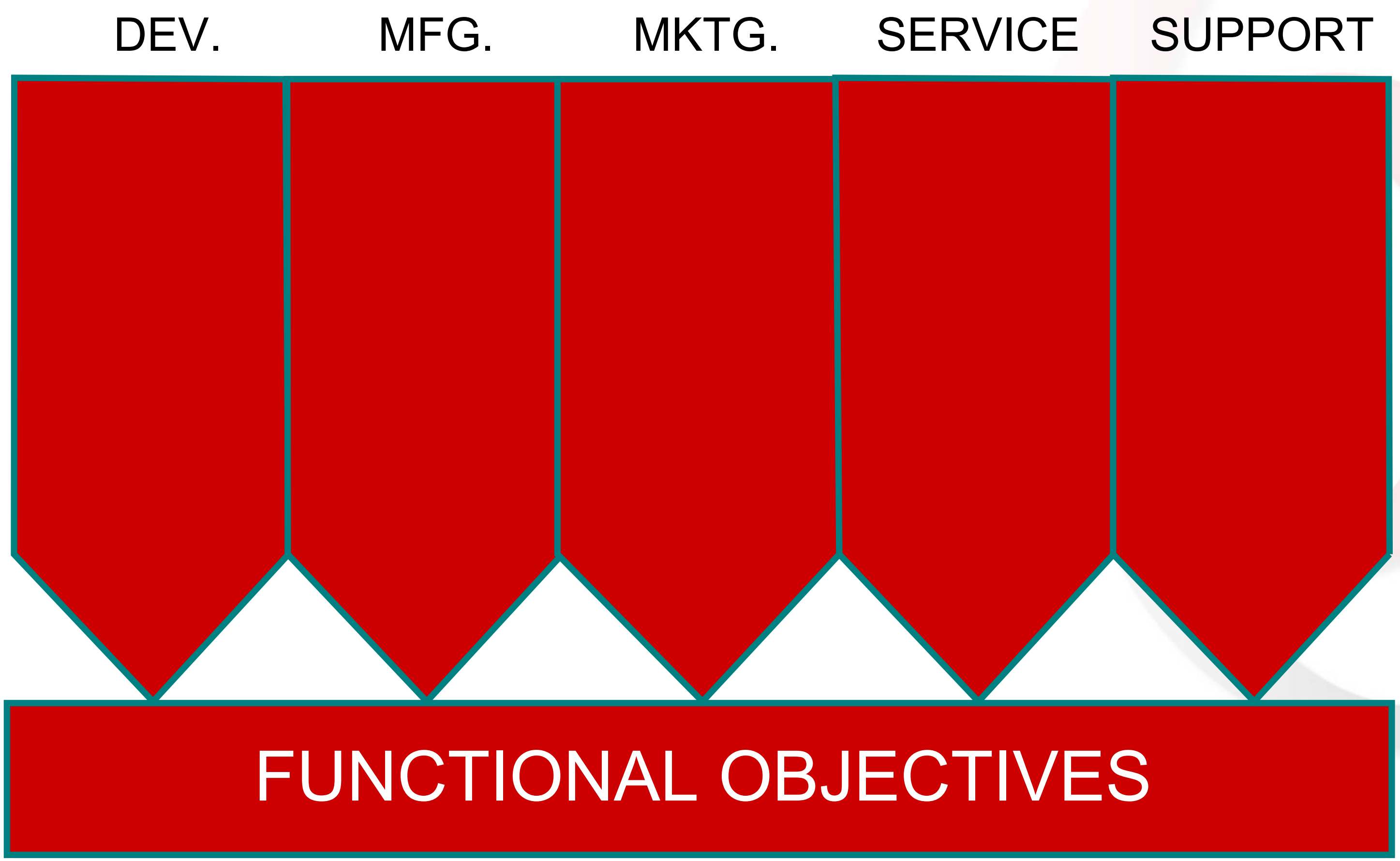


Define Tollgate

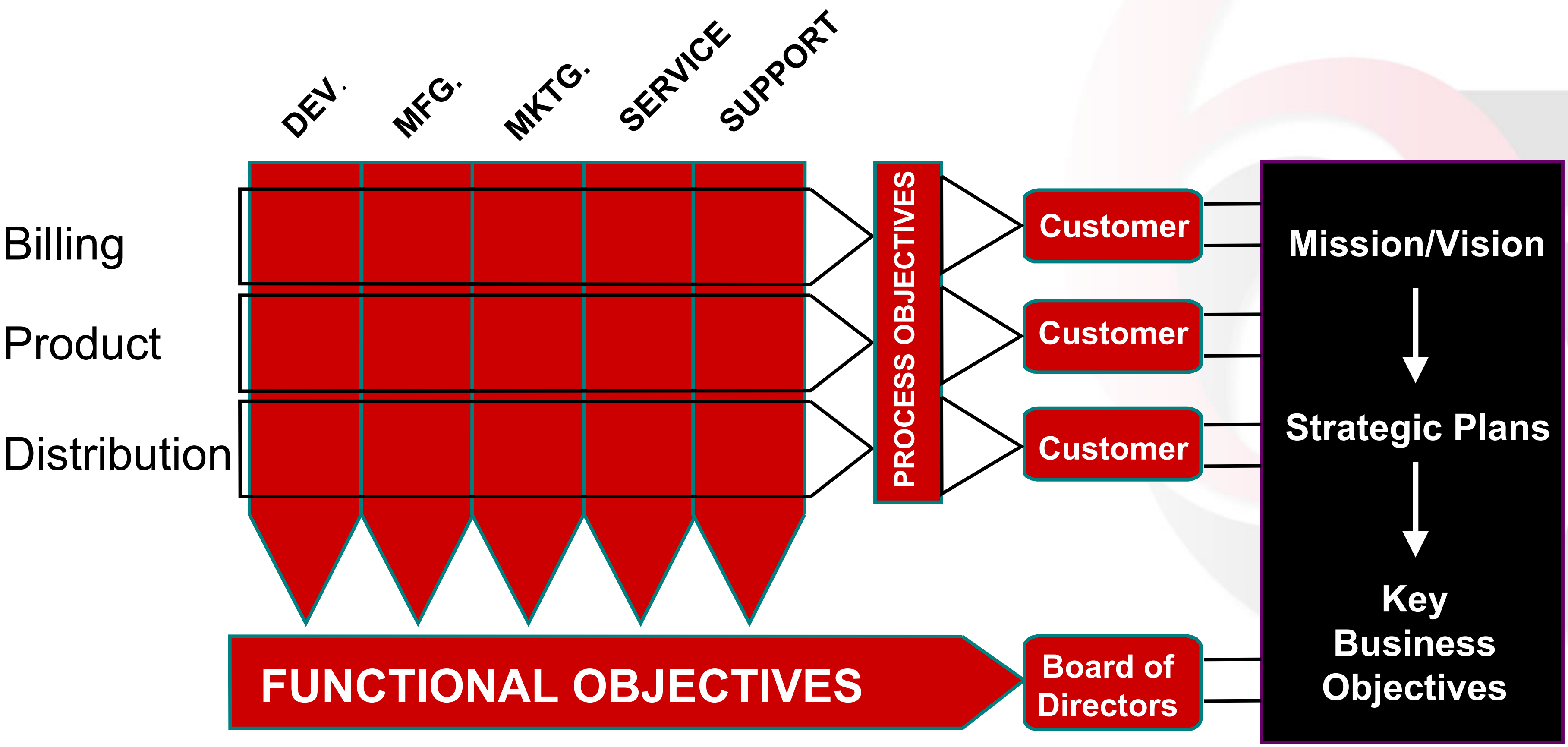
All Work is Done in a Process

- Work is done by people using facilities, energy, materials, and procedures.
- Most critical processes are highly cross-functional processes
- Most processes are undefined and unmanaged
- Many key processes fail often, are highly inefficient, and are extremely complex

Workflow in a Functional Organization



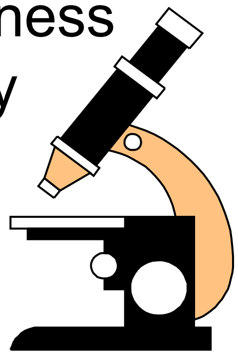
Workflow in a Functional Organization



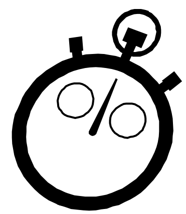
Process Analysis Focal Points

Measurement Data

Effectiveness
Efficiency

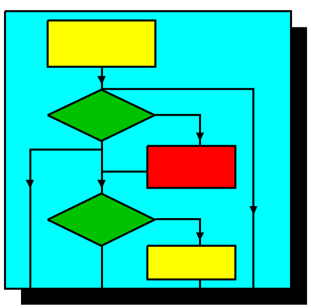


Control Situation

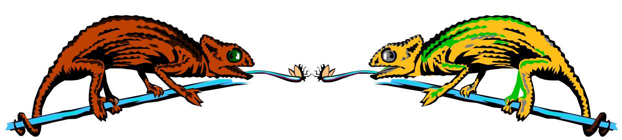


Cost of Poor Quality

Flow Analysis

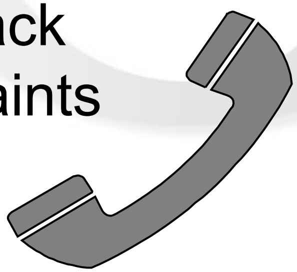


Adaptability



Customers: Internal & External

Feedback
Complaints



What Needs to be Done?

Can we live with it?

- Accept it
- Make minor improvements

Can we improve it?

- Continuous improvement
- Automate it
- Change parts

Should we redesign it?

- "Blow it up!"
- Start from scratch
- New technologies

Process Flow Maps

- SIPOC
- Process Flow Map
- Cross-functional or Swim Lane Process Flow Map

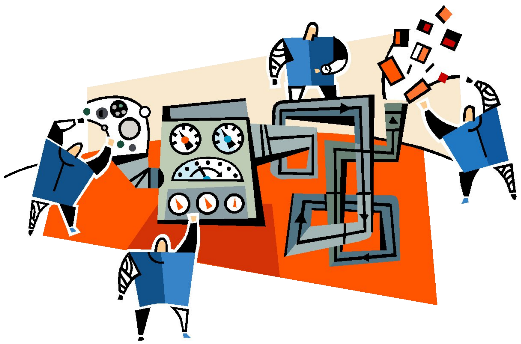
SIPOC

Supplier

Person, organization, or group that provides information, materials, or resources to be worked on.

Input

Information or materials that are consumed or transformed by the process.



Process

The 5 – 7 main steps that transform the inputs.

Output

The product or service used by the customer.

Customer

The people, company, or the next process that receives the output from the process.

SIPOC

SIPOC Worksheet

Date:

Project Title:

Project Leader:

Suppliers	Inputs	Process	Outputs	Customer

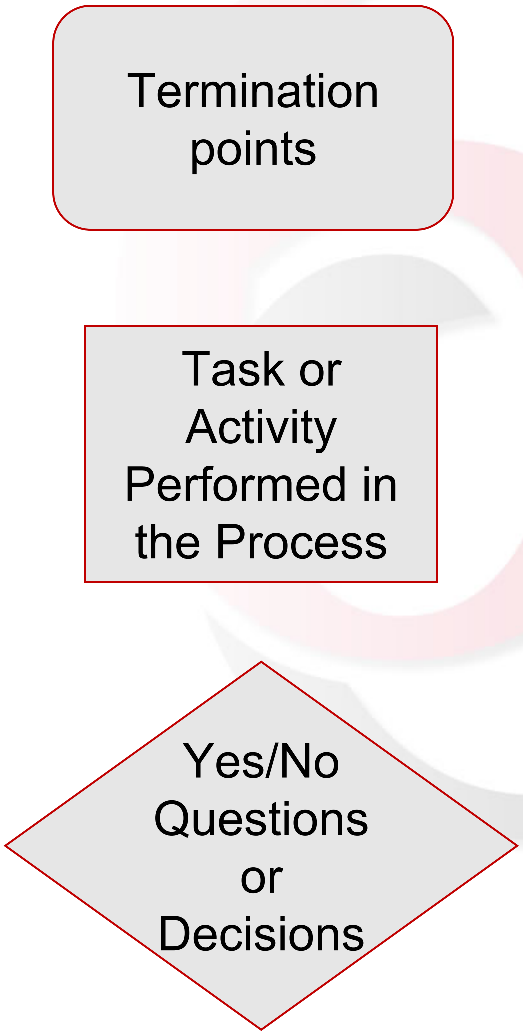
- Clearly define the start and end points of the process
- 30,000 foot view of the process
- A process may have multiple suppliers, inputs, outputs and customers

Textiles

IES INDUSTRIAL EXTENSION SERVICE

Detailed Process Flow Maps

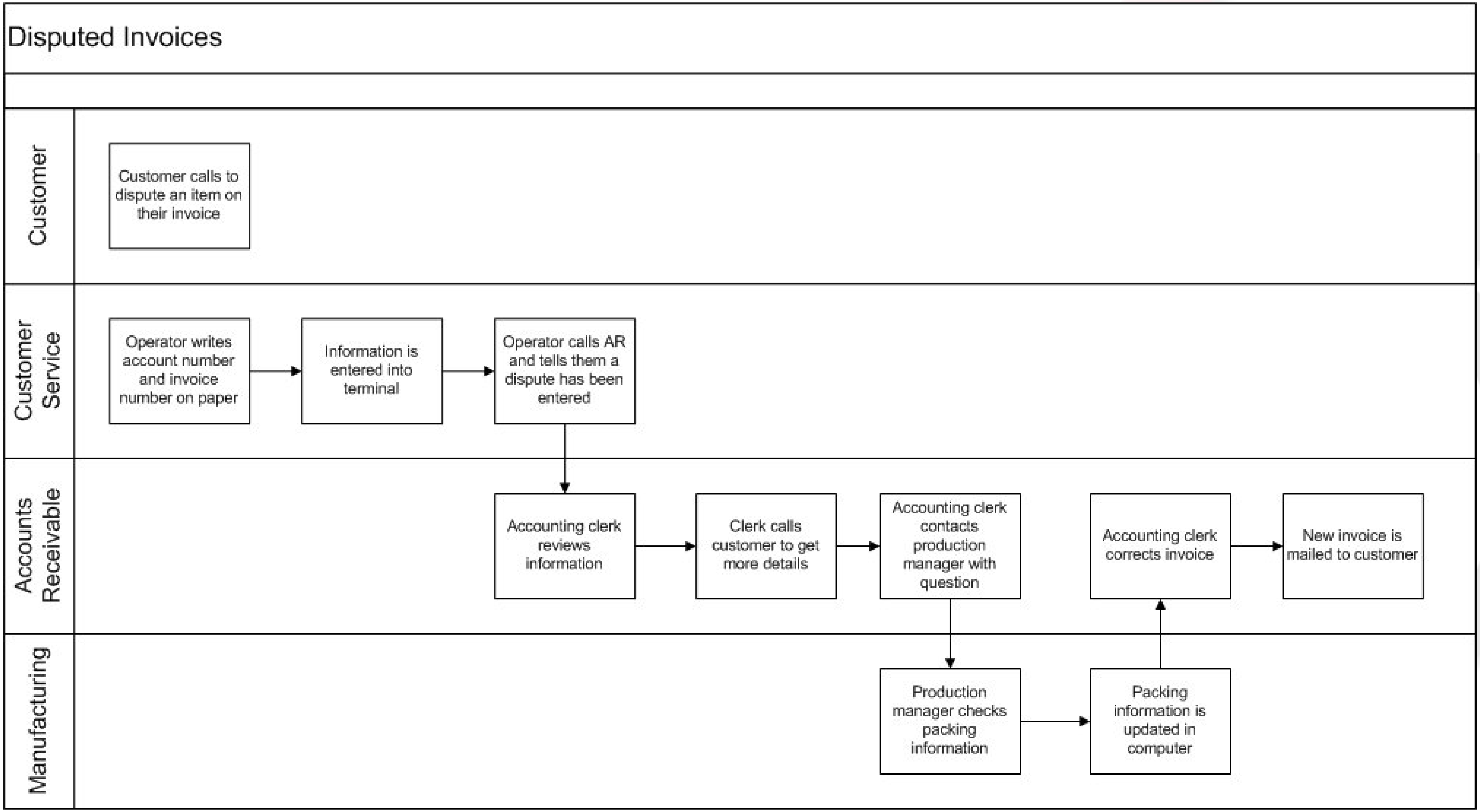
- Each member identifies the steps they believe occur in the process
- Working together, the team orders the steps
- Validate the map with people not on the team
- Use the map to look for improvement opportunities



Swim Lane Process Maps

- Show the complexity of processes that cross functional boundaries
- Highlight the handoffs that often lead to defects in a process
- Are useful as a tool to identify wastes in a process

Swim Lane Process Maps



THE CONCEPT OF PROCESS

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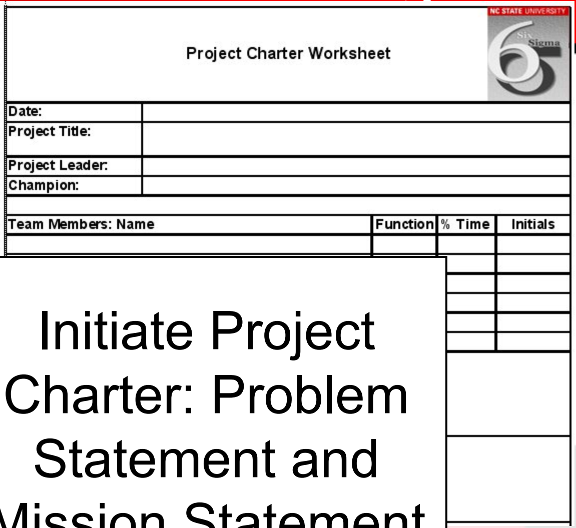
- Understand how a swim lane flow map illustrates the complexities of a process

Define Flow



Develop a List of Potential Projects

Evaluate Projects based on Organizational Criteria

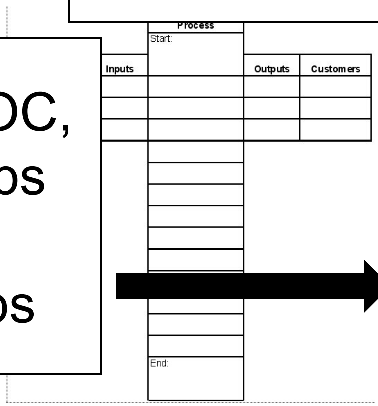
Initiate Project Charter: Problem Statement and Mission Statement

Collect VOC data

Use VOC Data to Develop CTQ Metrics

Complete a Stakeholder Analysis

Develop SIPOC, Process Maps and Value Stream Maps

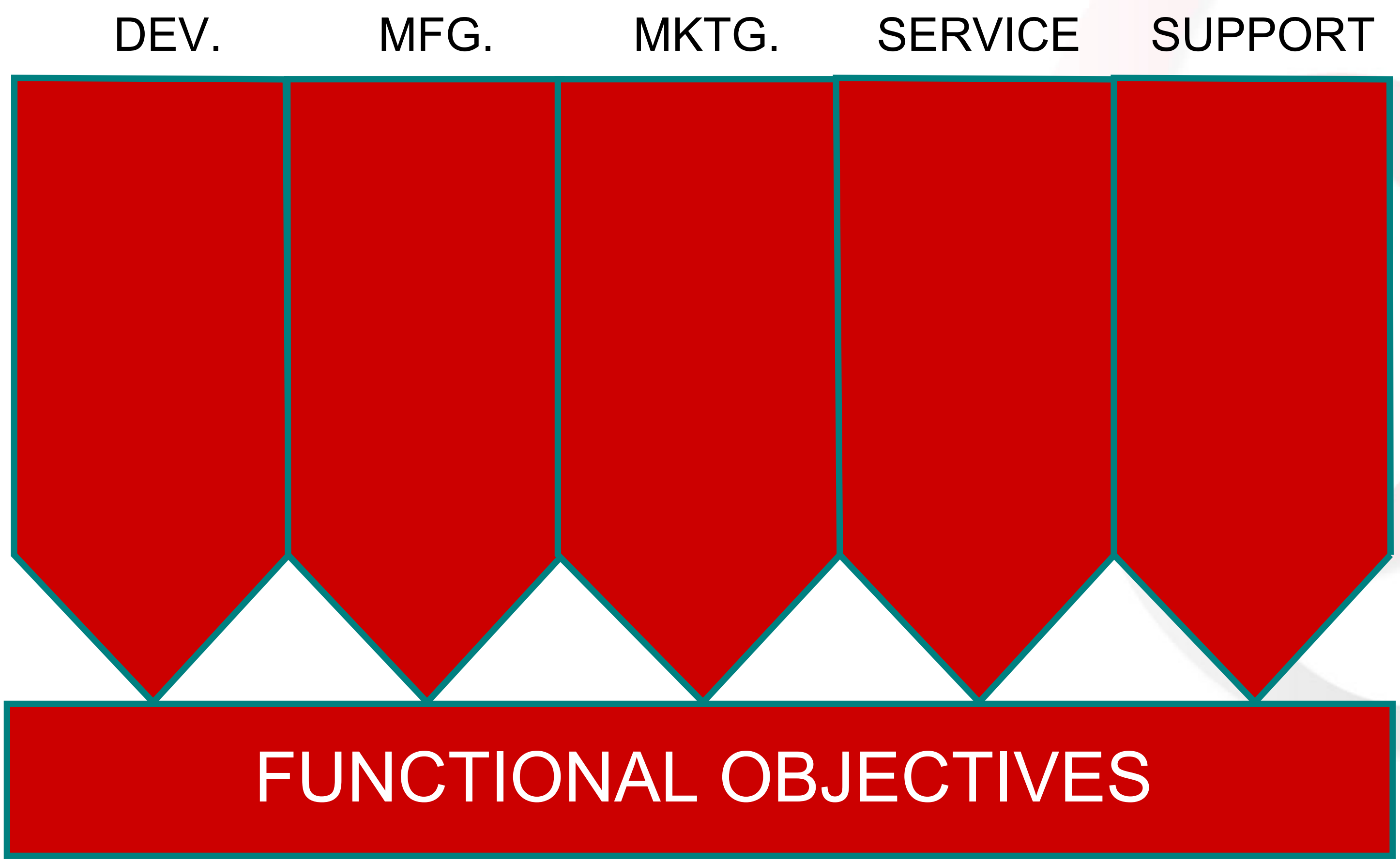


Define Tollgate

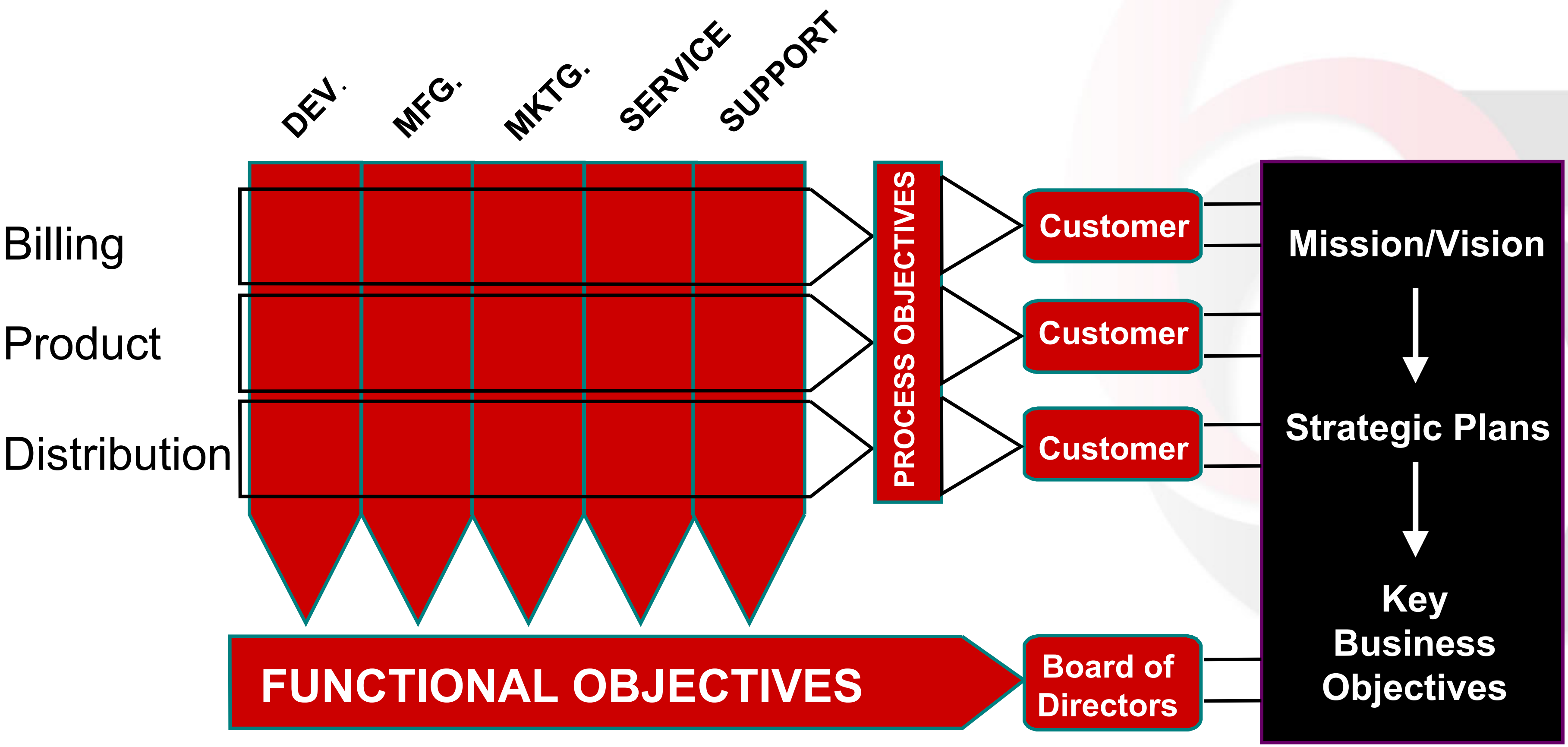
All Work is Done in a Process

- Work is done by people using facilities, energy, materials, and procedures.
- Most critical processes are highly cross-functional processes
- Most processes are undefined and unmanaged
- Many key processes fail often, are highly inefficient, and are extremely complex

Workflow in a Functional Organization



Workflow in a Functional Organization

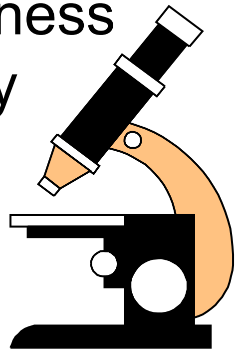


Process Analysis Focal Points

Measurement Data

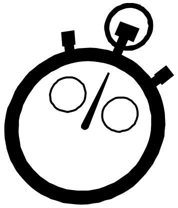
Effectiveness

Efficiency

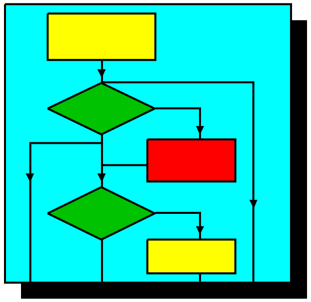


Cost of Poor Quality

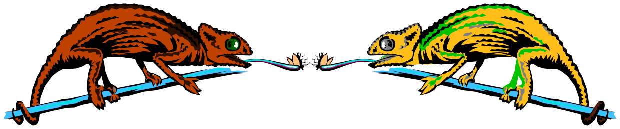
Control Situation



Flow Analysis



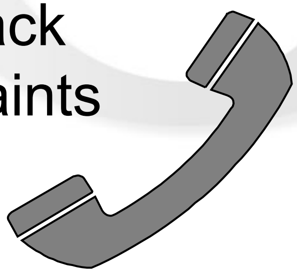
Adaptability



Customers: Internal & External

Feedback

Complaints



What Needs to be Done?

Can we live with it?

- Accept it
- Make minor improvements

Can we improve it?

- Continuous improvement
- Automate it
- Change parts

Should we redesign it?

- "Blow it up!"
- Start from scratch
- New technologies

Process Flow Maps

- SIPOC
- Process Flow Map
- Cross-functional or Swim Lane Process Flow Map

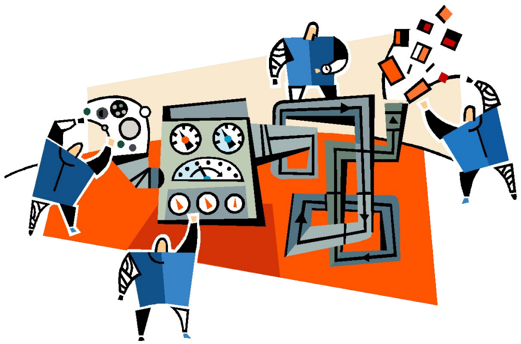
SIPOC

Supplier

Person, organization, or group that provides information, materials, or resources to be worked on.

Input

Information or materials that are consumed or transformed by the process.



Process

The 5 – 7 main steps that transform the inputs.

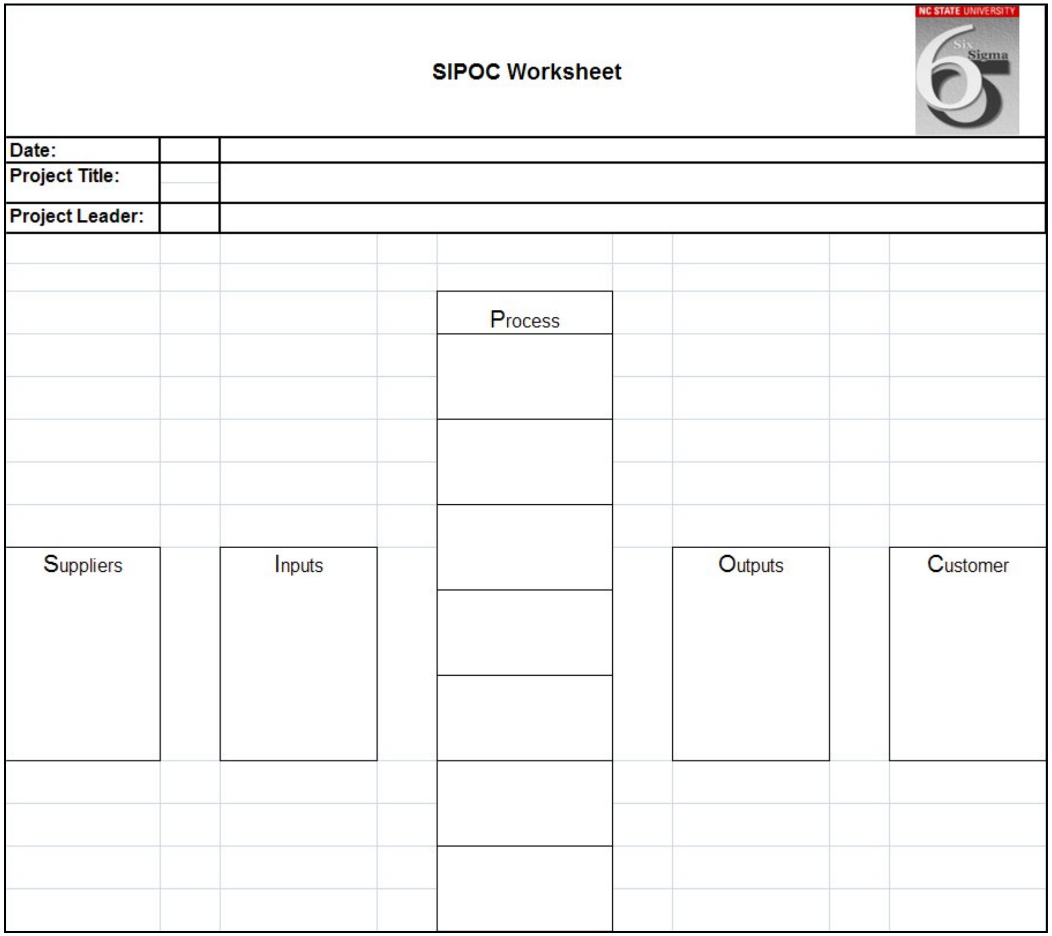
Output

The product or service used by the customer.

Customer

The people, company, or the next process that receives the output from the process.

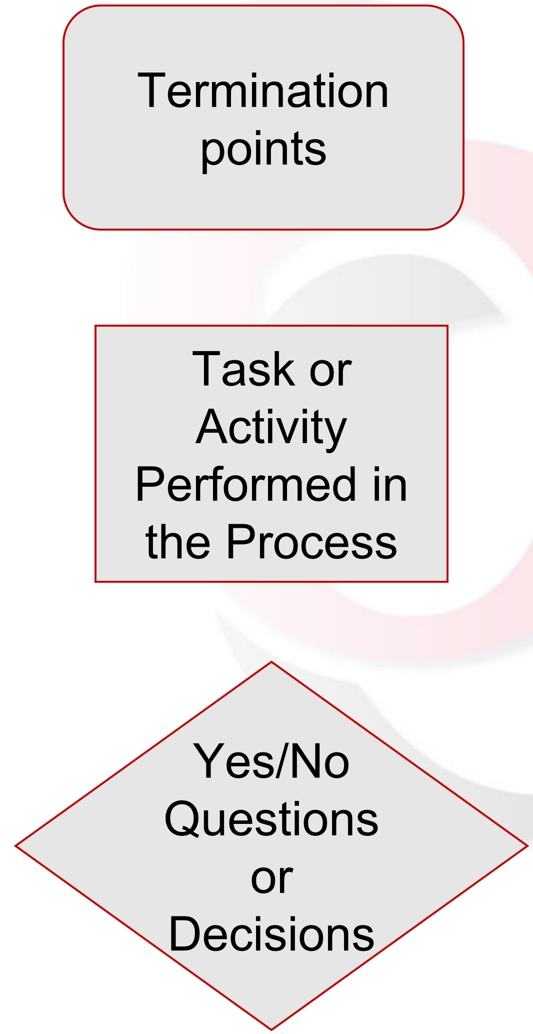
SIPOC



- Clearly define the start and end points of the process
- 30,000 foot view of the process
- A process may have multiple suppliers, inputs, outputs and customers

Detailed Process Flow Maps

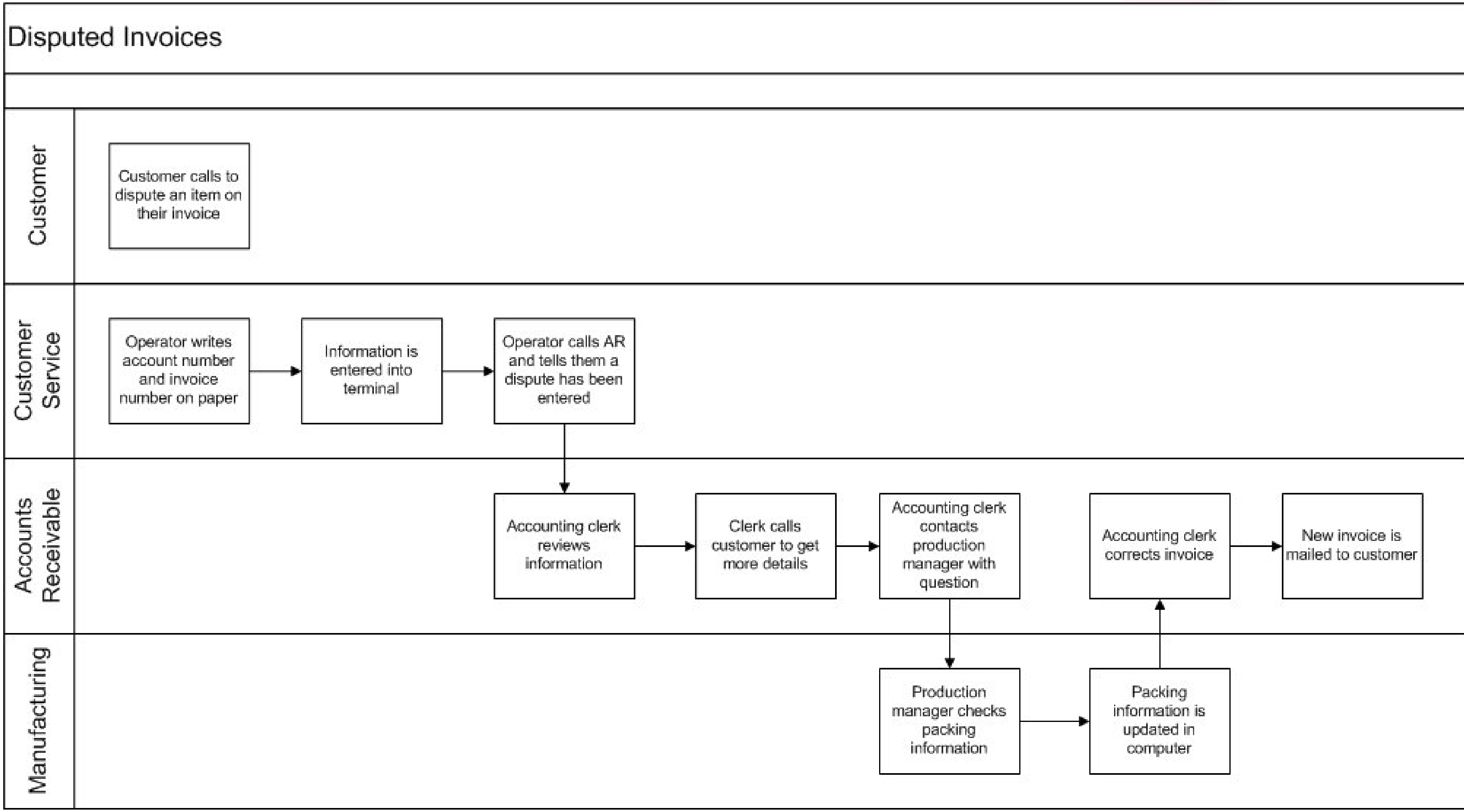
- Each member identifies the steps they believe occur in the process
- Working together, the team orders the steps
- Validate the map with people not on the team
- Use the map to look for improvement opportunities



Swim Lane Process Maps

- Show the complexity of processes that cross functional boundaries
- Highlight the handoffs that often lead to defects in a process
- Are useful as a tool to identify wastes in a process

Swim Lane Process Maps

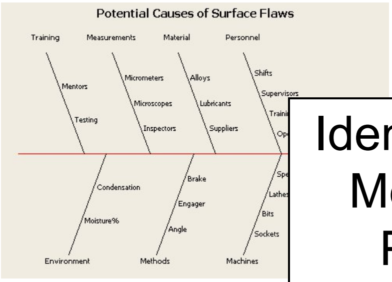


INTRODUCTION TO MEASURE

Objectives

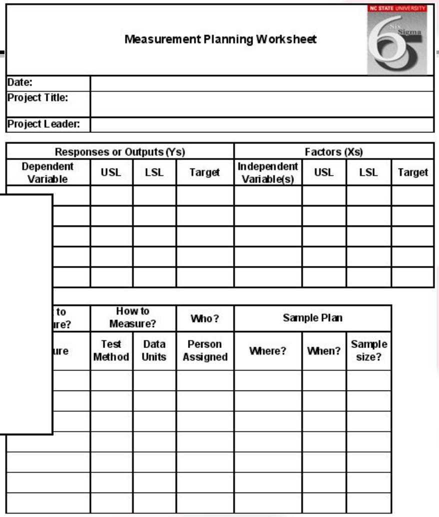
- Understand the flow through the Measure phase of a Lean Six Sigma project
- Use brainstorming and a cause-and-effect diagram to identify potential critical project Xs
- Discuss the elements of a data collection plan

Measure Flow



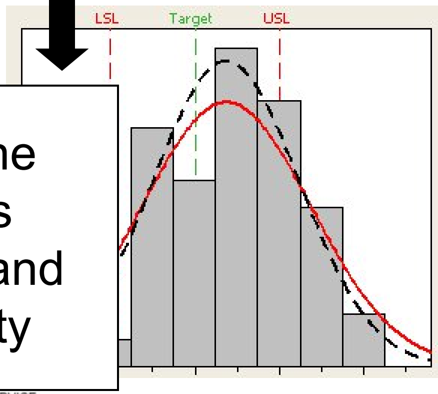
Identify Project Metrics and Potential Critical Xs

Create a Data Collection Plan



Validate Measurement System

Collect Data



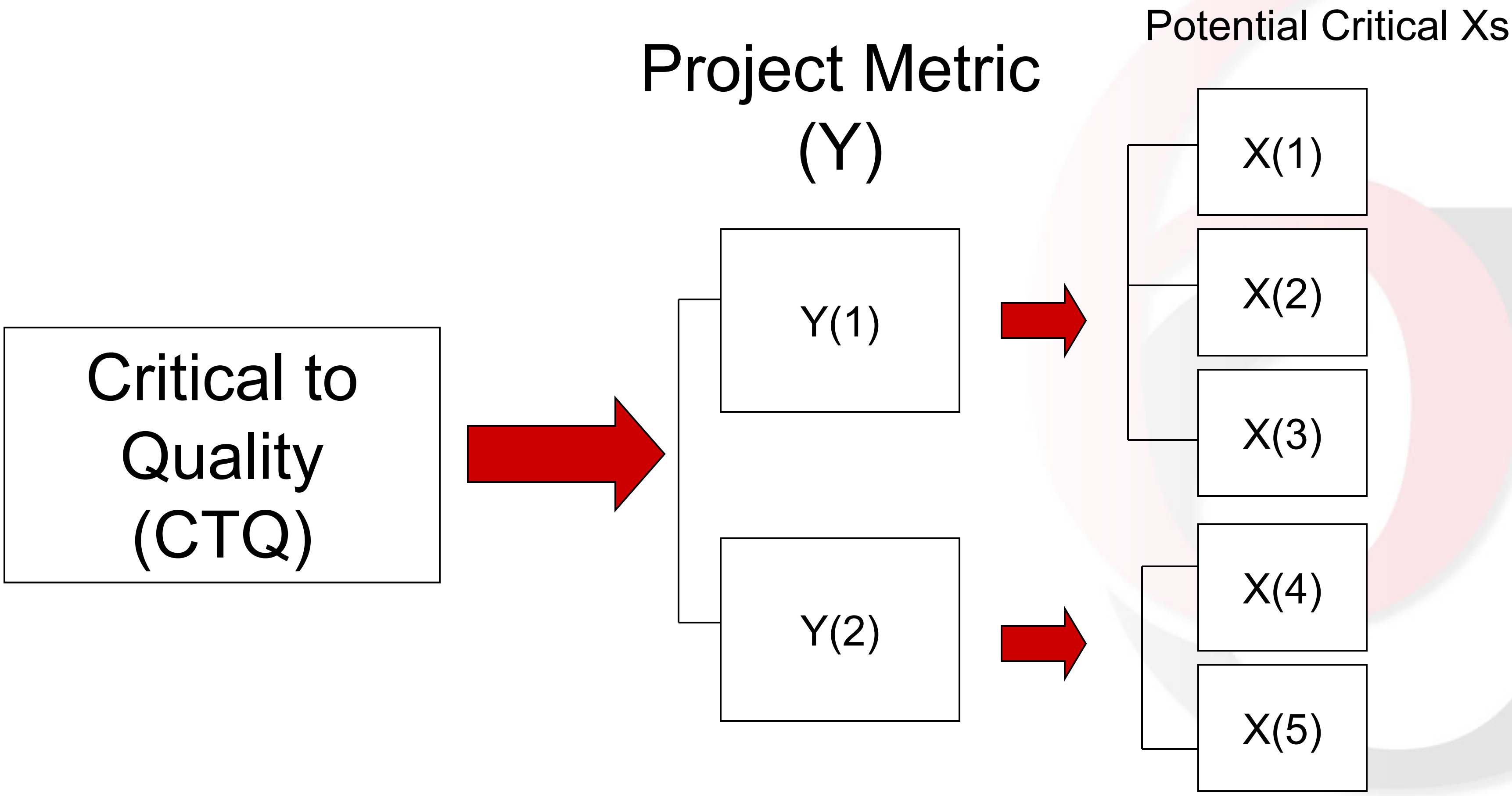
Determine Process Baseline and Capability

Update Charter and Project Plan and Complete Measure Tollgate

Deciding What Data to Collect

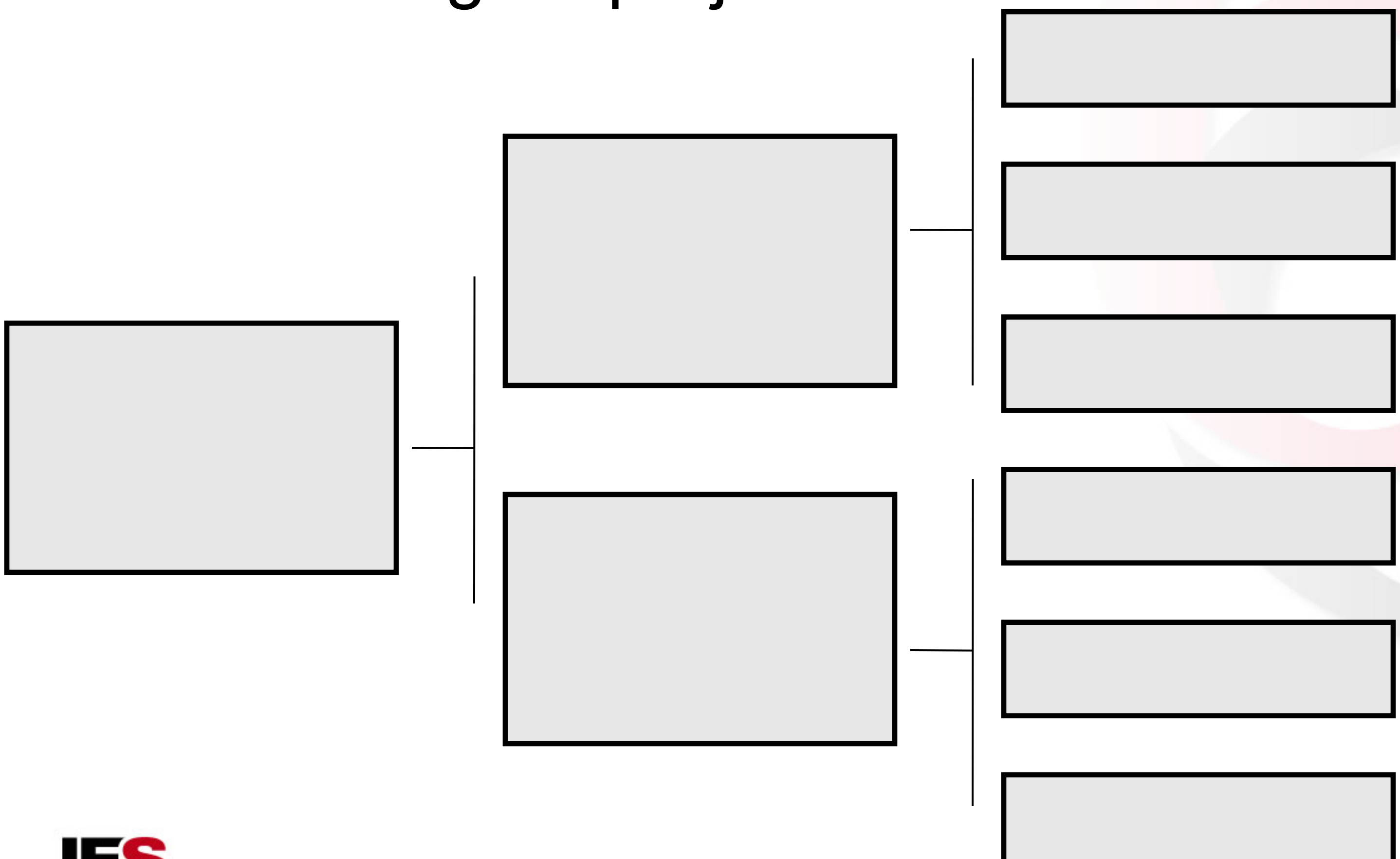
- Create a CTQ tree to link metrics and process Ys
- Brainstorm to generate a list of potential causes (process Xs)
- Organize potential Xs using a cause-and-effect diagram
- Generate a list of questions the team needs to be able to answer at the end of Analyze
- Create a data collection plan

CTQ Tree

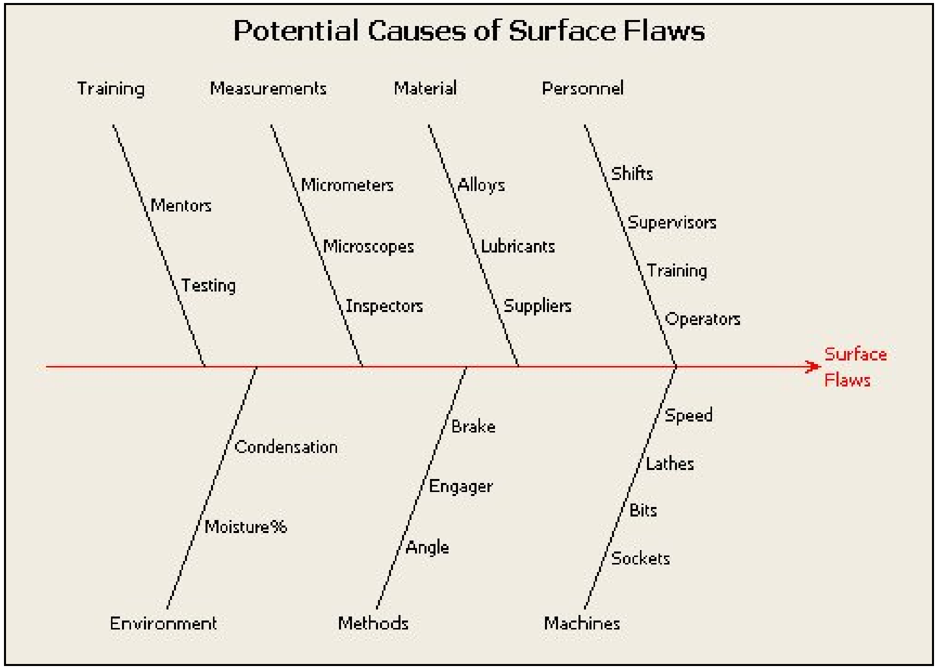

Potential Critical Xs
Project Metric
(Y)
Critical to
Quality
(CTQ)
Y(1)
Y(2)
X(1)
X(2)
X(3)
X(4)
X(5)

CTQ Tree Exercise

Use the template below to create a CTQ tree for your Lean Six Sigma project.



Cause and Effect Diagram



- The cause-and-effect diagram is a useful tool for organizing potential Xs during or after a brainstorming session.
- Prioritize the potential critical Xs that need to be investigated

Stratifying Data

- Generate a list of stratification questions that may need to be answered during Analyze
- Determine the data that needs to be collected to answer those questions
- Examples:
  - Is there a day-to-day difference in call volume?
  - Does the number of defects vary between machines?

Creating a Data Collection Plan

A data collection plan:

- Ensures that everyone has a clear understanding and definition of the data that will be collected,
- Details who will collect the data, and
- Assigns accountability for how and when the data will be collected.

Data Collection Plan

Measurement Planning Worksheet	
Date:	
Project Title:	
Project Leader:	

Responses or Outputs (Ys)				Factors (Xs)			
Dependent Variable	USL	LSL	Target	Independent Variable(s)	USL	LSL	Target

What to measure?	How to Measure?		Who?	Sample Plan		
Measure	Test Method	Data Units	Person Assigned	Where?	When?	Sample size?

Recording the allowable range of values for critical Ys and Xs allows the team to calculate process capability.

Check to see if needed data is already being collected. In some instances, teams will need to put temporary data collection tools in place.

Data or Operational Definitions

- A clear and understandable description of the data to be collected
- A good, well written, operational definition reduces the chance of not collecting the right data

Operational Definitions

- A company is receiving complaints that the flat washers recently shipped to a customer aren't made to specification. The Black Belt instructs a technician to select some washers, measure the diameter and give him the values.
- Is this a good operational definition? Why or why not?

Lean Six Sigma DMAIC Process

DEFINE
What problem are we addressing?

- ✓Potential projects evaluated and selected
- ✓Project charter completed
- ✓VOC collected and analyzed
- ✓Process mapped

MEASURE
What data is needed and what is the current performance?

- ✓Data collection plan created
- ❑Data collection completed
- ❑Process baseline established

ANALYZE
What are the root causes of the problem?

- ❑Potential root causes identified
- ❑Analysis of data completed

IMPROVE
What is the best solution to remove each root cause?

- ❑Brainstorm potential solutions
- ❑Pilot solutions
- ❑Optimize process outputs
- ❑Document solution implementation plan

CONTROL
How can we insure the gains are maintained?

- ❑Select appropriate controls
- ❑Document control plan
- ❑Deliver project documentation
- ❑Celebrate completed project

INTRODUCTION TO PROBABILITY AND STATISTICS

Objectives

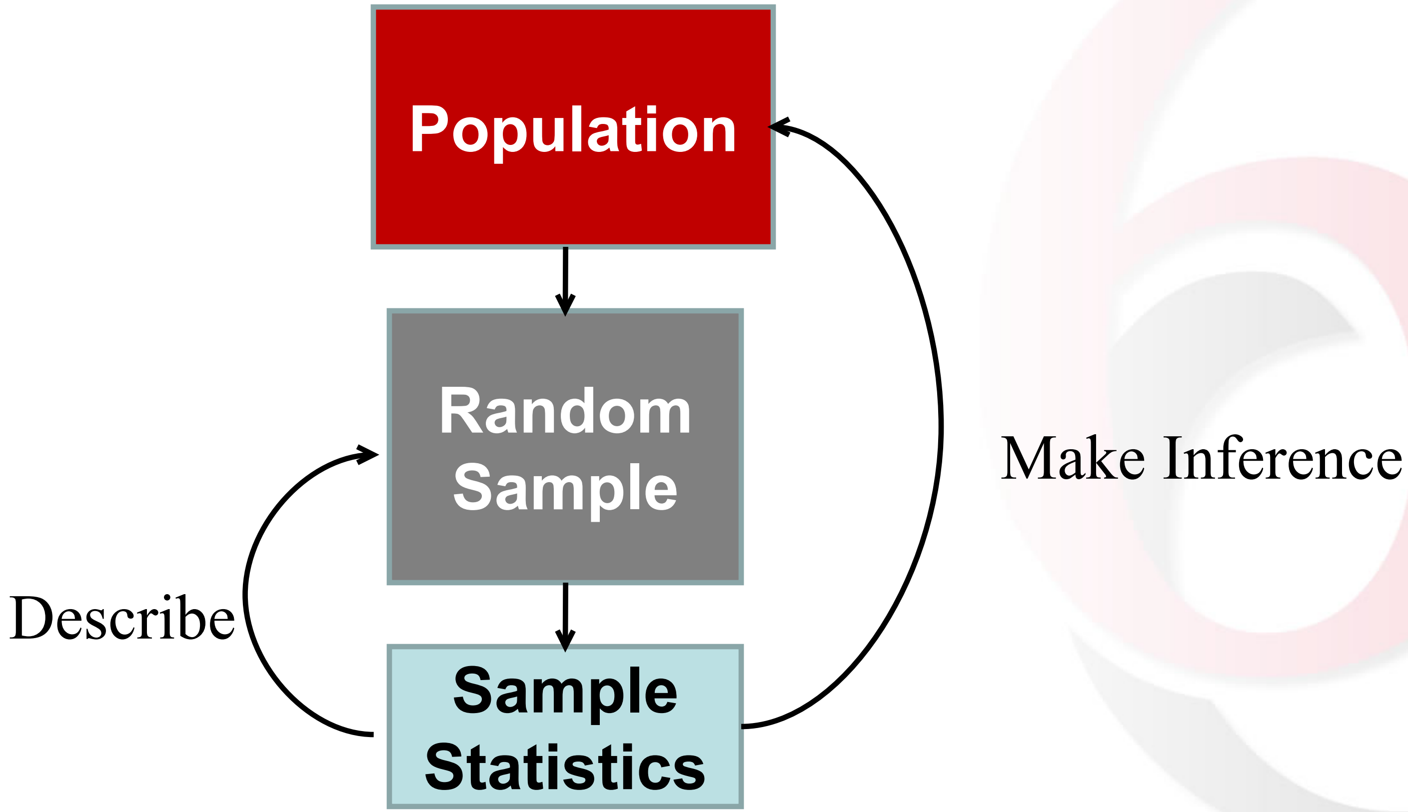
- Discuss the key statistical measures
- Understand data types
- Introduce probability
- Discuss the Central Limit Theorem

Why Study Probability and Statistics?

- Statistics is the collection, organization, analysis, interpretation, and presentation of data.
- Descriptive statistics provide us information about the performance of a process.
- Inferential statistics allow us to predict population performance of a process based on sample measures.

Probability is the foundation of prediction.

Inferential Statistics



Data Types

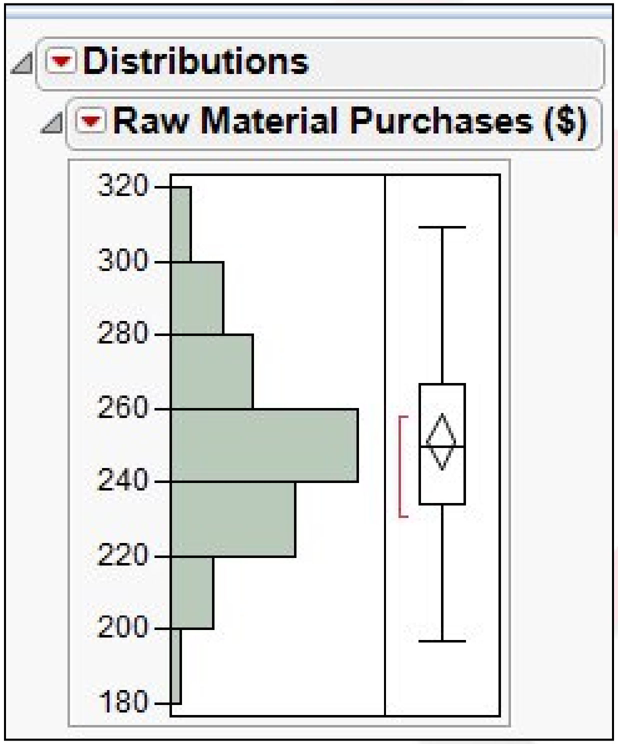
- Qualitative (Attribute)
  - Data that provide labels or names for categories
  - Examples: pass/fail, high/medium/low, drug name
  - Nominal or Ordinal
- Quantitative (Count)
  - Data that count the number of occurrences
  - Examples: number of defects, number of returns
- Quantitative (Variable)
  - Data that indicate how much or how many
  - Examples: weight, temperature, blood pressure
  - Continuous

Describing Data

- Location
  - Mean
  - Median
  - Mode
- Spread
  - Range
  - Variance
  - Standard Deviation
- Shape
  - Skewness
  - Kurtosis

Basic Statistics and Graphs

1. Open **RAW MATERIALS PURCHASE.jmp**.
2. Select **Analyze** → **Distribution**.
3. Select **Raw Materials Purchases ($)** → **Y, Columns**.
4. Select **OK**.



Basic Statistics and Graphs

6. Click the red triangle next to **Summary Statistics → Customize Summary Statistics → Check**
   - **→Sum Weight**
   - **→Sum**
   - **→Variance**
   - **→Skewness**
   - **→Kurtosis**
   - **→CV**
   - **→N Missing**
7. Select **OK.**

Quantiles

100.0%	maximum	308.902
99.5%		308.902
97.5%		307.271
90.0%		288.391
75.0%	quartile	266.875
50.0%	median	249.41
25.0%	quartile	234.045
10.0%		218.825
2.5%		197.79
0.5%		196.576
0.0%	minimum	196.576

Summary Statistics

Mean	250.88632
Std Dev	25.578023
Std Err Mean	3.6172787
Upper 95% Mean	258.15551
Lower 95% Mean	243.61712
N	50
Sum Wgt	50
Sum	12544.316
Variance	654.23525
Skewness	0.1330898
Kurtosis	-0.025592
CV	10.195065
N Missing	0

Location

- The **mean** (population) or **average** (sample) is the most common measure of location. The average is calculated by summing the measurements and dividing by the number of observations in the sample (n). The average will be influenced by outlying values in a sample.
- The **median** is the physical center of the data and is not adversely affected by outlying values. The median is almost always reported when measuring data that is likely to have a few outliers that skew the data such as salaries and housing prices.
- The **mode** is the value that occurs most often in a sample.

Spread

- The **Range** is the difference between the highest and lowest values in a sample. The larger the range, the greater the spread of values in the sample.
- The **variance** and the **standard deviation** measure how values deviate from the average of a sample. The variance is the sum of the squared distance of each point from the mean divided by (n-1).
- The **standard deviation** is the square root of the variance.

Shape

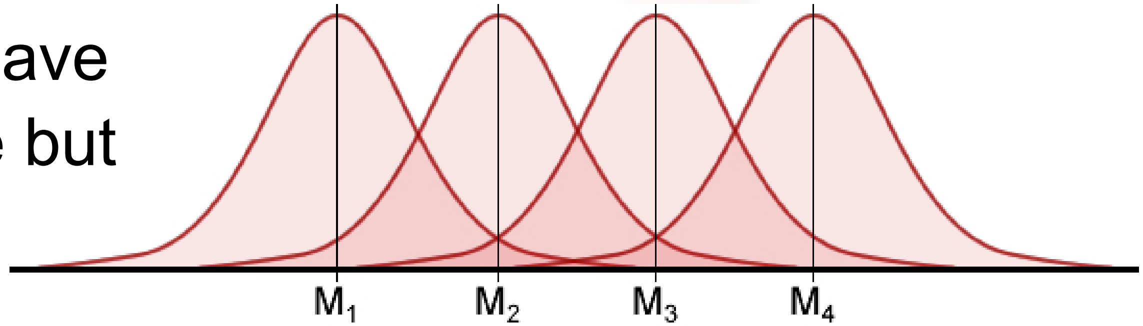
- Skewness measures indicate how symmetric, or not symmetric a distribution is. A positive skewness statistic indicates the data is skewed right and a negative skewness statistic indicates the data is skewed left.
- Kurtosis measures whether the data are peaked or flat relative to a normal distribution. The smaller the kurtosis value, the flatter the distribution of data.

Understanding the Normal Distribution

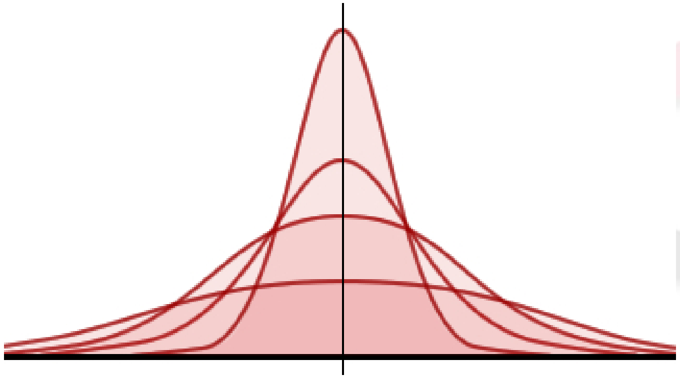
- Smooth, symmetrical, bell-shaped curve.
- Many of the statistical analyses used during a Six Sigma project, assumes the collected data are normally distributed
- The normal distribution is described by two numbers: the average and the standard deviation.

The Normal Distribution *(cont.)*

Four Normal distributions that have the same variance but different means.

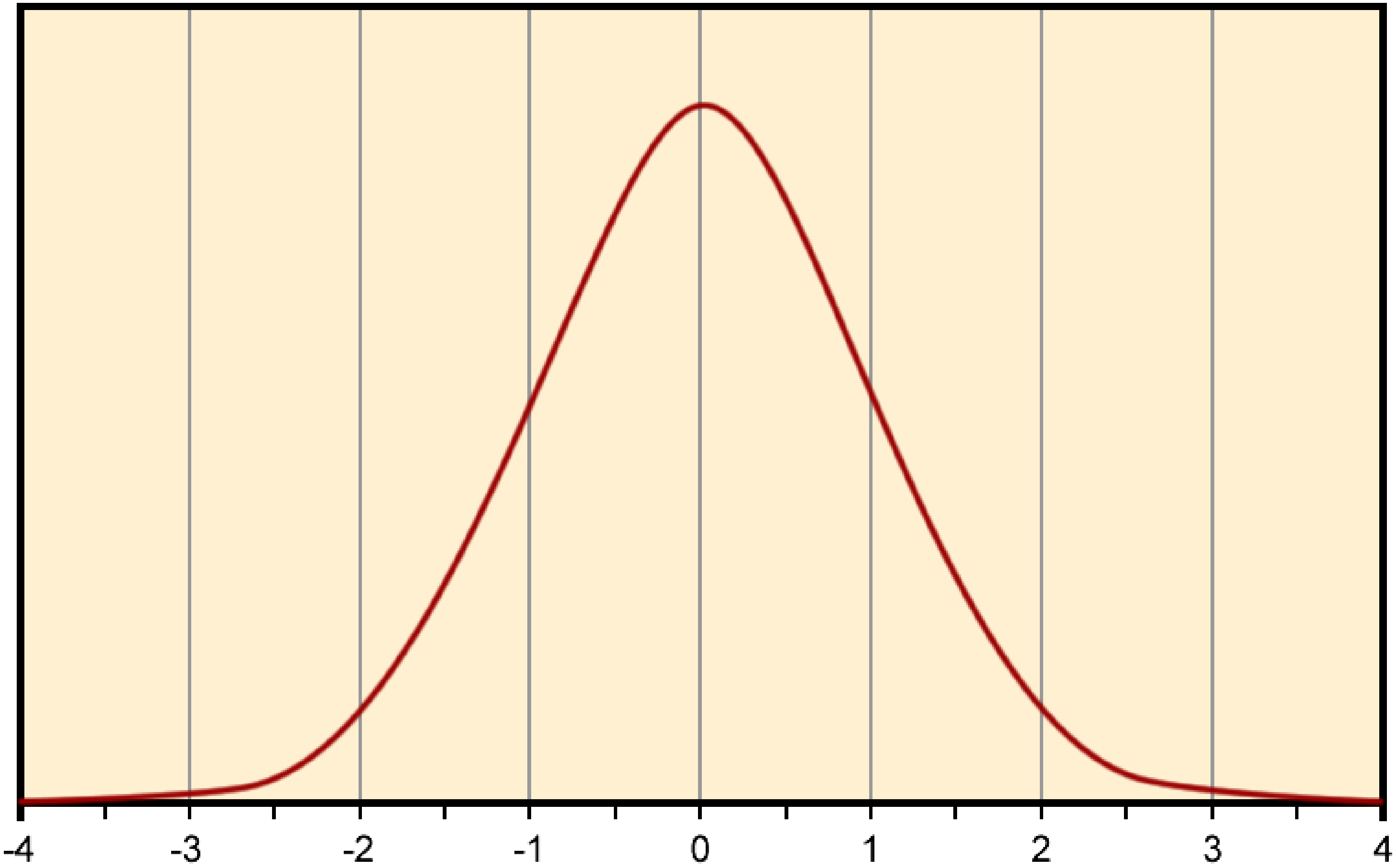


Four Normal distributions that have the same mean but different variances.



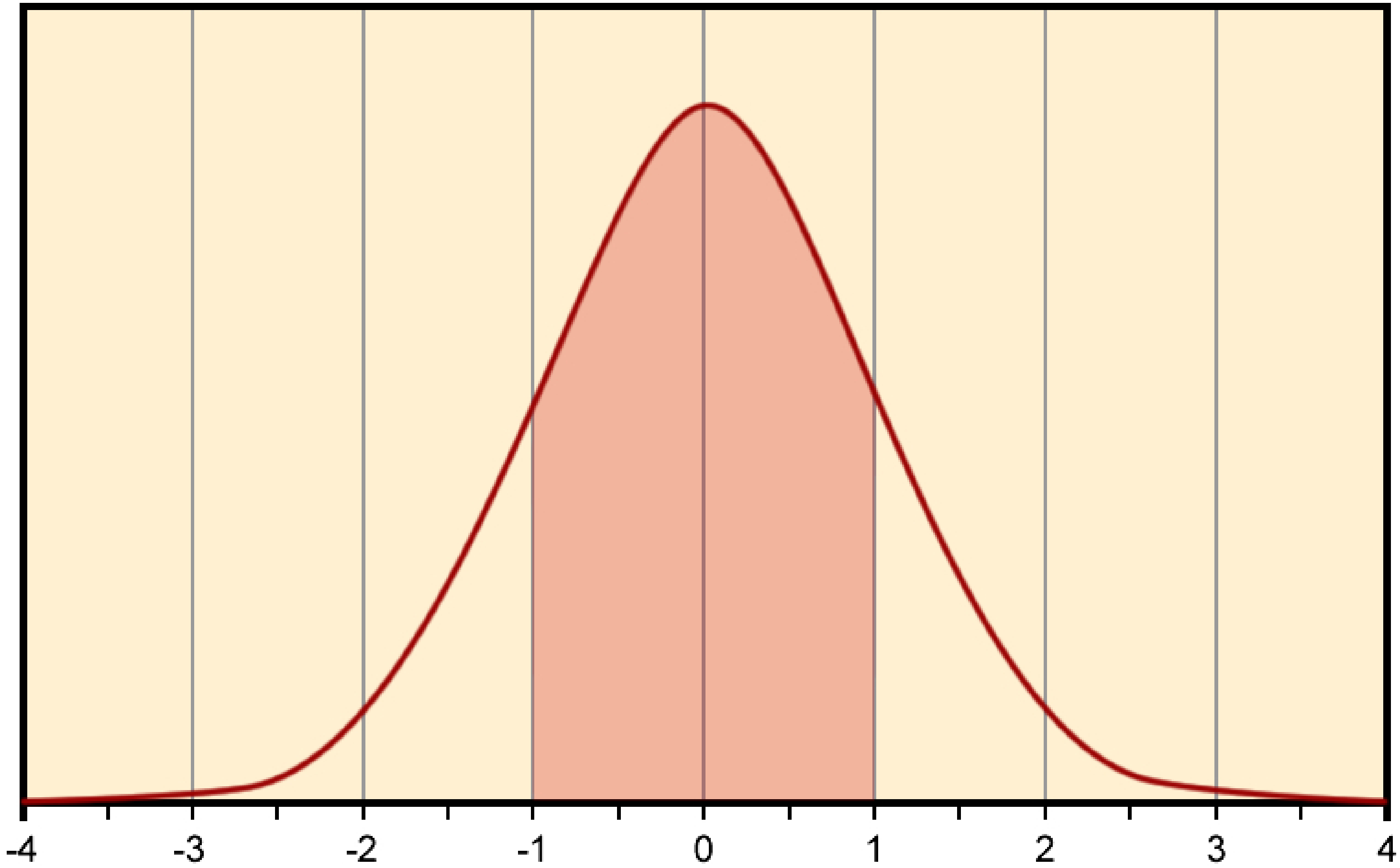
The Standard Normal Distribution

N (0, 1)



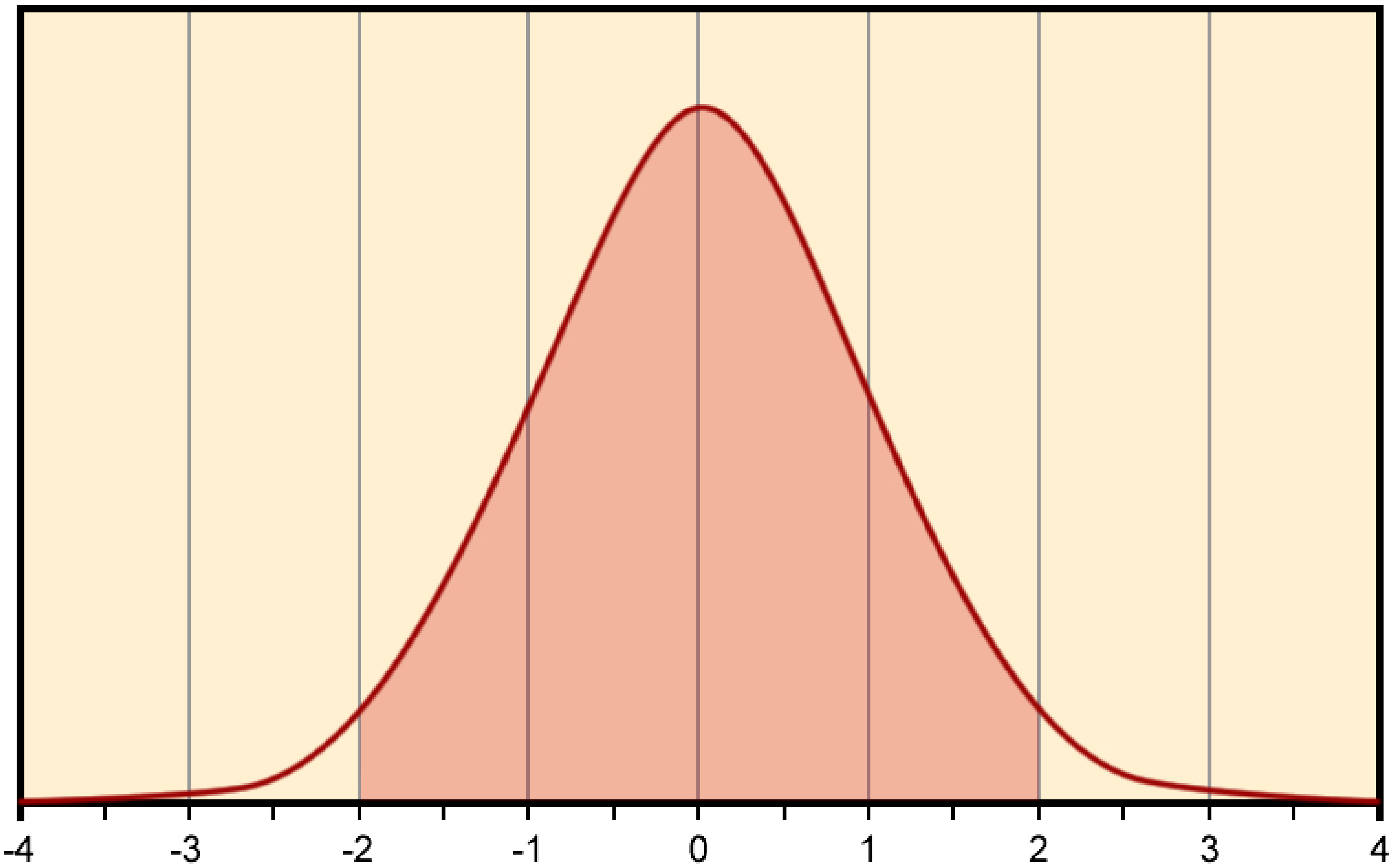
Standard Deviation of the Mean

68.3% of data fall within 1 Std Dev



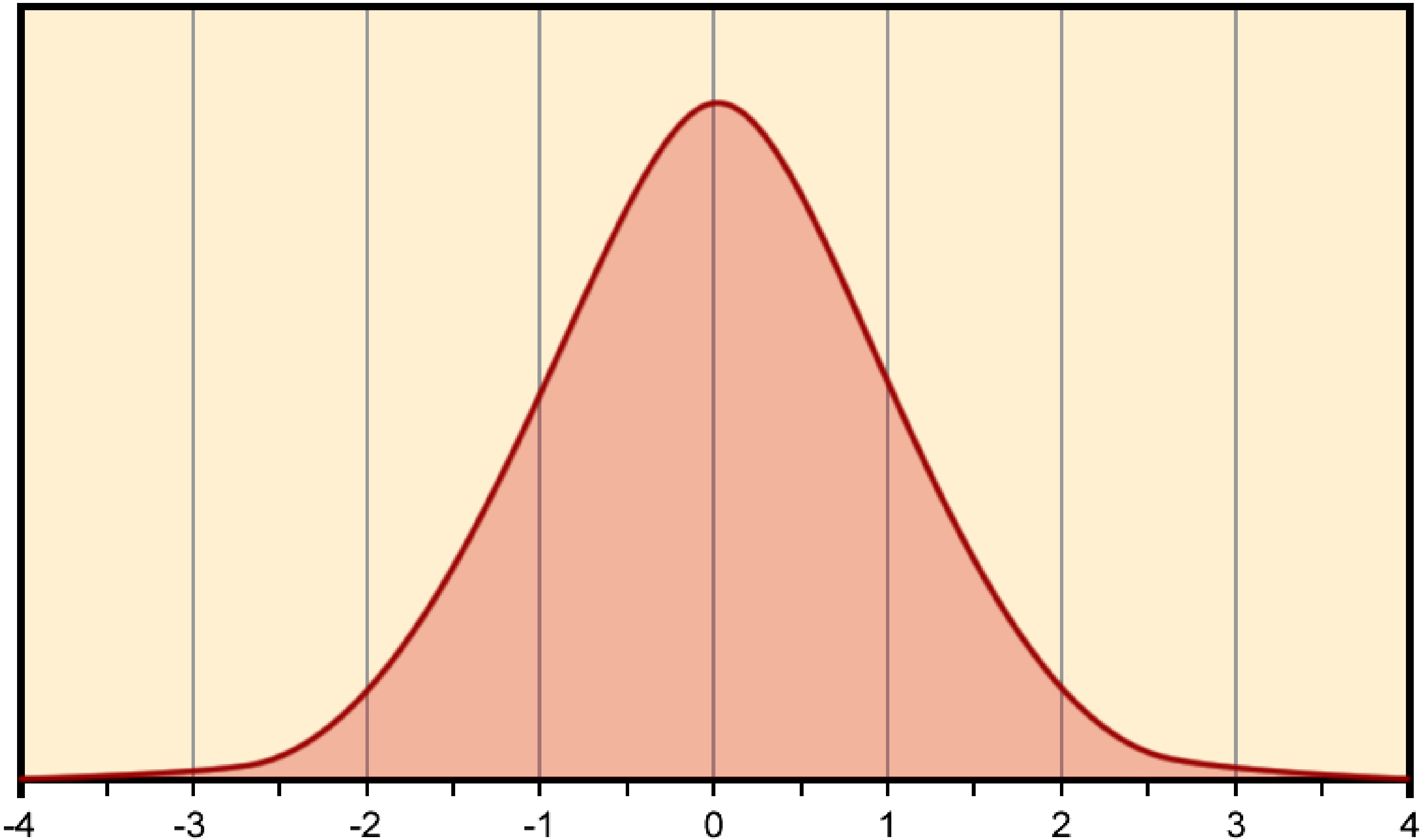
Standard Deviation of the Mean *(cont.)*

95.4% of data fall within 2 Std Dev



Standard Deviation of the Mean *(cont.)*

99.73% of data fall within 3 Std Dev



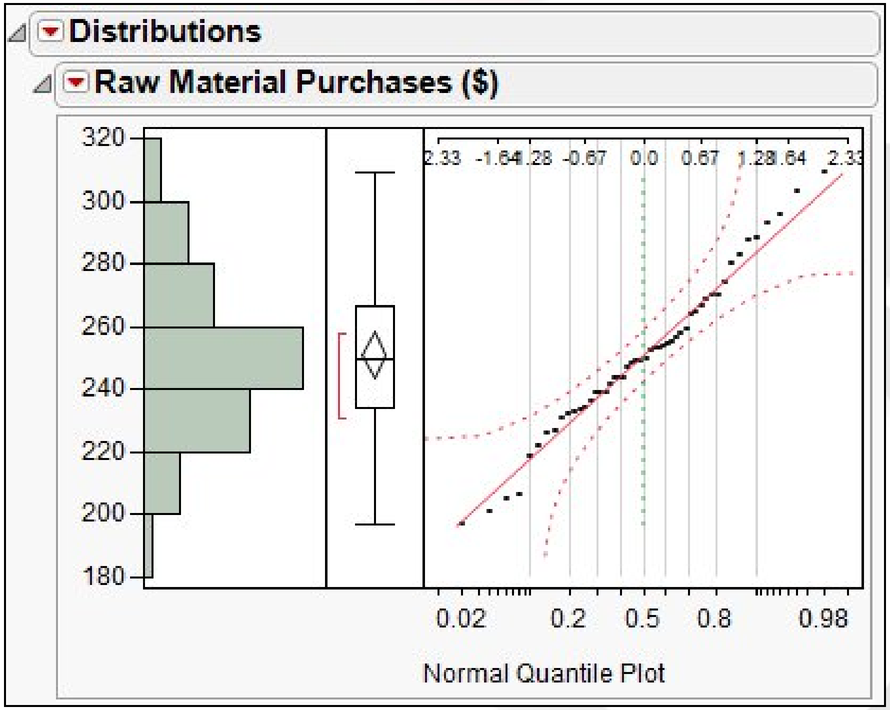
You can see ± 3 **s** when sketching

Validating Normality

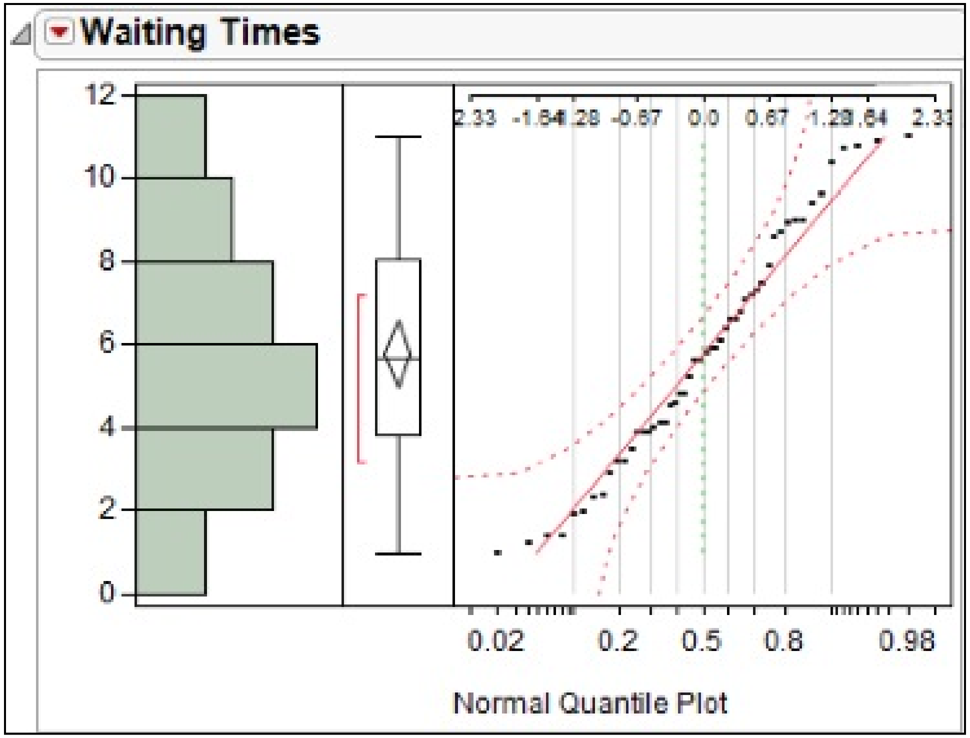
- Graphically
- Statistical Test
- Central Limit Theorem

Validating Normality

1. Open **RAW MATERIALS PURCHASE.jmp**.
2. Select **Analyze → Distribution**.
3. Select **Raw Materials Purchases ($) → Y, Columns**.
4. Select **OK**.
5. Click the red triangle next to **Raw Materials Purchases ($)** and select **Normal Quantile Plot**



Validating Normality

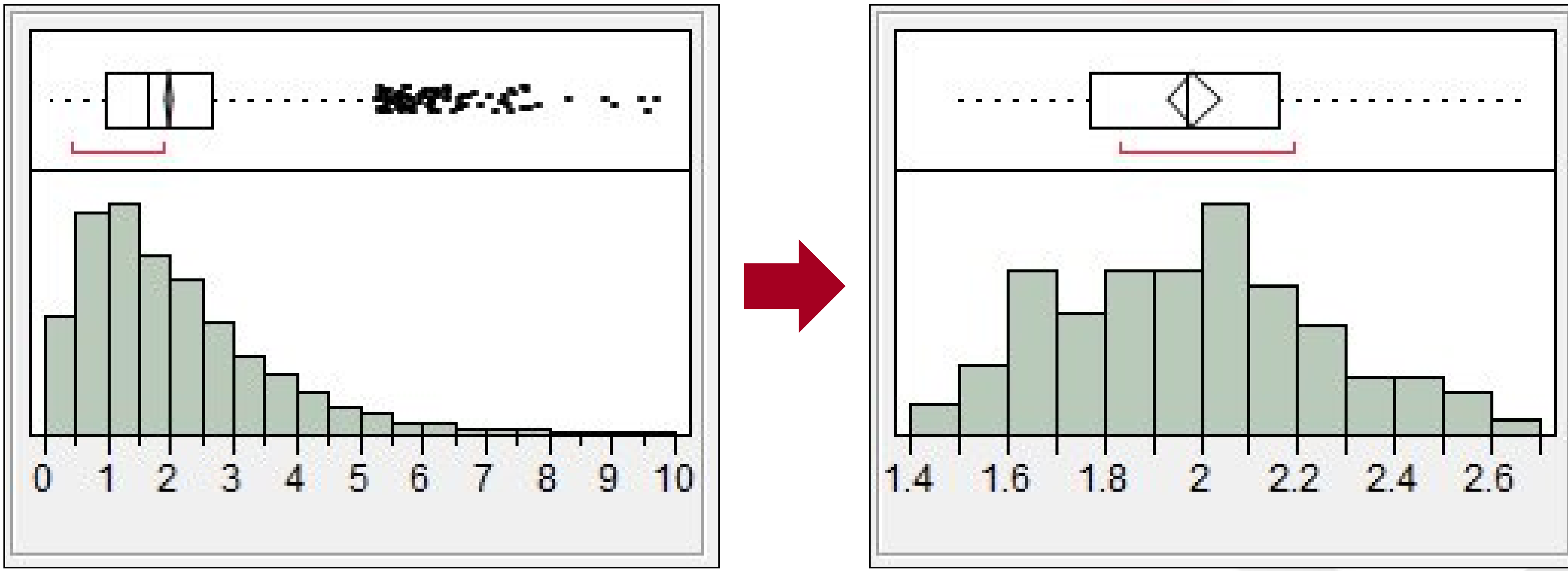


- Box and Whisker plot
  - Compare Median and Mean
  - Symmetry
- Normal Quantile plot
  - Compare actual distribution to predicted distribution
  - Click the red triangle next to Raw Material Purchases ($) and select Normal Quantile Plot
- Histogram
  - Shape

The Central Limit Theorem

- The Central Limit Theorem allows us to assume that the distribution of sample means will approximate the normal distribution if “n” is sufficiently high (n = 30 for unknown distributions).
- The Central Limit Theorem also allows us to assume that the distributions of sample means of a normal population are themselves normal, regardless of sample size.
- The standard error of the mean shows that as sample size increases, the standard deviation of the sample means decreases.

The Central Limit Theorem



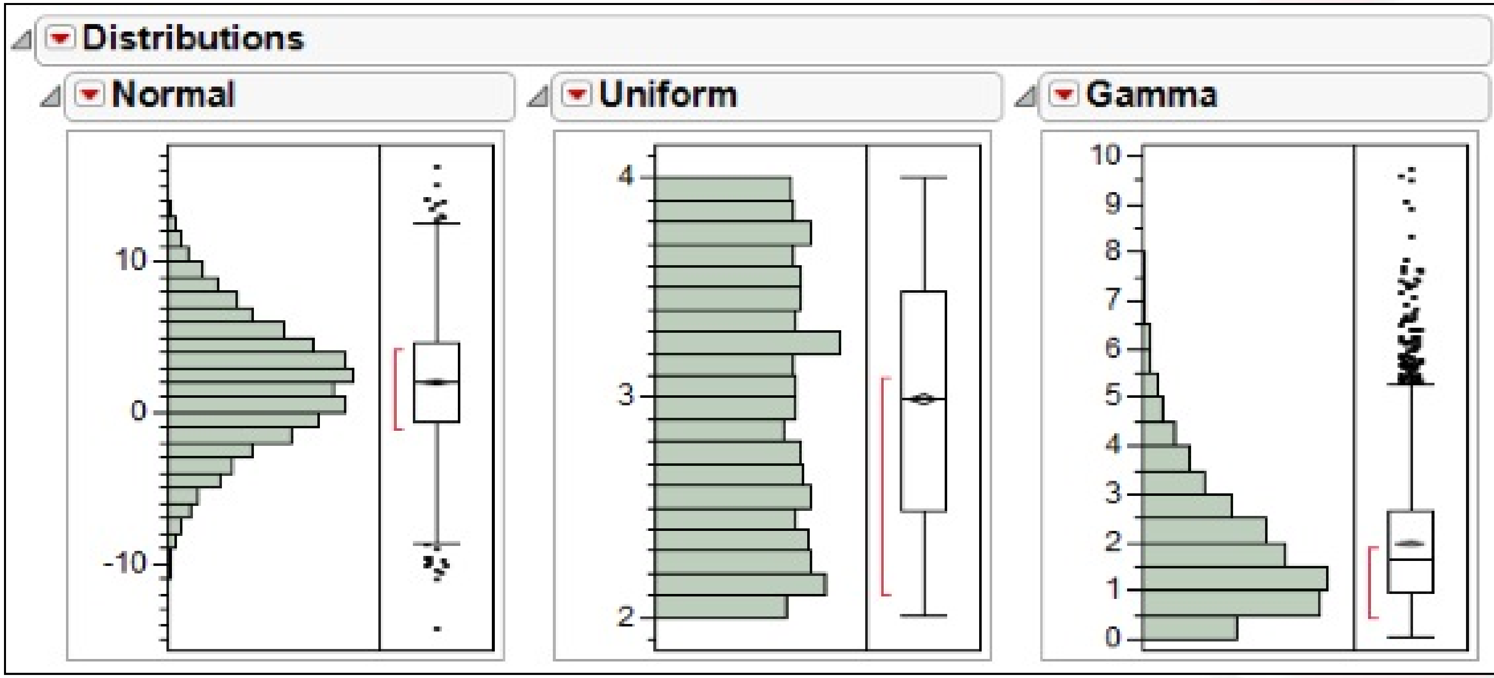
For the majority of distributions, as the sample size increases, the distribution of sample means is approximately normal.

The Central Limit Theorem

The data table, CLT Raw Data.jmp, contains 3 columns. The data in the columns are from known normal, uniform and gamma distributions.

1. Open **CLT Raw Data.jmp**.
2. Select **Analyze → Distribution**.
3. Select **Normal, Uniform and Gamma → Y, Columns**.
4. Select **OK**.

The Central Limit Theorem



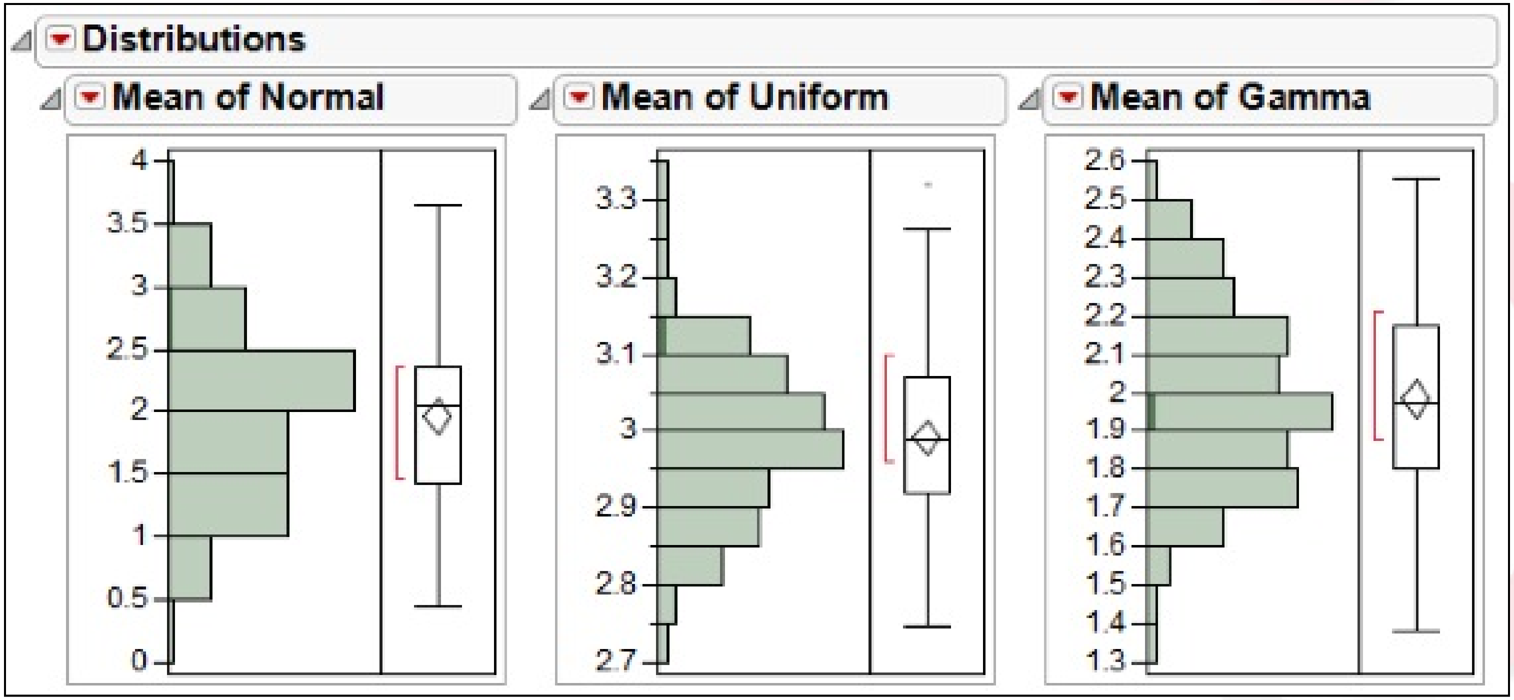
Summary Statistics (Normal)		Summary Statistics (Uniform)		Summary Statistics (Gamma)	
Mean	1.9621116	Mean	2.9916953	Mean	1.9850212
Std Dev	4.0391389	Std Dev	0.5766591	Std Dev	1.4020907
Std Err Mean	0.0737442	Std Err Mean	0.0105283	Std Err Mean	0.0255986
Upper 95% Mean	2.1067061	Upper 95% Mean	3.0123387	Upper 95% Mean	2.0352137
Lower 95% Mean	1.8175172	Lower 95% Mean	2.9710519	Lower 95% Mean	1.9348287
N	3000	N	3000	N	3000

The Central Limit Theorem

According to the Central Limit Theorem, if a population is sampled from repeatedly, the sample averages will be normally distributed.

1. Open **CLT Data Summary.jmp**.
2. Select **Analyze → Distribution**.
3. Select **Mean of Normal, Mean of Uniform, and Mean of Gamma → Y, Columns**.
4. Select **OK**.

The Central Limit Theorem



Summary Statistics	
Mean	1.9621116
Std Dev	0.705528
Std Err Mean	0.0705528
Upper 95% Mean	2.1021037
Lower 95% Mean	1.8221196
N	100

Summary Statistics	
Mean	2.9916953
Std Dev	0.1083526
Std Err Mean	0.0108353
Upper 95% Mean	3.0131948
Lower 95% Mean	2.9701958
N	100

Summary Statistics	
Mean	1.9850212
Std Dev	0.2440649
Std Err Mean	0.0244065
Upper 95% Mean	2.0334489
Lower 95% Mean	1.9365934
N	100

Central Limit Theorem Example

- What happened to the shapes of the distributions?
- What happened to the Standard Deviations?
- Why is it important to be able to assume the sample averages are normally distributed?

MEASUREMENT SYSTEMS ANALYSIS

Objectives

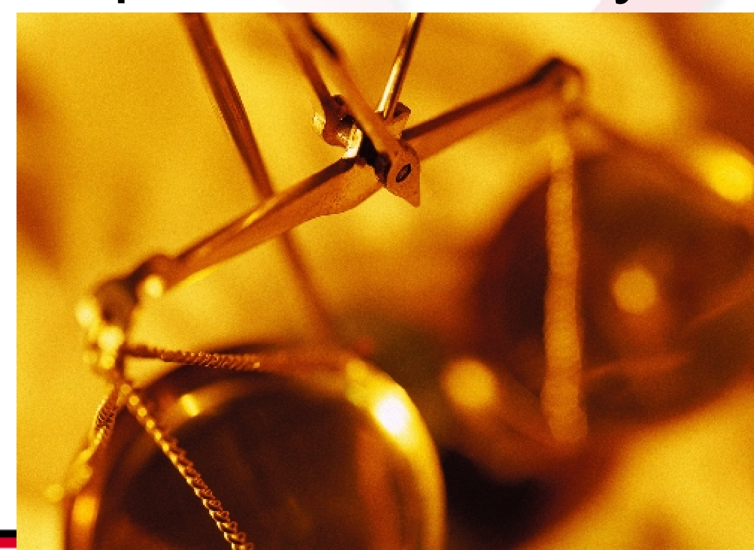
- Discuss the importance of knowing how data was collected
- Understand how poor data collection methods increase variation in data
- Create a list of potential sources of variation in the data being collected for a Lean Six Sigma project
- Review of some methods used to quantify measurement variation.

Measurement System

- The measurement system is the complete process used to collect data. The people, methods, equipment and technology employed in data collection comprise the measurement system.
- The ability to measure process and material parameters accurately and precisely are critical for making decisions that affect the project.
- The measurement system must be analyzed and improved before data is collected.

Questions we are trying to answer

- Do we have the data that we need?
- What type of data is involved?
- How will it be collected?
- Is it accurate and precise enough for us to be able to determine if a change to the process actually improved the process?



Bad Data

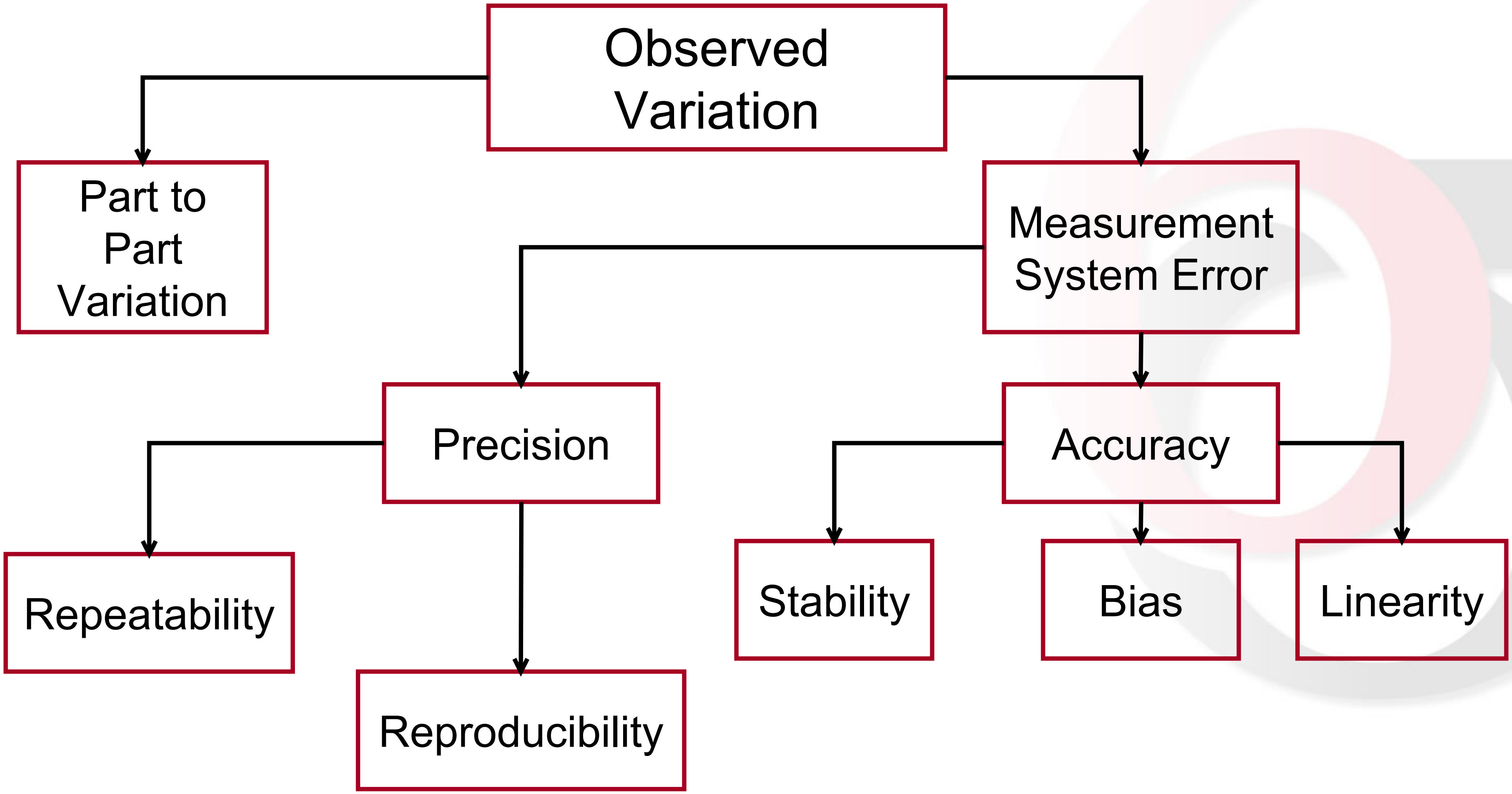
The reasons the data we collect is not reliable include:

- Lack of clear operational definitions
- Data are difficult to collect
- The sampling plan is insufficient
- Measurement devices are not accurate
- Testing procedures are not documented or not clearly written

Assessing the Measurement System

- Gage R&R
  - Variables Data
- Attribute MSA
  - Count Data
- MSA Who, What, When, Where, and How

MSA – Variables Data



Precision

- A system is precise if it returns the same value every time regardless of who does the measurement and the tool they use.
- The spread of the data is driven by the precision of the system.
- The two components of precision are Repeatability and Reproducibility.
- A Gage R & R study quantifies Repeatability and Reproducibility in manufacturing.

Repeatability and Reproducibility

- Repeatability is the variation present when the same part is measured repeatedly by the same appraiser using the same tool/method.
- Reproducibility is the variation present when different appraisers use the same tool/method to measure the same parts.

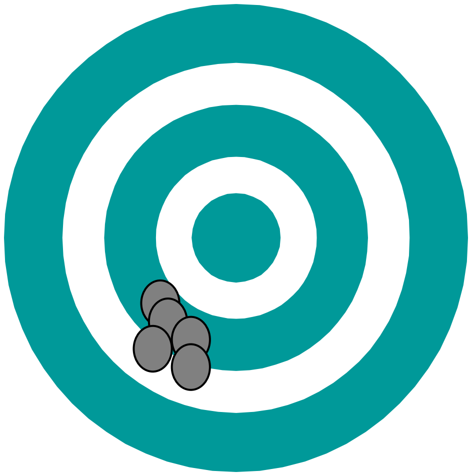
Accuracy

- Accuracy is the difference between an observed value and a reference value.
- Accuracy is related to the average – on average how does the measurement system compare to the true average.
- Accuracy may be assessed against a standard, another measurement method or a predicted value.

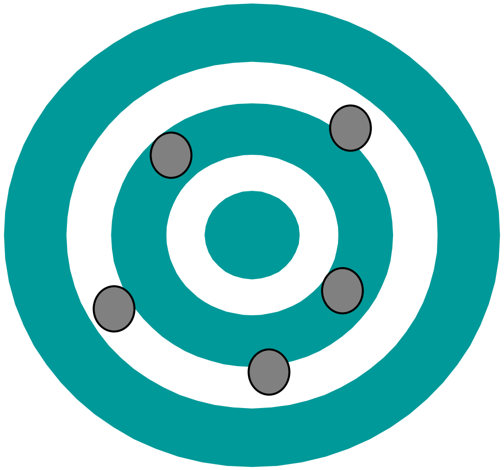
Measuring Accuracy

- Bias: the deviation of the measured value from the actual value.
- Linearity: a measure of how size affects accuracy of a measurement system.
- Stability: a measure of how accurate the system performs over time.

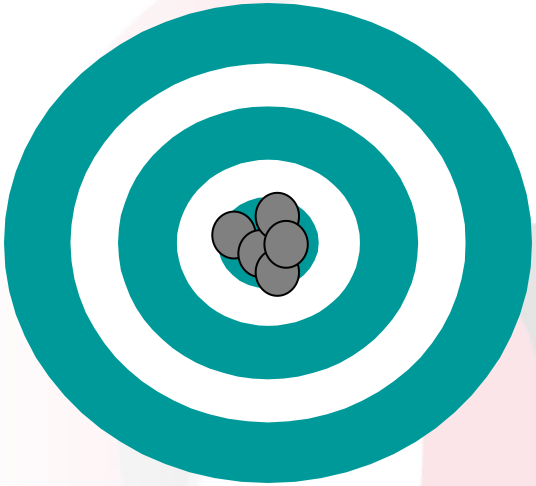
Precision versus Accuracy



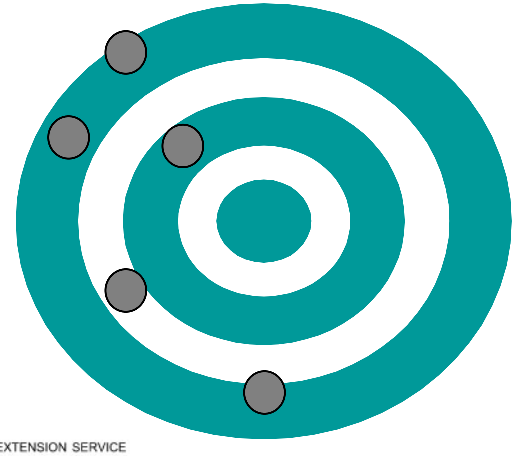
Precise



Accurate



Both



Neither

MSA – Who, What, When, Where, & How

- A traditional gage R & R or Attribute MSA may not always be appropriate. In those situations, the team should make an in-depth study of the measurement system to determine the precision and accuracy of the data they are collecting.
- The team should map the measurement process and then use an FMEA or the 5 Whys tool to make certain potential failures in the measurement system are identified and addressed.

GAGE R&R

Objectives

- Understand the goal of a Gage R & R study
- Conduct and analyze a Gage R & R study

MSA - Gage R&R Study

Gage R&R (Reproducibility & Repeatability) studies determine how much of your observed process variation is due to your Measurement System variation.

Overall Variation, SS_T

Part-to-part Variation

SS_{Part}

Measurement System Variation

$SS_{R\&R}$

Variation due to gage

Repeatability

SS_{Gage}

Variation due to operators

Reproducibility

$SS_{Operator}$

Sources of Variation *(cont.)*

Part to part
Operator
Device (equipment)

$$SS_{Total} = SSpart + SS_{Operator} + SS_{Gage}$$

SS - Sum of Square :

Measure the distance from an average, square it and sum them all together.
SS is a measure of variation.

Sources of Variation *(cont.)*

Part to Part
Operator
Device (equipment)

$$SS_{Total} = SS_{Part} + \underbrace{SS_{Operator} + SS_{Gage}}_{SS_{R\&R}}$$

Reproducibility & Repeatability

$$SS_{Total} = SS_{Part} + SS_{R\&R}$$

MSA – Gage R&R Studies

$$SS_{Total} = SS_{Part} + \underbrace{SS_{Operator} + SS_{Gage}}_{SS_{R\&R}}$$

Reproducibility & Repeatability

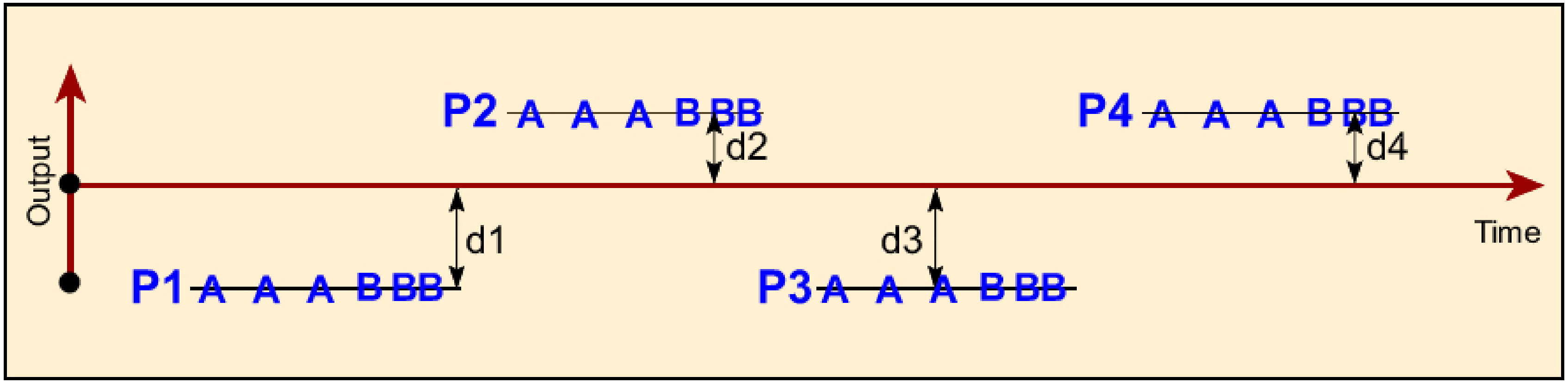
$$SS_{Total} = SS_{Part} + SS_{R\&R}$$

For a good Measurement System

$$SS_{Part} / SS_{Total} \gg SS_{R\&R} / SS_{Total}$$

$$> 90\% \qquad < 10\%$$

MSA – Gage R&R Studies *(cont.)*



We want a small Measurement System Variation ($SS_{R\&R}$) compared to the part-to-part variation (SS_{Part})

Acceptance Criteria

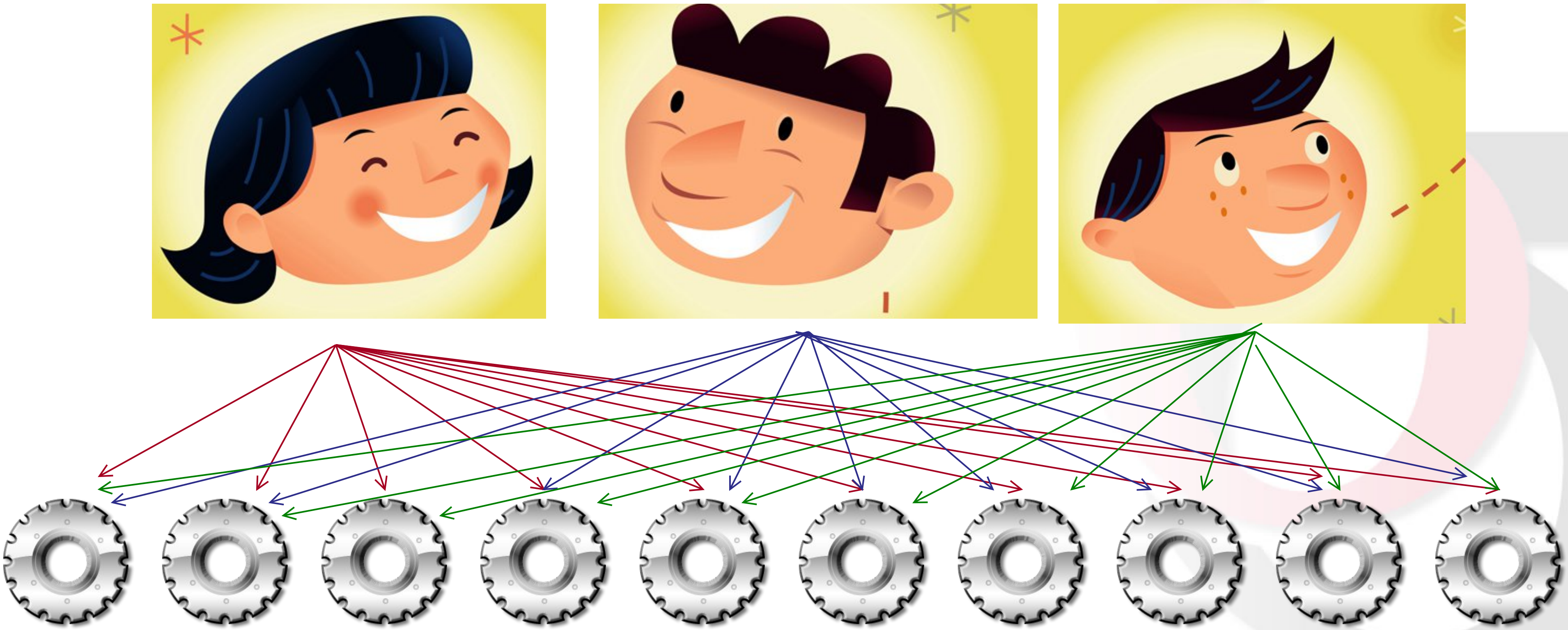
- There are four common methods used to qualify a measurement system.
  - % Contribution
  - % Study Variation
  - Distinct Categories
  - Discrimination Ratio
- The rules for each method are shown below.

	% Contribution	% Study Variation	Distinct Categories	Discrimination Ratio
Accept	< 1 %	<10 %	> 10	> 10
Consider criticality	1 % - 9 %	10 % - 30 %	4 - 9	4 - 9
Reject	> 10 %	> 30 %	< 4	< 4

Example

- Ten parts were selected that represent the expected range of the process variation (usually we want to assure at least 80% coverage).
- Three operators measured the ten parts, three times per part, in a random order.

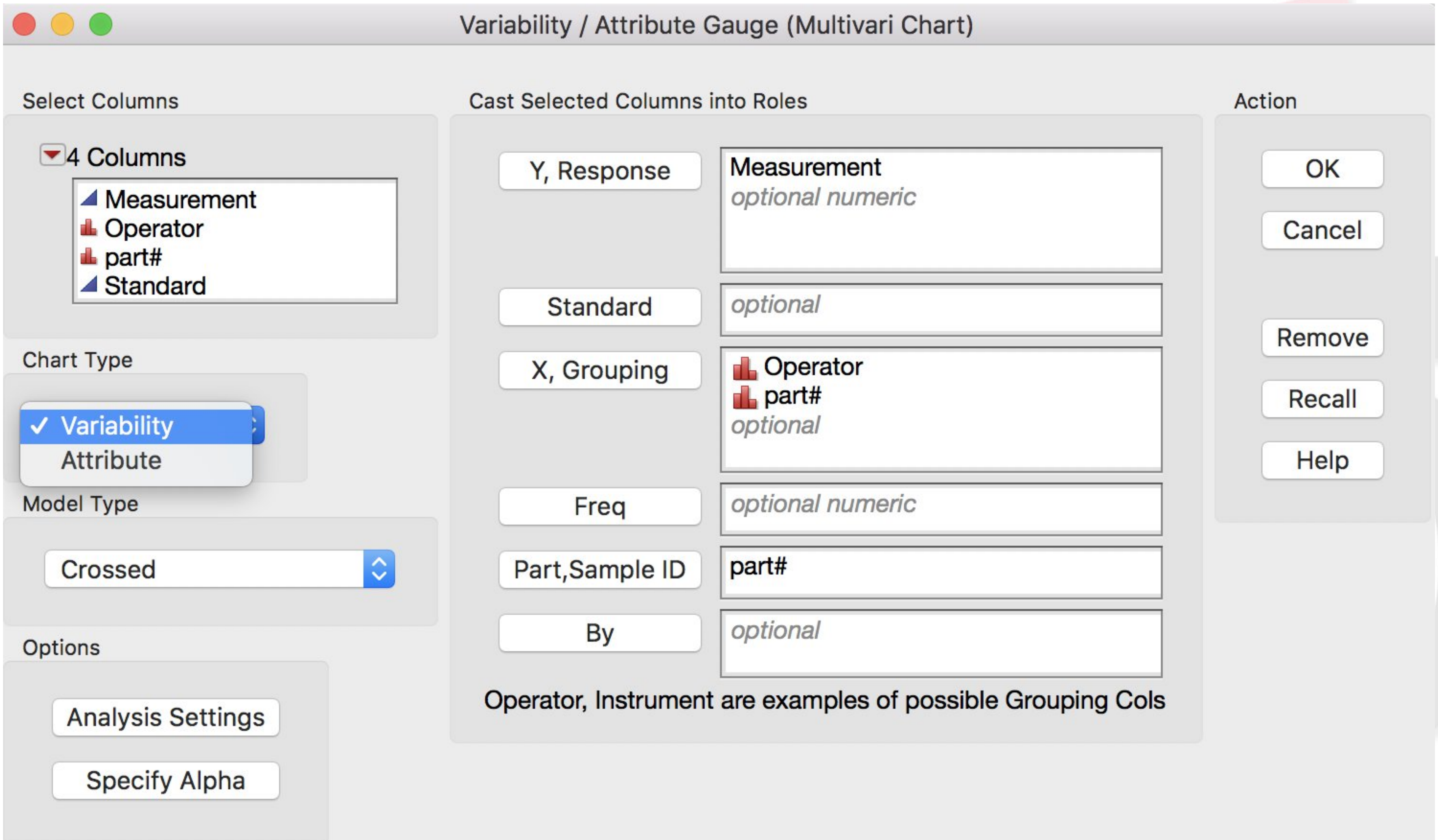
Example



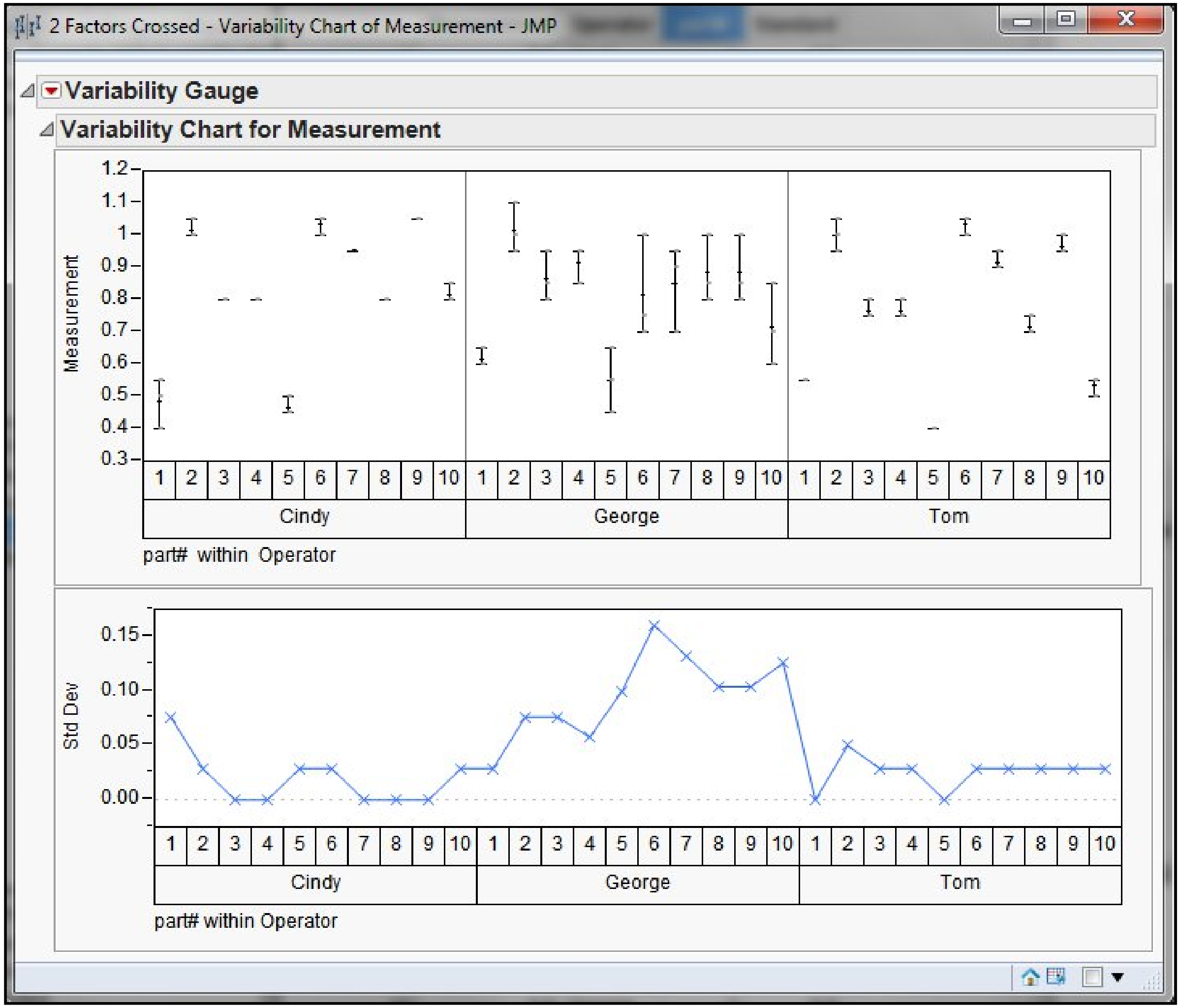
Example

1. Select **Help → Sample Index**.
2. Click the diamond next to **Measurement Systems**.
3. Select **2 Factors Crossed.jmp**.
4. Select **Analyze → Quality and Process → Measurement Systems Analysis Variability/Attribute Gage Chart (make sure you select the second line of the two)**

1. **Chart Type → Select Variability**
2. Select **Measurement → Y, Response**.
3. Select **Operator** and **Part # → X, Grouping**.
4. Select **Part# → Part, Sample ID**
5. Select **Model Type** and select **Crossed**
6. Select **OK**


Variability / Attribute Gauge (Multivari Chart)
Select Columns
4 Columns
Measurement
Operator
part#
Standard
Chart Type
✓ Variability
Attribute
Model Type
Crossed
Options
Analysis Settings
Specify Alpha
Cast Selected Columns into Roles
Y, Response
Measurement
optional numeric
Standard
optional
X, Grouping
Operator
part#
optional
Freq
optional numeric
Part,Sample ID
part#
By
optional
Operator, Instrument are examples of possible Grouping Cols
Action
OK
Cancel
Remove
Recall
Help

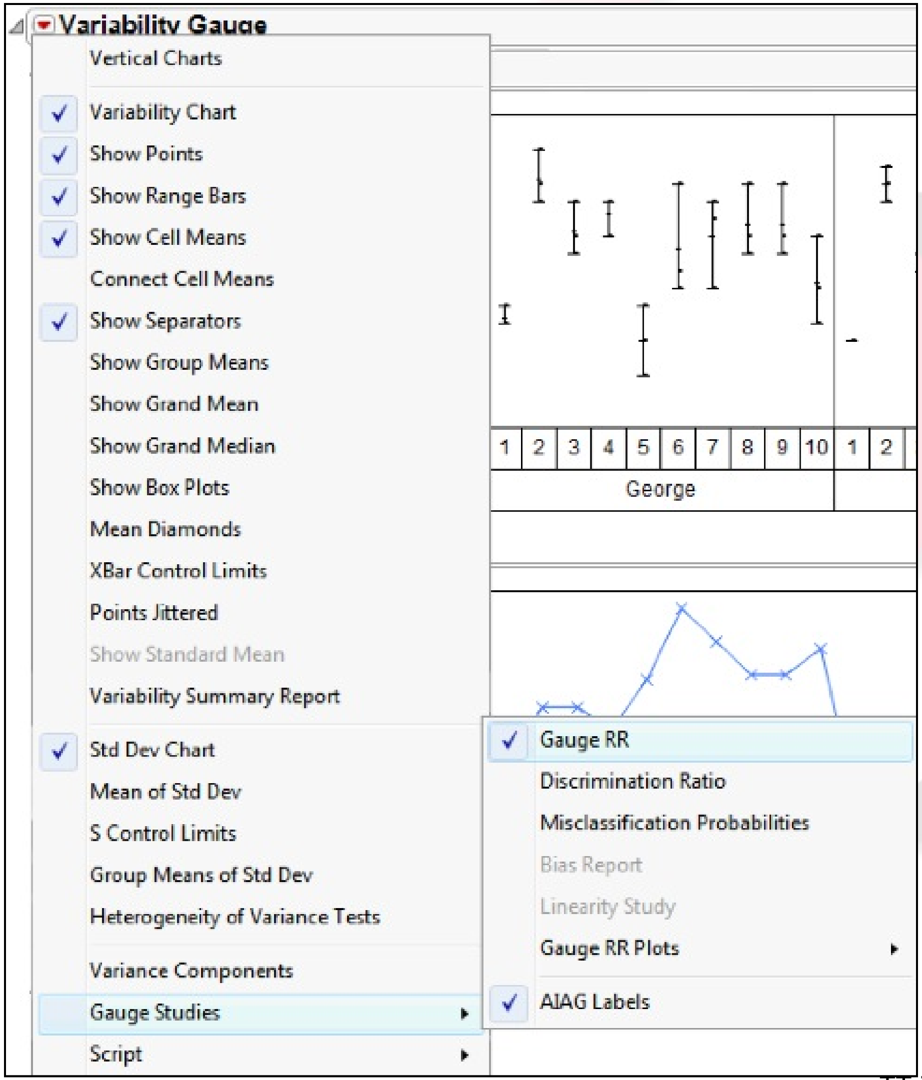
Example

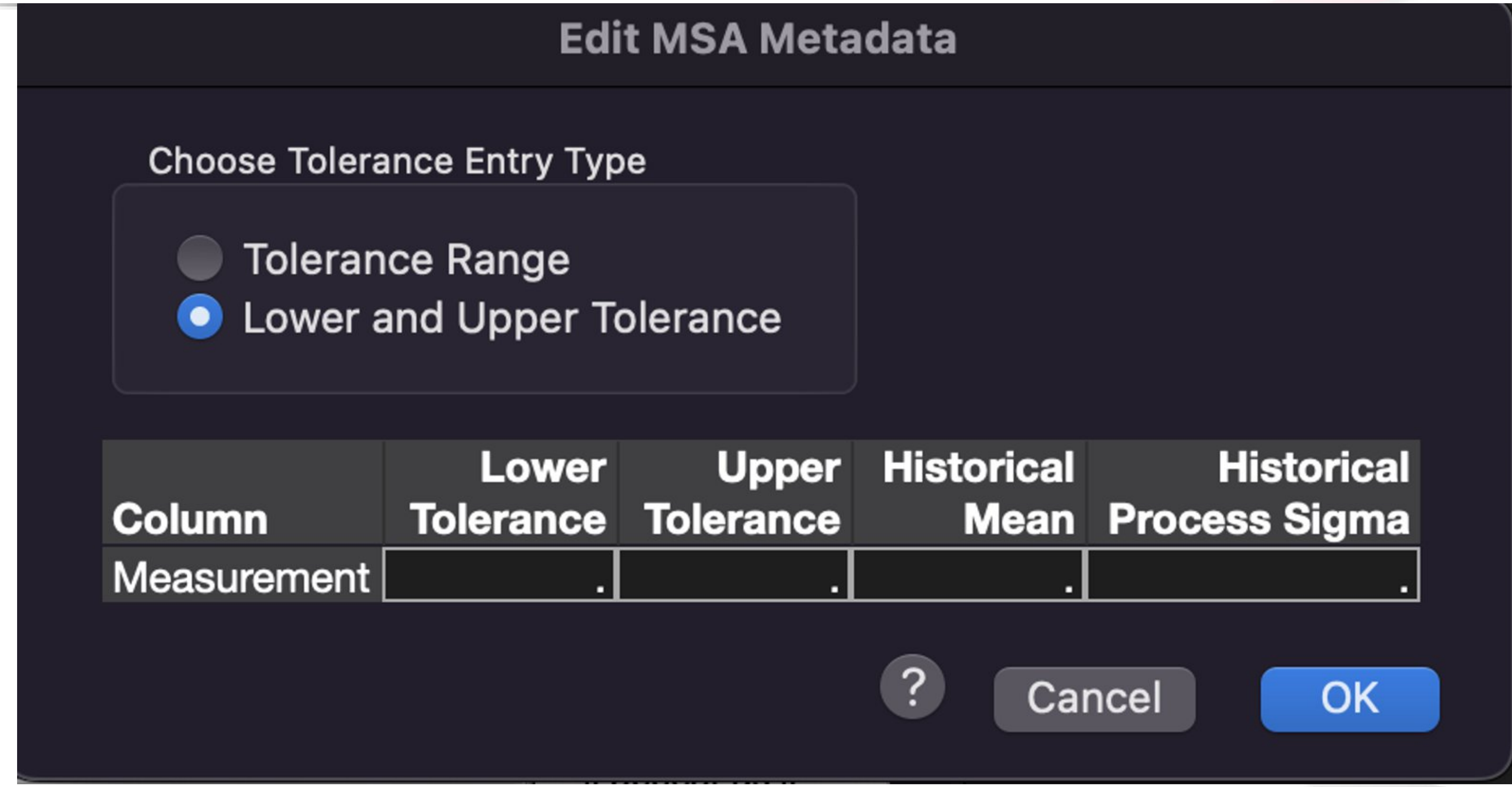


- Graphically, does it appear as if one operator has more variation in measurements?

Example

1. Click the red triangle next to **Variability Gauge** and select **Gauge Studies → Gauge RR**.
2. Select **OK**.




Edit MSA Metadata
Choose Tolerance Entry Type
Tolerance Range
Lower and Upper Tolerance
Column
Lower Tolerance
Upper Tolerance
Historical Mean
Historical Process Sigma
Measurement
?
Cancel
OK

Example

Variance Components for Gauge R&R

Component	Var Component	% of Total
Gauge R&R	0.00993519	24.76
Repeatability	0.00413889	10.31
Reproducibility	0.00579630	14.44
Part-to-Part	0.03019444	75.24

Gauge R&R + Part-to-Part = 100

- The variance components report may be used to determine the amount of variation in the data due to the measurement system.
- Is the measurement system adequate?
- If the measurement system is not adequate, what steps should be taken?

Example

Measurement Source		Variation (6*StdDev)		which is 6*sqrt of
Repeatability	(EV)	0.3860052	Equipment Variation	V(Within)
Reproducibility	(AV)	0.4568005	Appraiser Variation	V(Operator) + V(Operator*part#)
Operator		0.0888194		V(Operator)
Operator*part#		0.4480823		V(Operator*part#)
Gauge R&R	(RR)	0.5980524	Measurement Variation	V(Within) + V(Operator) + V(Operator*part#)
Part Variation	(PV)	1.0425929	Part Variation	V(part#)
Total Variation	(TV)	1.2019429	Total Variation	V(Within) + V(Operator) + V(Operator*part#) + V(part#)

Summary and Gauge R&R Statistics

- You will also get much more information with great detail about the variation due to the equipment and variation due to the appraiser.
- Remember the part variation is what is important, we want it to be high compared to the equipment and appraiser variation.

Example

6	k
49.7571	% Gauge R&R = 100*(RR/TV)
0.57362	Precision to Part Variation = RR/PV
2	Number of Distinct Categories = Floor(sqrt(2)*(PV/RR))

- Sometimes people want the report in distinct categories. JMP Pro 17 gives you this information too.
- Remember these are just different ways of presenting the same results. Most of us find the Variance Components for Gauge R&R the easiest to understand and to explain to others.

MEASUREMENT SYSTEMS ANALYSIS ATTRIBUTE DATA

Measurement Systems Analysis - Attribute Data

Go/No-Go

Go/No-Go

Go/No-Go

Go/No-Go

Go/No-Go

Attribute Instrument Study

- Technique of comparing to specific set of limits and accepting or rejecting item
- Accept/reject rule establishes data set for binomial distribution and P and NP control charts
- We use a simple spreadsheet to analyze

Why Do We Need Attribute Gage Studies?

- To determine how well quality associates are conforming to known values
- To determine how well quality inspectors are consistent within themselves
- To determine if the existing standard samples provide sufficient criteria for associates

Terms

- **Attribute Measurement System**: compares parts to a specific set of limits and accepts the parts if the limits are satisfied.
- **Screen**: 100% evaluation of output using an attribute measurement system
- **Screen Effectiveness (%)**: ability of the attribute measurement system to properly discern good parts from bad.

Attribute Gage Study

- Attribute data (Good/Bad, ---)
- You can have multiple categories for attributes.
- Compares parts to specific standards for accept/reject
- Must screen for effectiveness to discern good from bad
- At least two associates and two trials each

X-Ray Chart Illustrative Example

- X-rays are read by two technicians.
- Twenty X-rays are selected for review by each technician. (some X-rays with no problems and others with bone fractures.)
- Objective: Evaluate the effectiveness of the measurement system to determine if there are differences in the readings.

X-Ray Illustrative Example

1. Twenty X-rays were selected that included good (no fracture) and bad (with fractures)
2. Two technicians independently and randomly reviewed the 20 X-rays as good (no fracture) or bad (with fractures).
3. Data are entered in spreadsheet and the Screen Effectiveness score is computed.

X-Ray Illustrative Example

	Associate A		Associate B		
	1	2	1	2	Standard
1	G	G	G	G	G
2	G	G	G	G	G
3	NG	G	G	G	G
4	NG	NG	NG	NG	NG
5	G	G	G	G	G
6	G	G	NG	G	G
7	NG	NG	G	NG	NG
8	NG	NG	G	G	NG
9	G	G	G	G	G
10	G	G	G	G	G
11	G	G	G	G	G
12	G	G	G	G	G
13	G	NG	G	G	G
14	G	G	G	G	G
15	G	G	G	G	NG
16	G	G	G	G	G
17	G	G	G	G	G
18	G	G	NG	G	G
19	G	G	G	G	G
20	G	G	G	G	G

X-Ray Measurement System Evaluation

1. Do associates agree with themselves? (Individual Effectiveness)
2. Do associates agree with each other? (Group Effectiveness)
3. Do associates agree with the Standard? (Department Effectiveness)

X-Ray Example:

Individual Effectiveness:

Associate A:

18/20 = .90

90%

Associate B:

?

	Associate A		Associate B		
	1	2	1	2	Standard
1	G	G	G	G	G
2	G	G	G	G	G
3	~~NG~~	~~G~~	G	G	G
4	NG	NG	NG	NG	NG
5	G	G	G	G	G
6	G	G	NG	G	G
7	NG	NG	G	NG	NG
8	NG	NG	G	G	NG
9	G	G	G	G	G
10	G	G	G	NG	G
11	G	G	G	G	G
12	G	G	G	G	G
13	~~G~~	~~NG~~	G	G	G
14	G	G	G	G	G
15	G	G	G	G	NG
16	G	G	G	G	G
17	G	G	G	G	G
18	G	G	NG	G	G
19	G	G	G	G	G
20	G	G	G	G	G

X-Ray Example:

Individual Effectiveness:

Associate A:
18/20 = .90
90%

Associate B:
16/20 = .80
80%

	Associate A		Associate B	
	1	2	1	2
1	G	G	G	G
2	G	G	G	G
3	~~NG~~	~~G~~	G	G
4	NG	NG	NG	NG
5	G	G	G	G
6	G	G	~~NG~~	~~G~~
7	NG	NG	~~G~~	~~NG~~
8	NG	NG	G	G
9	G	G	G	G
10	G	G	~~G~~	~~NG~~
11	G	G	G	G
12	G	G	G	G
13	~~G~~	~~NG~~	G	G
14	G	G	G	G
15	G	G	G	G
16	G	G	G	G
17	G	G	G	G
18	G	G	~~NG~~	~~G~~
19	G	G	G	G
20	G	G	G	G

X-Ray Example:

Group Effectiveness:

	Associate A		Associate B	
	1	2	1	2
1	G	G	G	G
2	G	G	G	G
3	NG	G	G	G
4	NG	NG	NG	NG
5	G	G	G	G
6	G	G	NG	G
7	NG	NG	G	NG
8	NG	NG	G	G
9	G	G	G	G
10	G	G	G	NG
11	G	G	G	G
12	G	G	G	G
13	G	NG	G	G
14	G	G	G	G
15	G	G	G	G
16	G	G	G	G
17	G	G	G	G
18	G	G	NG	G
19	G	G	G	G
20	G	G	G	G

X-Ray Example:

Group Effectiveness:

13/20 = .65

65%

	Associate A		Associate B	
	1	2	1	2
1	G	G	G	G
2	G	G	G	G
3	~~NG~~	~~G~~	~~G~~	~~G~~
4	NG	NG	NG	NG
5	G	G	G	G
6	~~G~~	~~G~~	~~NG~~	~~G~~
7	~~NG~~	~~NG~~	~~G~~	~~NG~~
8	~~NG~~	~~NG~~	~~G~~	~~G~~
9	G	G	G	G
10	~~G~~	~~G~~	~~G~~	~~NG~~
11	G	G	G	G
12	G	G	G	G
13	~~G~~	~~NG~~	~~G~~	~~G~~
14	G	G	G	G
15	G	G	G	G
16	G	G	G	G
17	G	G	G	G
18	~~G~~	~~G~~	~~NG~~	~~G~~
19	G	G	G	G
20	G	G	G	G

X-Ray Example:

Departmental Effectiveness:

**Compare every observation with the standard,*

$$\frac{\#\ \text{correct}}{\text{Total Obs.}}$$

	Associate A		Associate B		
	1	2	1	2	Standard
1	G	G	G	G	G
2	G	G	G	G	G
3	NG	G	G	G	G
4	NG	NG	NG	NG	NG
5	G	G	G	G	G
6	G	G	NG	G	G
7	NG	NG	G	NG	NG
8	NG	NG	G	G	NG
9	G	G	G	G	G
10	G	G	G	NG	G
11	G	G	G	G	G
12	G	G	G	G	G
13	G	NG	G	G	G
14	G	G	G	G	G
15	G	G	G	G	NG
16	G	G	G	G	G
17	G	G	G	G	G
18	G	G	NG	G	G
19	G	G	G	G	G
20	G	G	G	G	G

X-Ray Example:

Departmental Effectiveness:

$$\frac{20 - 8}{20} = \frac{12}{20}$$

= .60
60%

	1	2	1	2	Standard
1	G	G	G	G	G
2	G	G	G	G	G
3	~~NG~~	~~G~~	~~G~~	~~G~~	~~G~~
4	NG	NG	NG	NG	NG
5	G	G	G	G	G
6	~~G~~	~~G~~	~~NG~~	~~G~~	~~G~~
7	~~NG~~	~~NG~~	~~G~~	~~NG~~	~~NG~~
8	~~NG~~	~~NG~~	~~G~~	~~G~~	~~NG~~
9	G	G	G	G	G
10	~~G~~	~~G~~	~~G~~	~~NG~~	~~G~~
11	G	G	G	G	G
12	G	G	G	G	G
13	~~G~~	~~NG~~	~~G~~	~~G~~	~~G~~
14	G	G	G	G	G
15	~~G~~	~~G~~	~~G~~	~~G~~	~~NG~~
16	G	G	G	G	G
17	G	G	G	G	G
18	~~G~~	~~G~~	~~NG~~	~~G~~	~~G~~
19	G	G	G	G	G
20	G	G	G	G	G

X-Ray Measurement System Evaluation

Detailed Analysis (meaning of data)

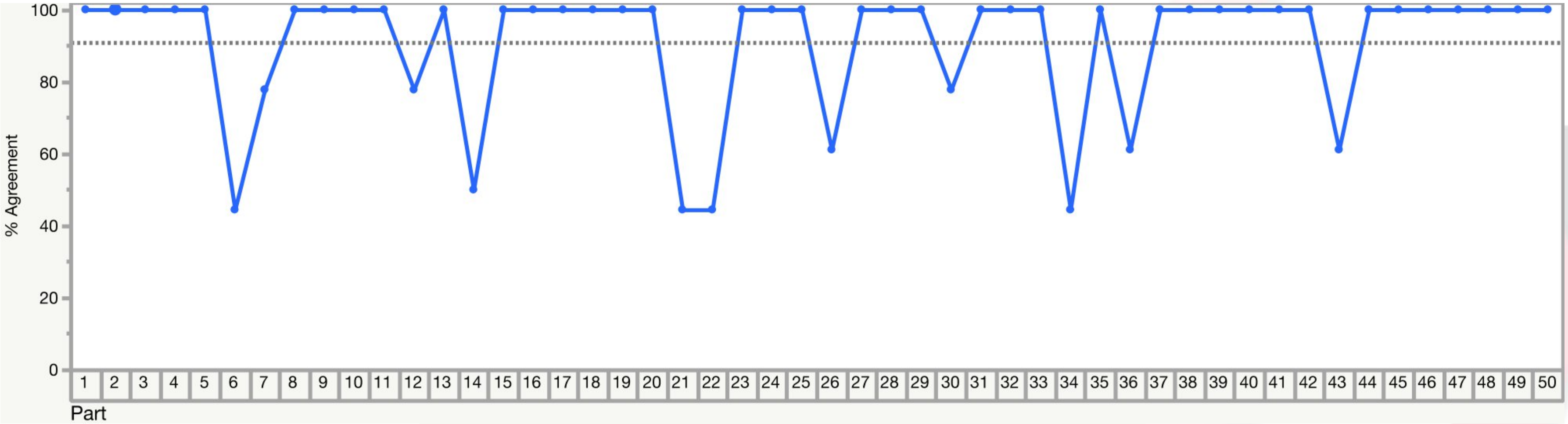
Corrective Actions

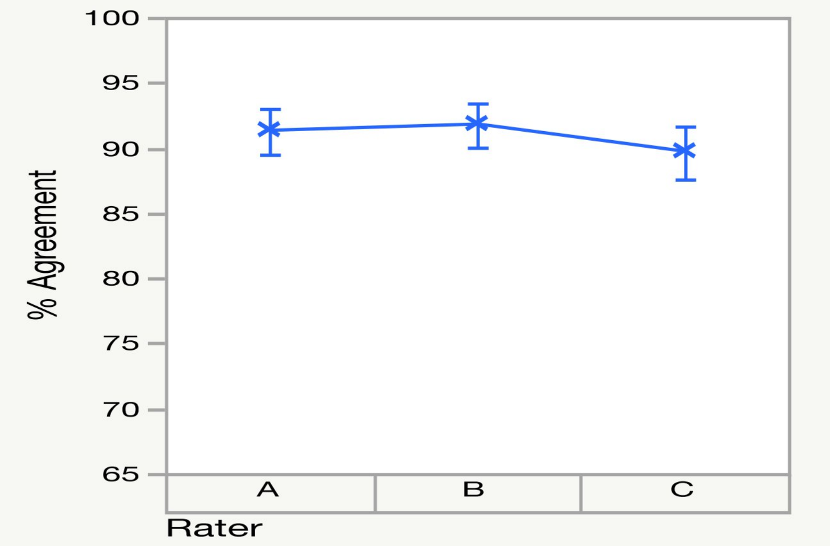
MEASUREMENT SYSTEMS ANALYSIS ATTRIBUTE DATA USING JMP 17

Example

1. Select **Help** → **Sample Index**.
2. Click the diamond next to **Measurement Systems**.
3. Select **Attribute Gauge**.
4. Select **Analyze** → **Quality and Process** → **Measurement Systems Analysis Variability/Attribute Gage Chart**
5. **Chart Type → Select Attribute**
6. Select **A, B, & C** → **Y, Response**.
7. Select **Part** → **X, Grouping**.
8. Select **Standard** → **Standard**
9. Select **OK**

Gauge Attribute Chart





Agreement Report

Agreement Report

Rater	% Agreement	95% Lower CI	95% Upper CI
A	91.4286	89.5082	93.0248
B	91.9048	90.0502	93.4388
C	89.8095	87.6057	91.6588

Number Inspected	Number Matched	% Agreement	95% Lower CI	95% Upper CI
50	39	78.000	64.758	87.246

Agreement Comparisons

Rater	Compared with Rater	Kappa		Standard Error
A	B	0.8629		0.0442
A	C	0.7761		0.0547
B	C	0.7880		0.0537

Agreement Comparisons

Rater	Compared with Standard	Kappa		Standard Error
A	Standard	0.8788		0.0416
B	Standard	0.9230		0.0338
C	Standard	0.7740		0.0551

Agreement within Raters & Across Categories

Rater	Number Inspected	Number Matched	Rater Score	95% Lower CI	95% Upper CI
A	50	42	84.0000	71.4858	91.6626
B	50	45	90.0000	78.6398	95.6524
C	50	40	80.0000	66.9629	88.7562

Agreement within Raters

Agreement across Categories

Category	Kappa		Standard Error
0	0.7936		0.0236
1	0.7936		0.0236
Overall	0.7936		0.0236

Effectiveness Report

Rater	Correct(0)	Correct(1)	Total Correct	Incorrect(0)	Incorrect(1)	Grand Total
A	45	97	142	3	5	150
B	45	100	145	3	2	150
C	42	93	135	6	9	150

Rater	Effectiveness	95% Lower CI	95% Upper CI	Error rate
A	94.6667	89.8296	97.2730	0.0533
B	96.6667	92.4348	98.5680	0.0333
C	90.0000	84.1565	93.8459	0.1000
Overall	93.7778	91.1542	95.6603	0.0622

Misclassifications

Standard Level	0	1
0	.	16
1	12	.
Other	0	0

Conformance Report & Agreement Report

Rater	P(False Alarms)	P(Misses)
A	0.0490	0.0625
B	0.0196	0.0625
C	0.0882	0.1250

Rater	% Agreement	95% Lower CI	95% Upper CI
A	91.4286	89.5082	93.0248
B	91.9048	90.0502	93.4388
C	89.8095	87.6057	91.6588

Agreement Report

Number Inspected	Number Matched	% Agreement	95% Lower CI	95% Upper CI
50	39	78.000	64.758	87.246

MEASUREMENT SYSTEMS ANALYSIS

Objectives

- Discuss the importance of knowing how data was collected
- Understand how poor data collection methods increase variation in data
- Create a list of potential sources of variation in the data being collected for a Lean Six Sigma project
- Review of some methods used to quantify measurement variation.

Measurement System

- The measurement system is the complete process used to collect data. The people, methods, equipment and technology employed in data collection comprise the measurement system.
- The ability to measure process and material parameters accurately and precisely are critical for making decisions that affect the project.
- The measurement system must be analyzed and improved before data is collected.

Questions we are trying to answer

- Do we have the data that we need?
- What type of data is involved?
- How will it be collected?
- Is it accurate and precise enough for us to be able to determine if a change to the process actually improved the process?

Bad Data

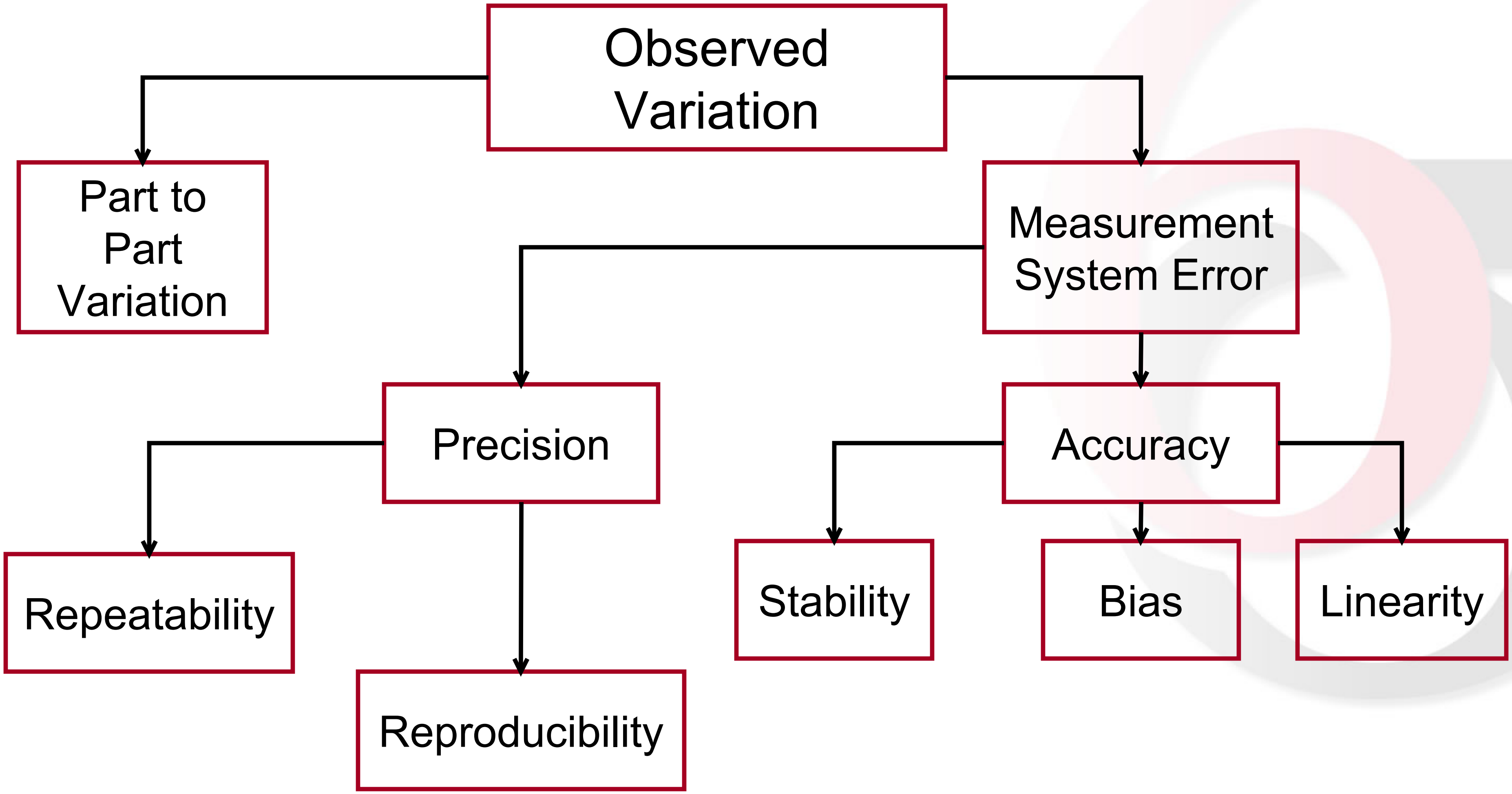
The reasons the data we collect is not reliable include:

- Lack of clear operational definitions
- Data are difficult to collect
- The sampling plan is insufficient
- Measurement devices are not accurate
- Testing procedures are not documented or not clearly written

Assessing the Measurement System

- Gage R&R
  - Variables Data
- Attribute MSA
  - Count Data
- MSA Who, What, When, Where, and How

MSA – Variables Data



Precision

- A system is precise if it returns the same value every time regardless of who does the measurement and the tool they use.
- The spread of the data is driven by the precision of the system.
- The two components of precision are Repeatability and Reproducibility.
- A Gage R & R study quantifies Repeatability and Reproducibility in manufacturing.

Repeatability and Reproducibility

- Repeatability is the variation present when the same part is measured repeatedly by the same appraiser using the same tool/method.
- Reproducibility is the variation present when different appraisers use the same tool/method to measure the same parts.

Accuracy

- Accuracy is the difference between an observed value and a reference value.
- Accuracy is related to the average – on average how does the measurement system compare to the true average.
- Accuracy may be assessed against a standard, another measurement method or a predicted value.