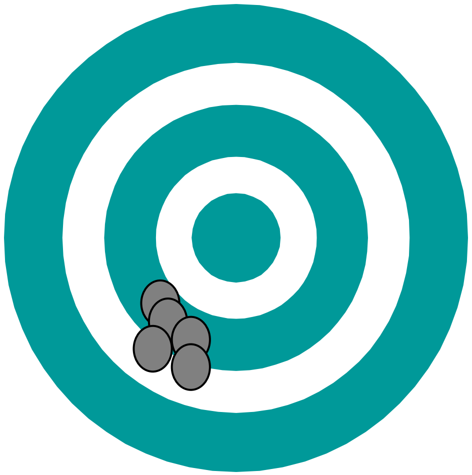
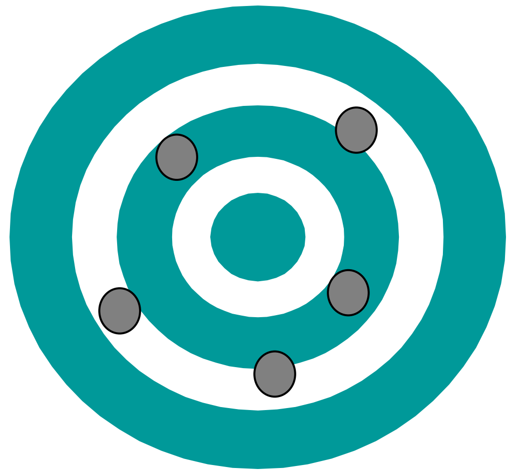
Measuring Accuracy

- 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.

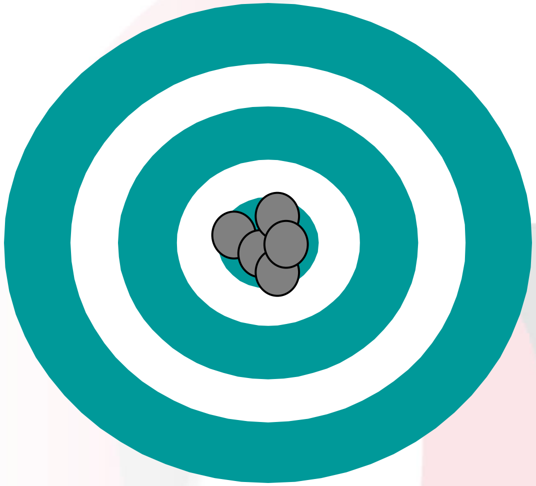
Precision versus Accuracy



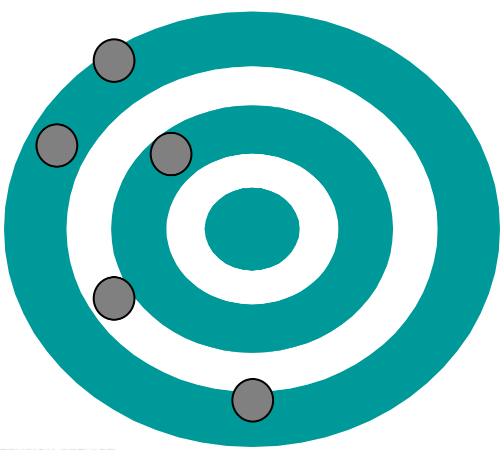
Precise



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

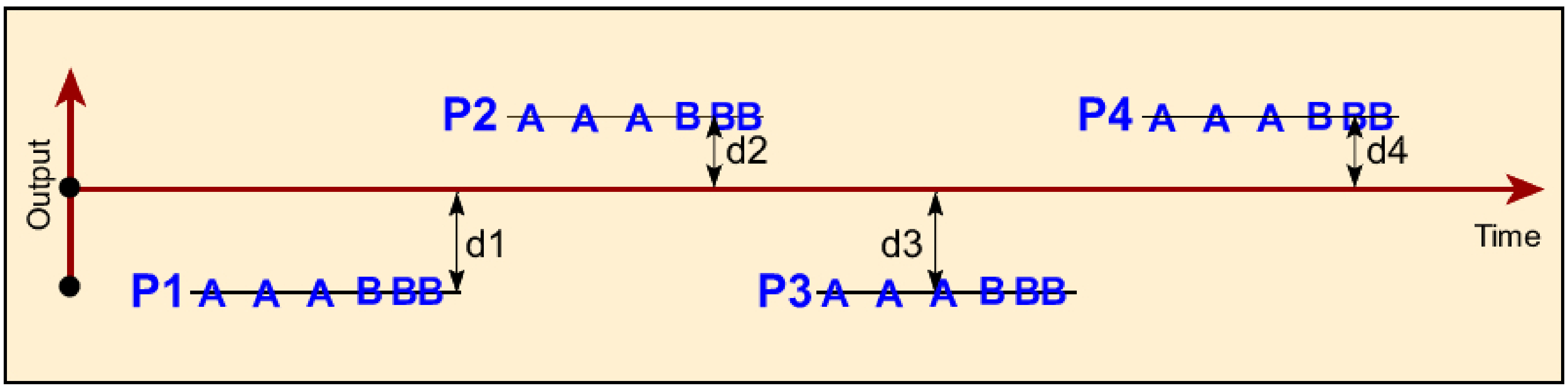
$$SS_{Total} = SS_{Part} + SS_{R\&R}$$

For a good Measurement System

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

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

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

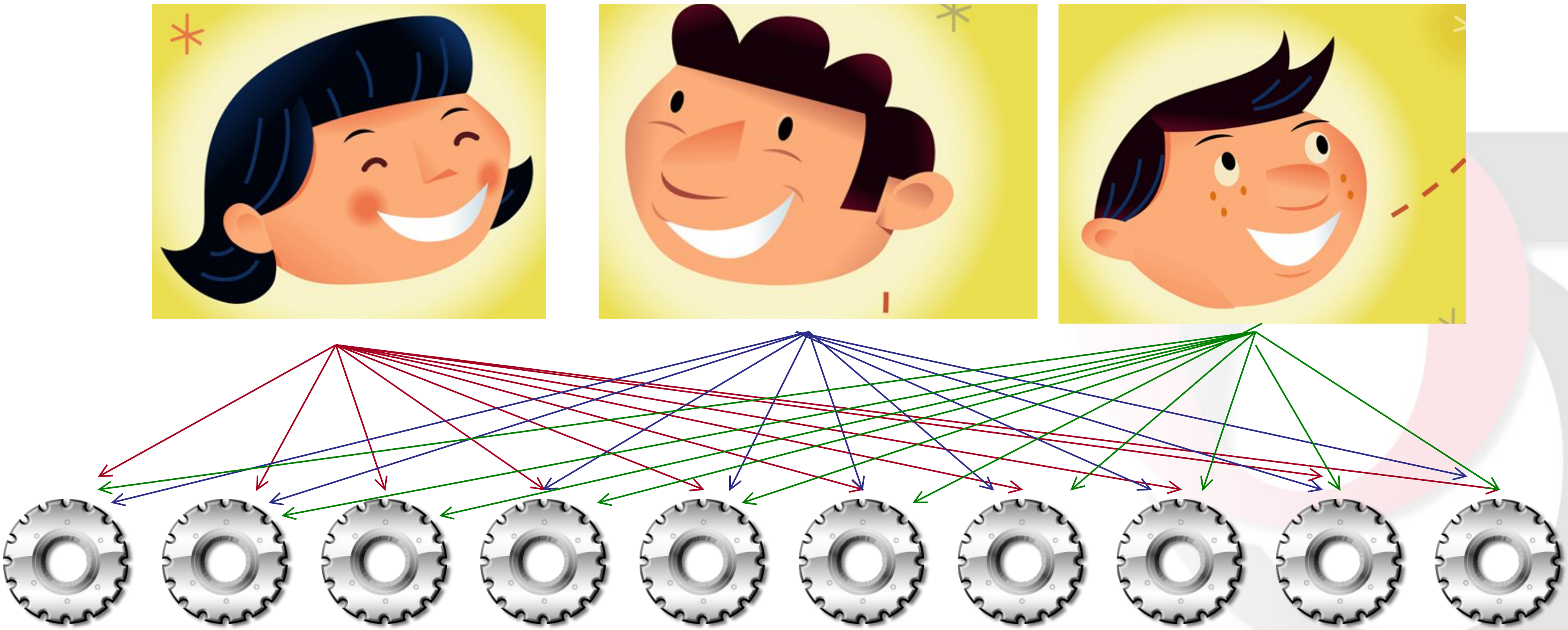
- There are four common methods used to qualify a measurement system.
  - % Contribution
  - % Study Variation
  - Distinct Categories
  - Discrimination Ratio
- The rules for each method are shown below.

	% 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.

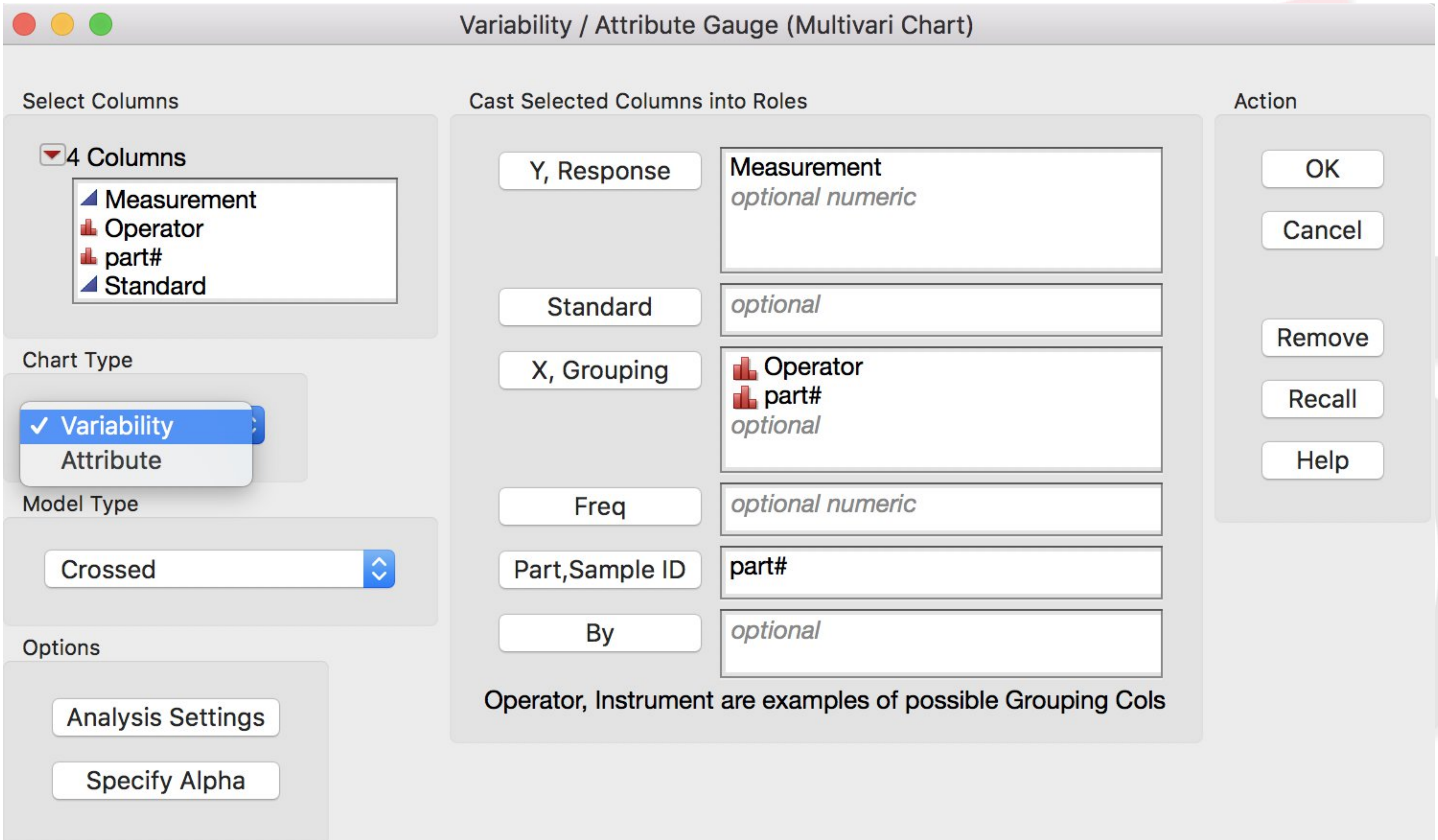
Example



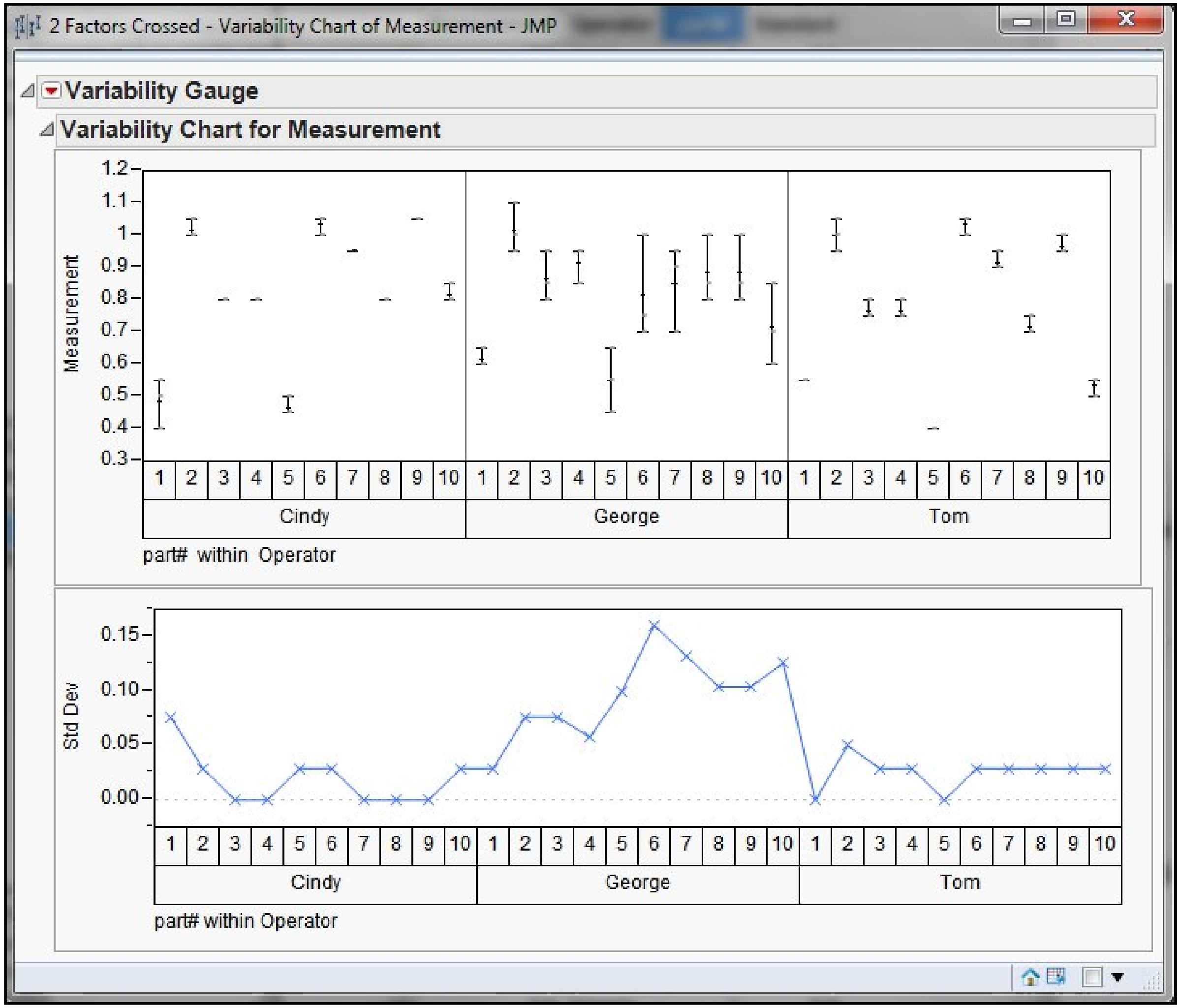
Example

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

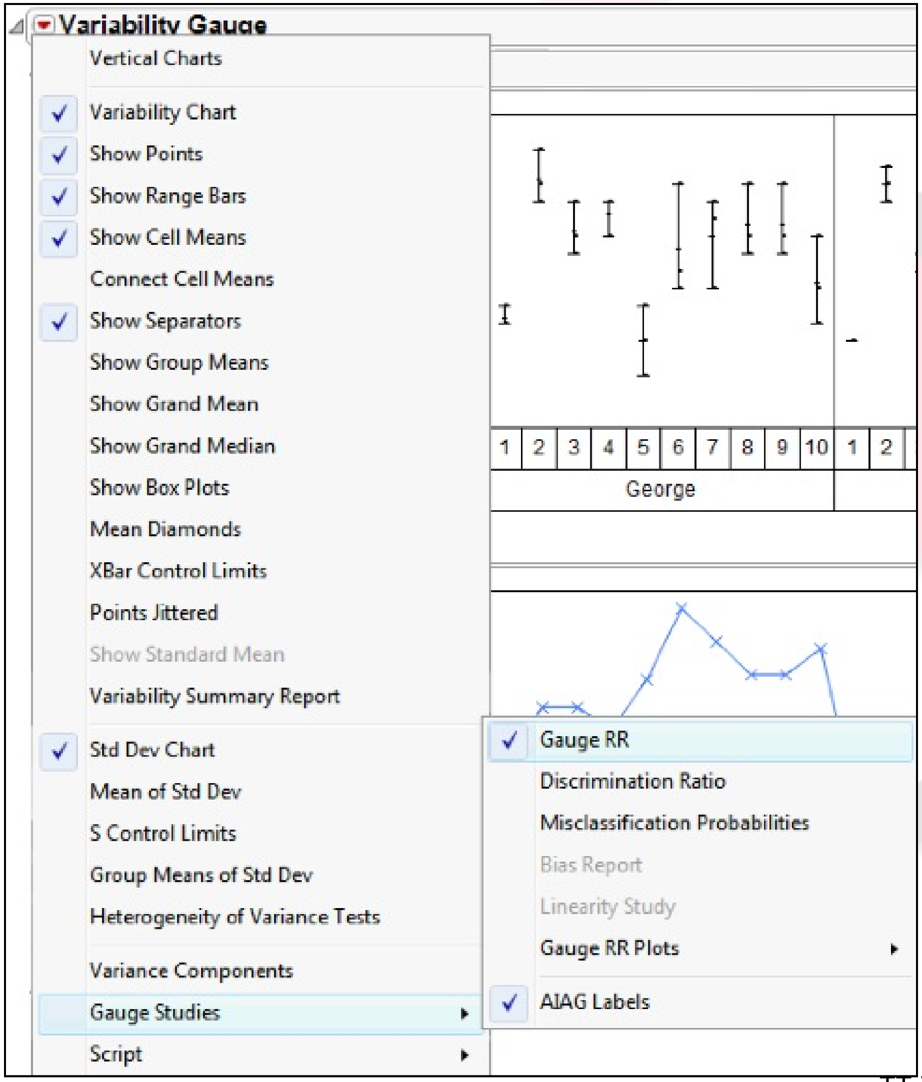
Example

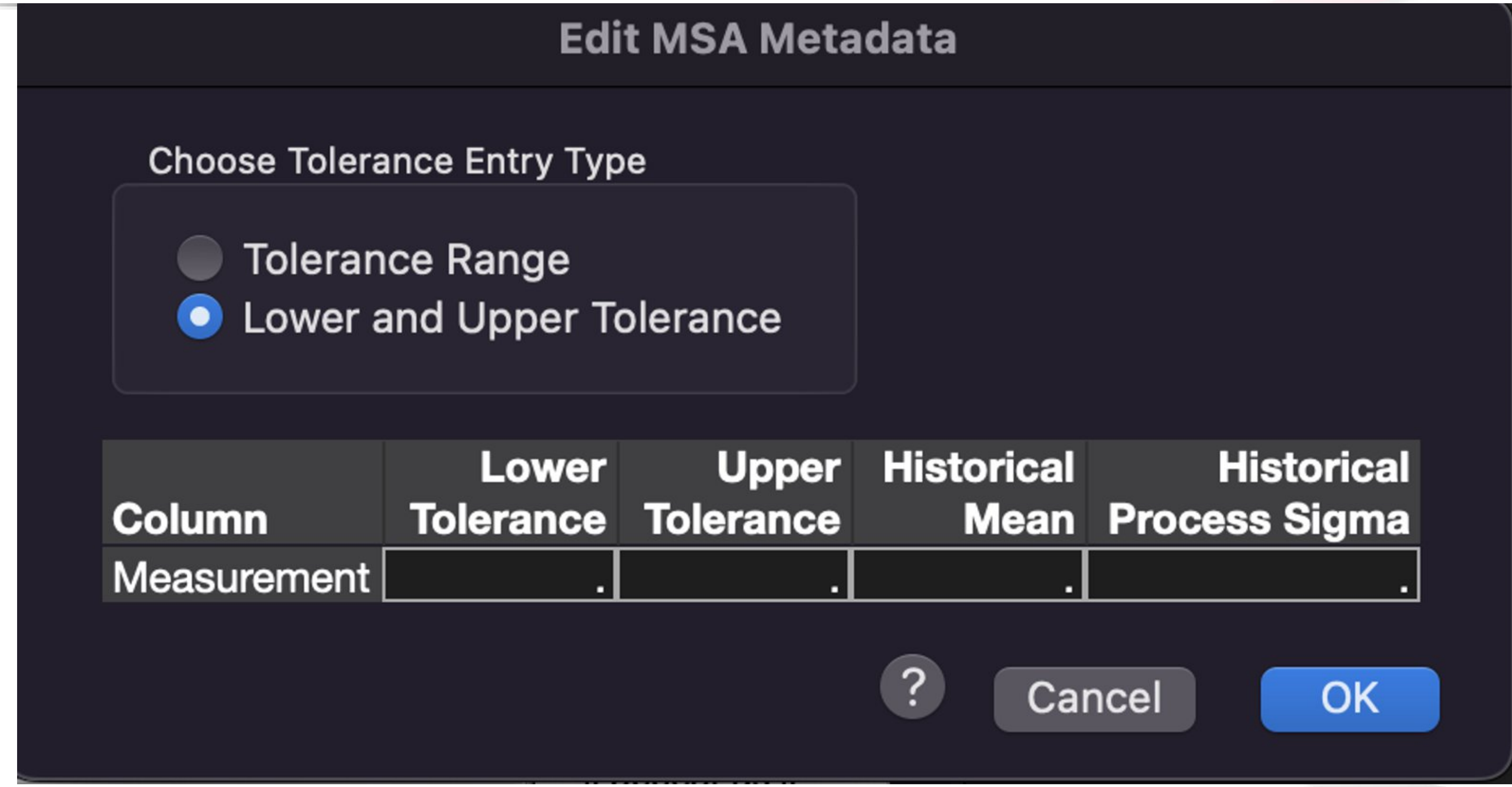


- Graphically, does it appear as if one operator has more variation in measurements?

Example

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

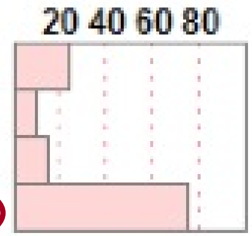



Edit MSA Metadata
Choose Tolerance Entry Type
Tolerance Range
Lower and Upper Tolerance
Column
Lower Tolerance
Upper Tolerance
Historical Mean
Historical Process Sigma
Measurement
?
Cancel
OK

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,*

 # correct / 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)

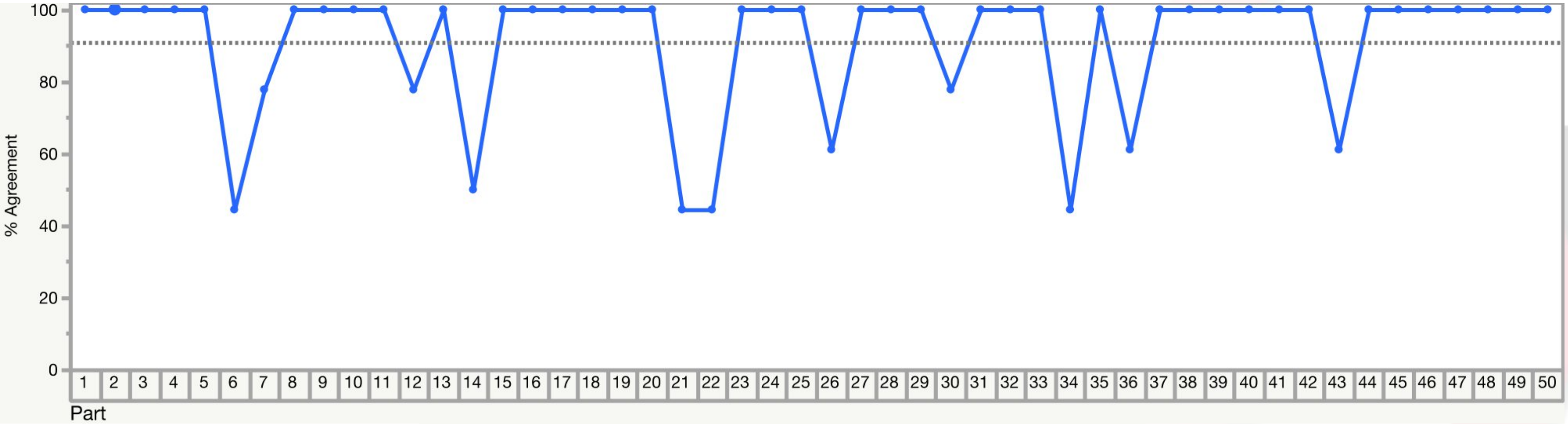
Corrective Actions

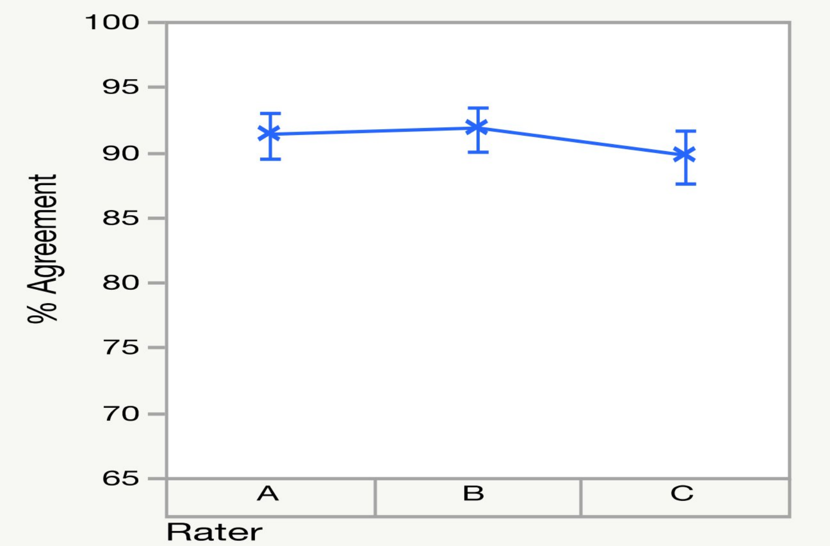
MEASUREMENT SYSTEMS ANALYSIS ATTRIBUTE DATA USING JMP 17

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

Agreement within Raters

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 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

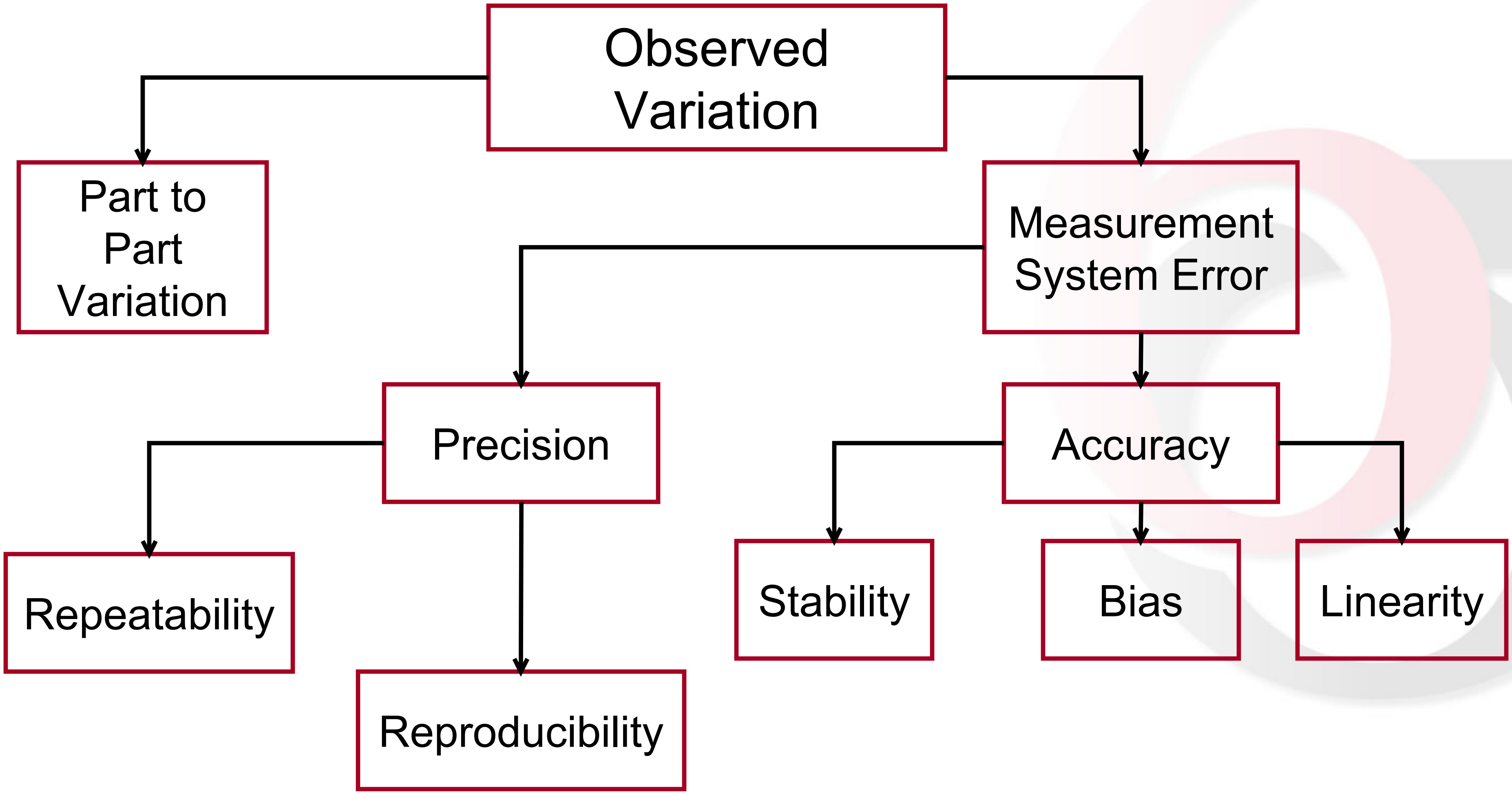
The reasons the data we collect is not reliable include:

- 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.

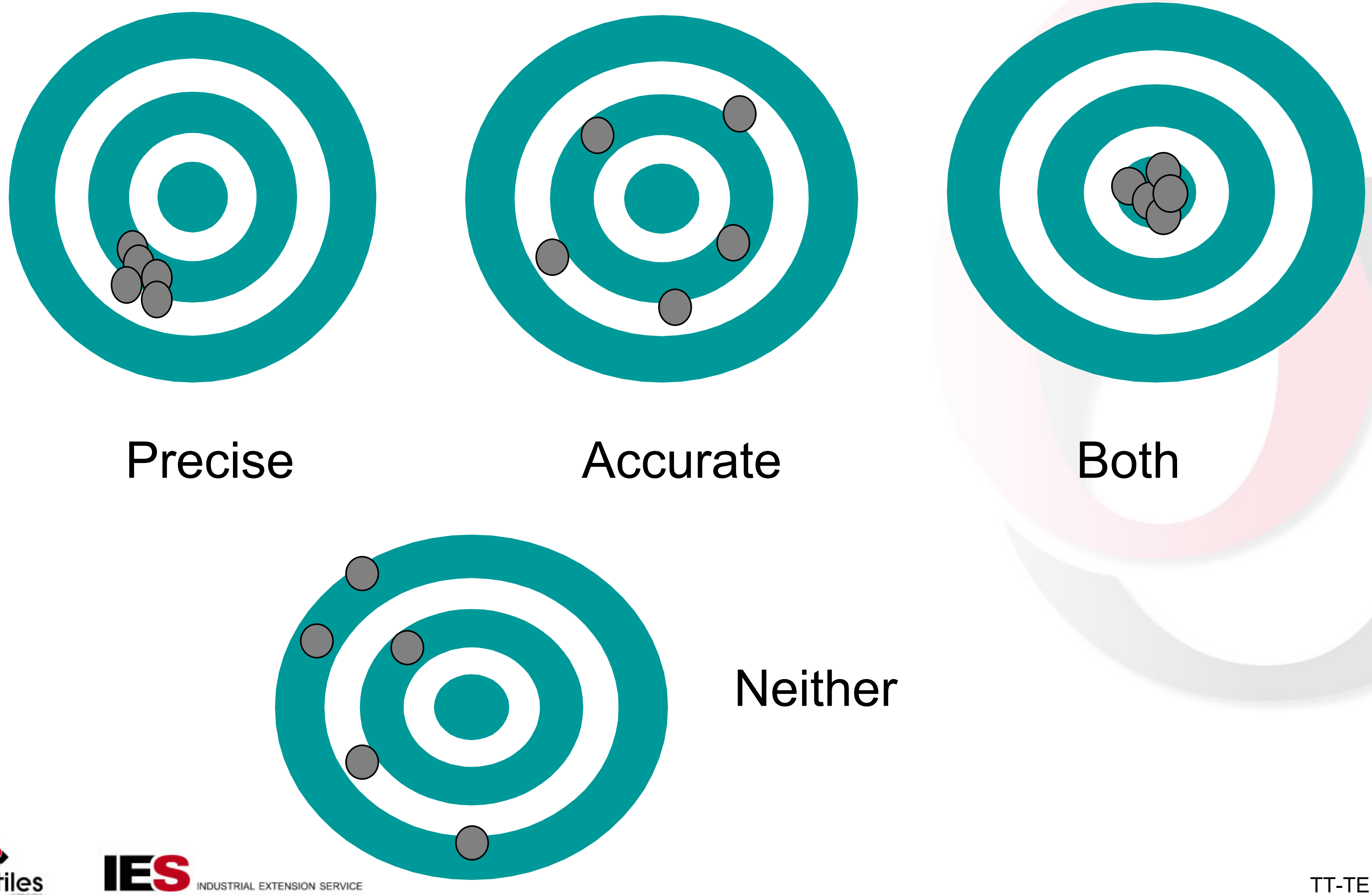
Accuracy

- 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.

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



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)

$$SS_{Total} = SS_{Part} + \underbrace{SS_{Operator} + SS_{Gage}}_{\text{Reproducibility \& Repeatability}}$$

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

MSA – Gage R&R Studies

$$SS_{Total} = SS_{Part} + \underbrace{SS_{Operator}}_{\text{Reproducibility}} + \underbrace{SS_{Gage}}_{\text{Repeatability}}$$

Reproducibility & Repeatability

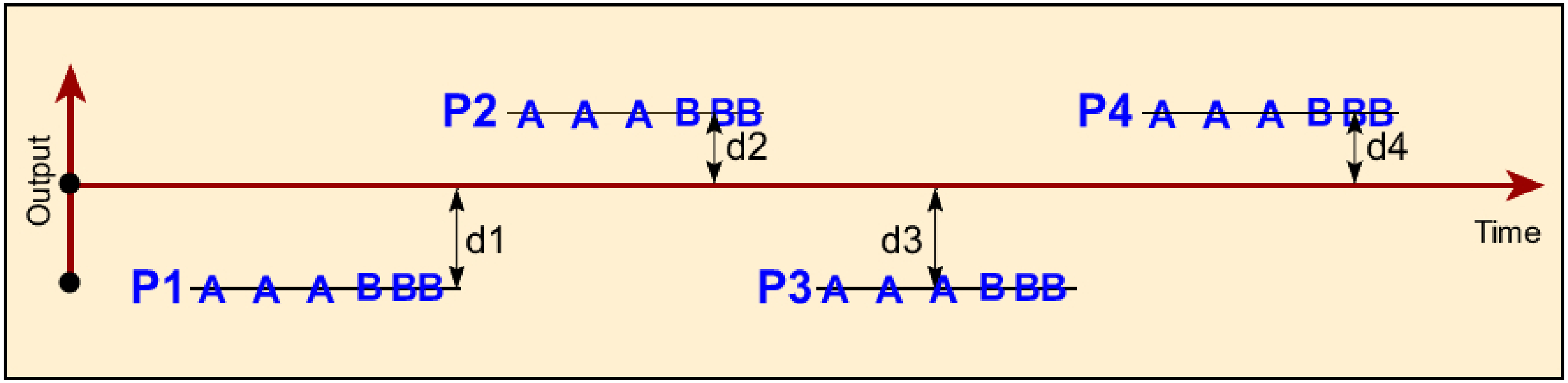
$$SS_{Total} = SS_{Part} + SS_{R\&R}$$

For a good Measurement System

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

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

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

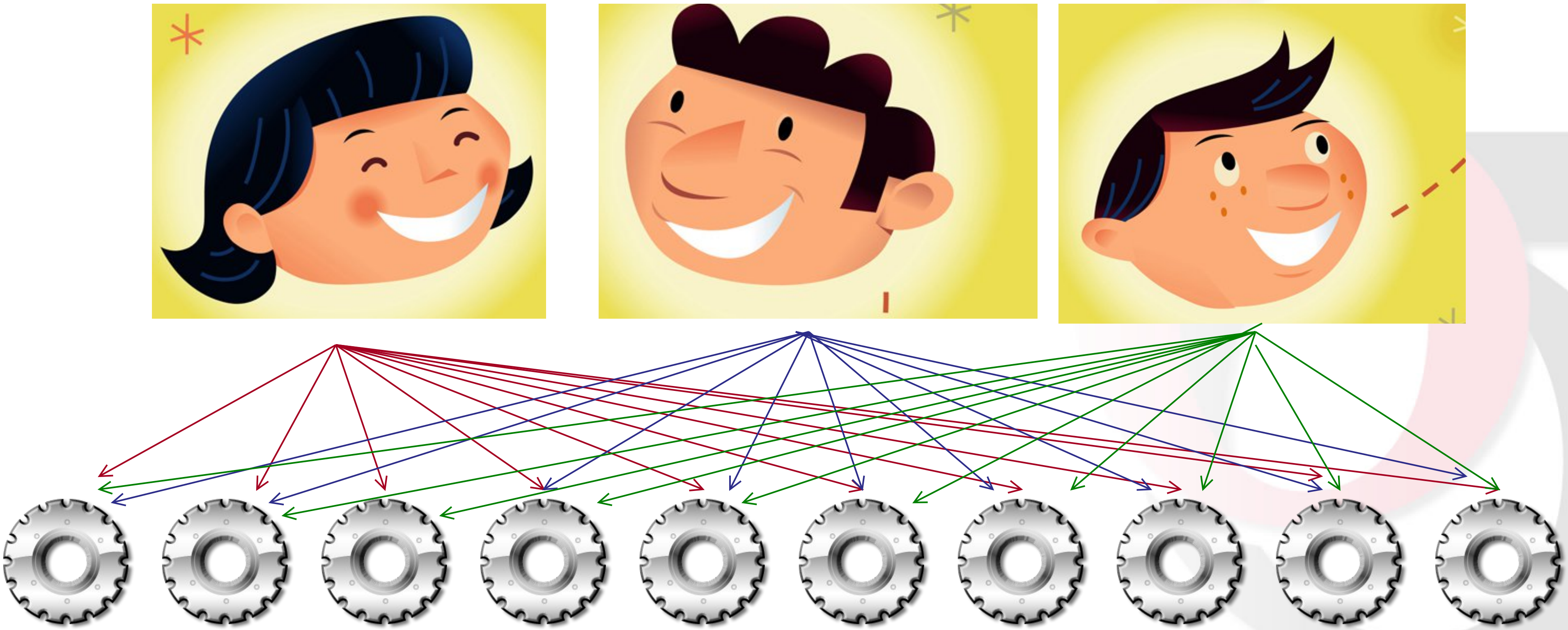
- There are four common methods used to qualify a measurement system.
  - % Contribution
  - % Study Variation
  - Distinct Categories
  - Discrimination Ratio
- The rules for each method are shown below.

	% 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.

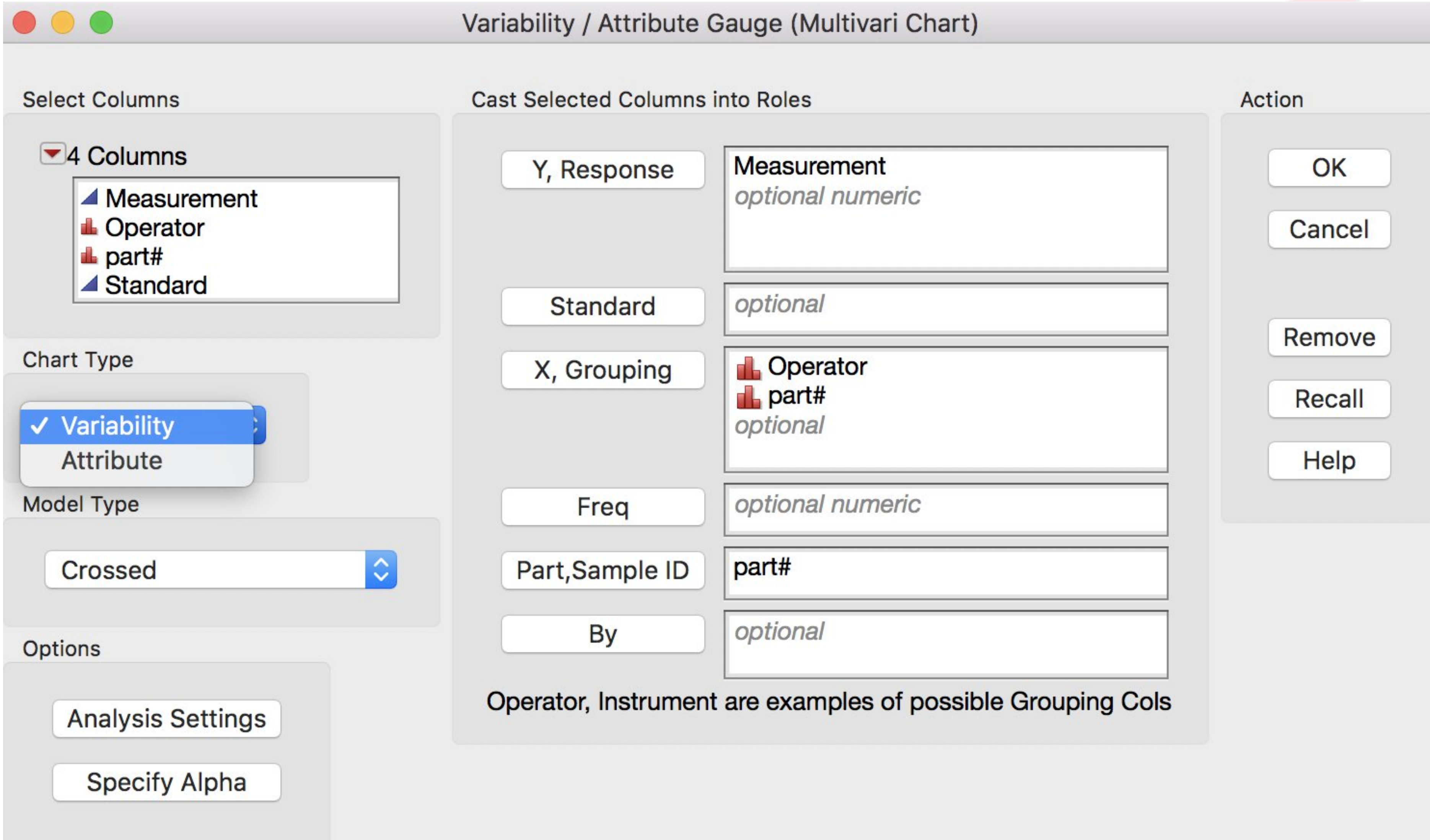
Example



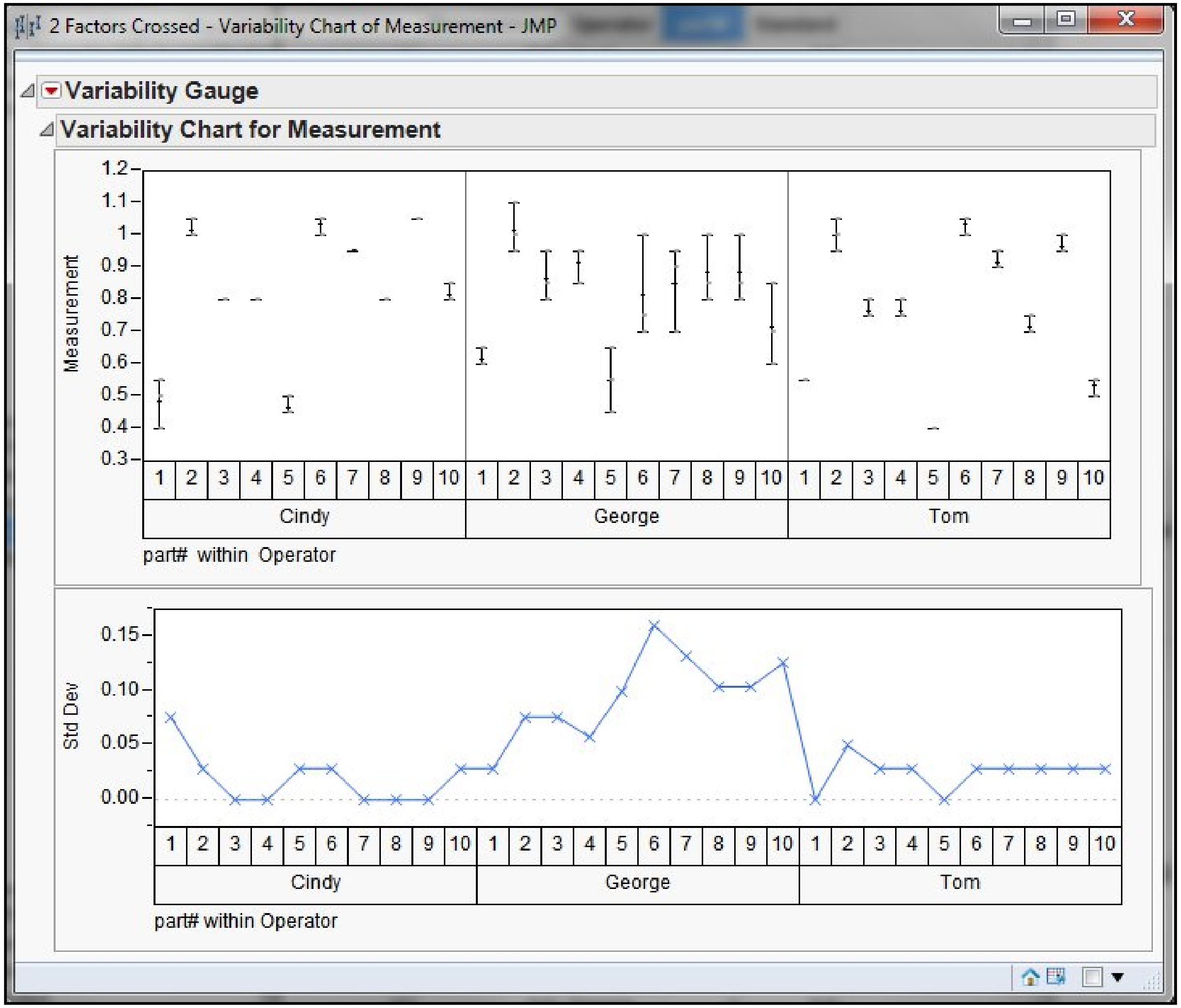
Example

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

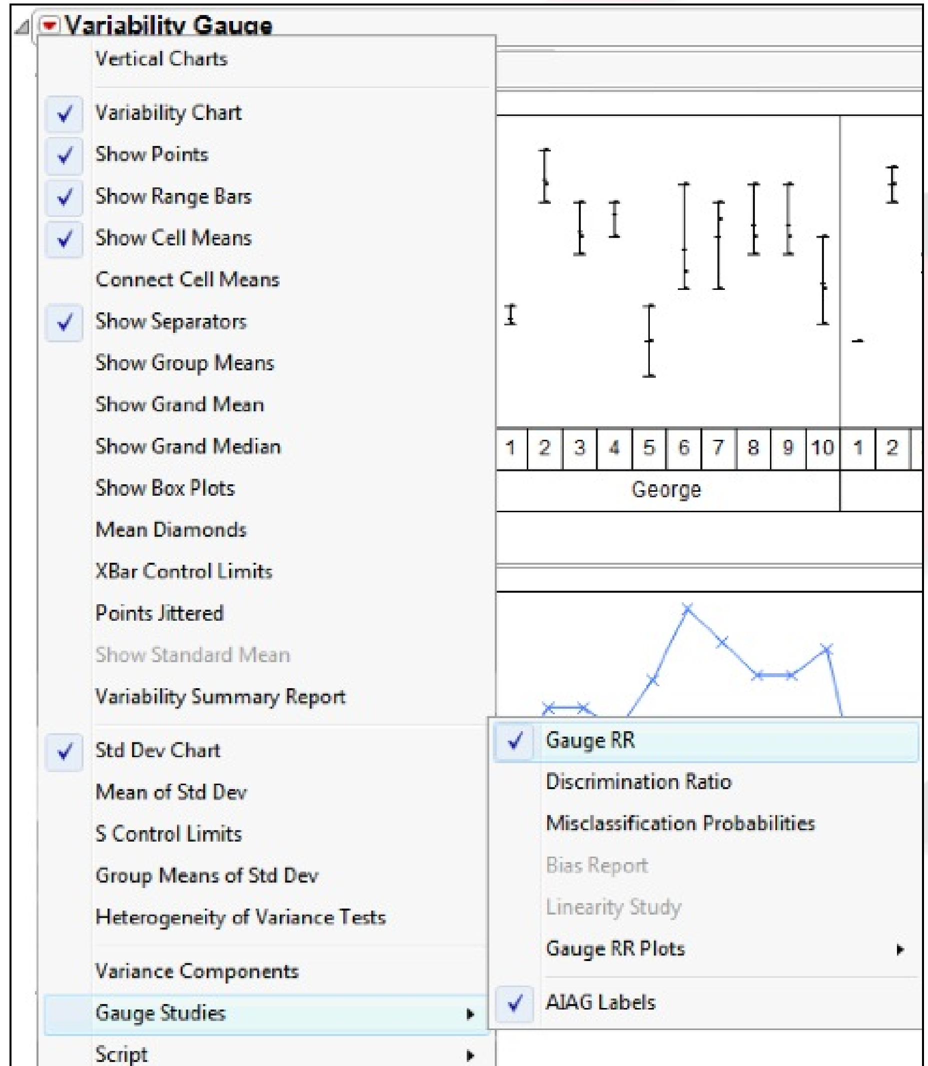
Example

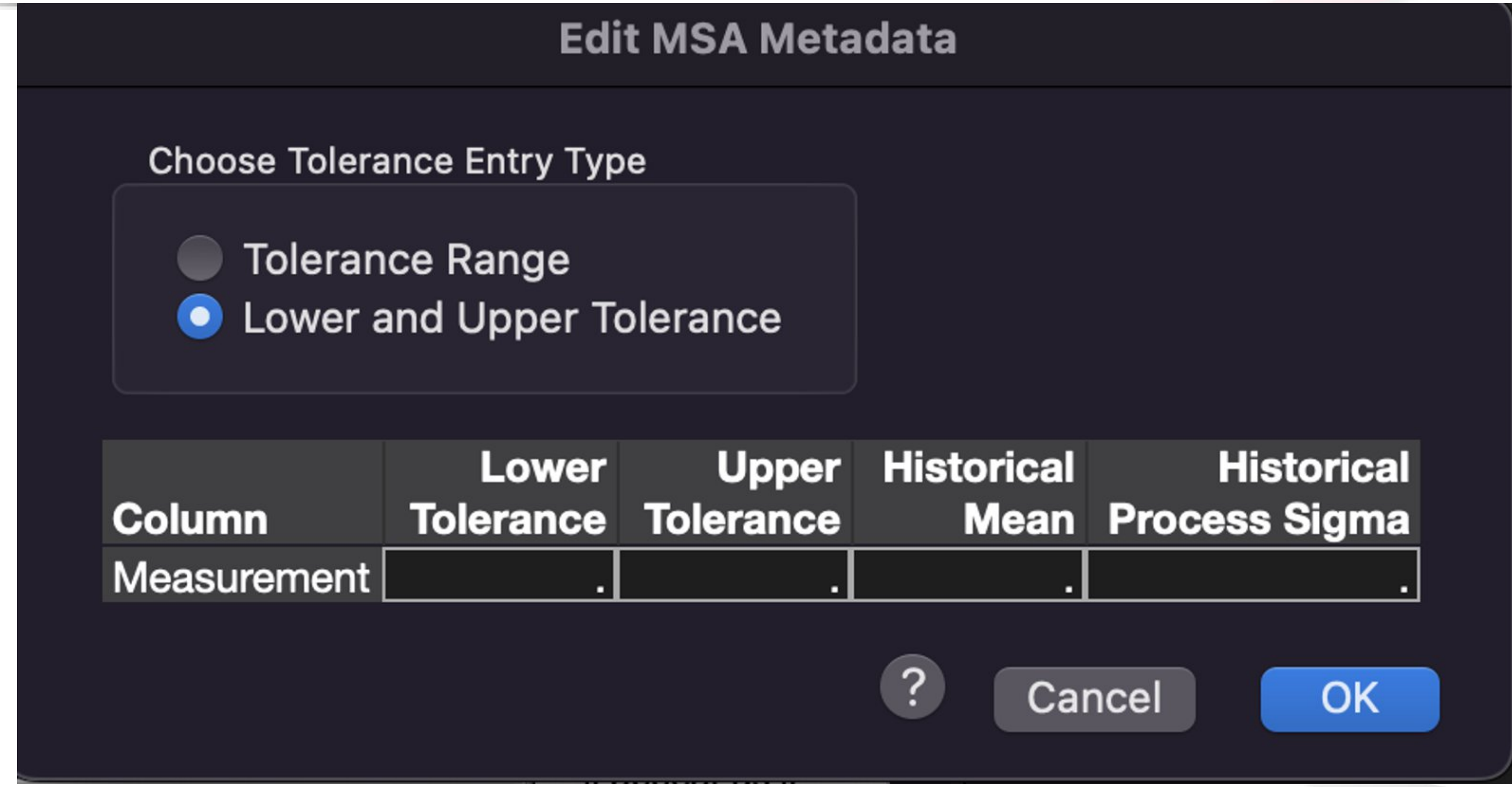


- Graphically, does it appear as if one operator has more variation in measurements?

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,*

 # correct / 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)

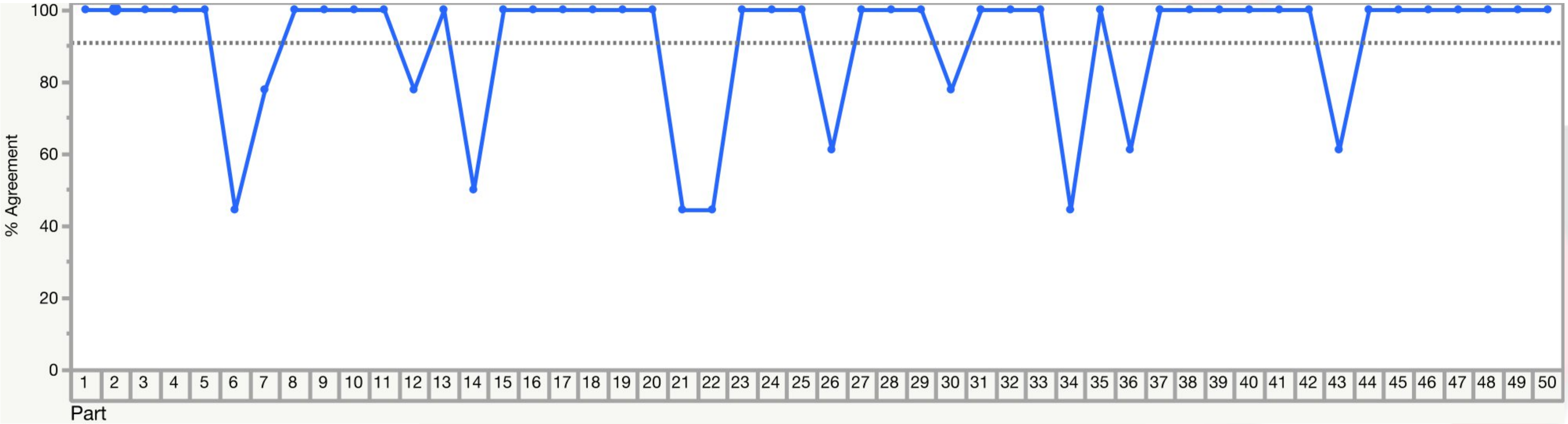
Corrective Actions

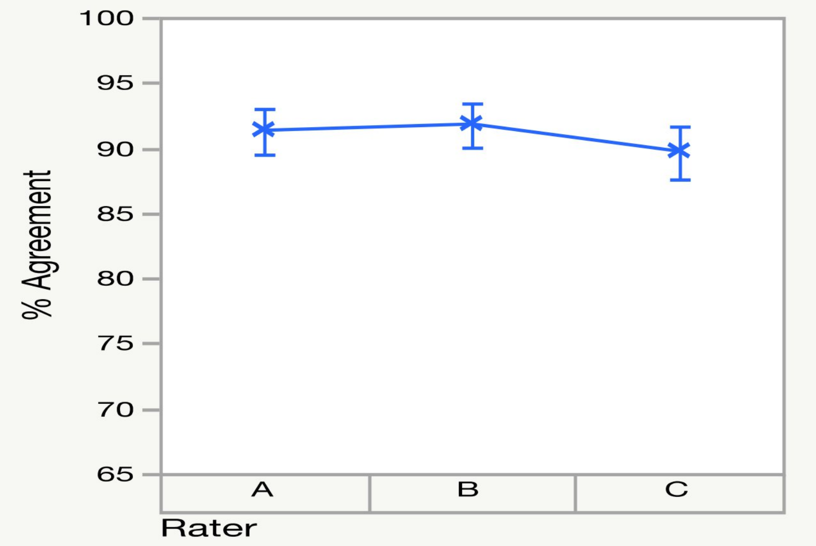
MEASUREMENT SYSTEMS ANALYSIS ATTRIBUTE DATA USING JMP 17

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

PROCESS CAPABILITY

Objectives

- Discuss process capability terms
- Illustrate assessing process capability
- Understand the different capability indices
- Calculate process capability using JMP 17
- Discuss using run charts and Pareto charts to establish a process baseline
- Review the Measure Tollgate

Process Baseline

- The team's last task in Measure is to report the current process baseline.
- The team will continue to collect data on the project metric throughout the project and compare it to the baseline.
- Process capability is one way to report the process baseline.
- Graphically, the baseline may be reported with a run chart or even a Pareto plot.

Process Capability Terminology

- **Specification Limits**
  - Boundaries, usually set by management, engineering or customers, within which a process must operate
  - Voice of the customer
  - Is the service or product meeting the customer's expectations?
- **Process Capability**
  - Compares the output of an in-control process to specification limits using capability indices
  - Answers the question of how well a process meets a customer's expectations

Why Assess Process Capability?

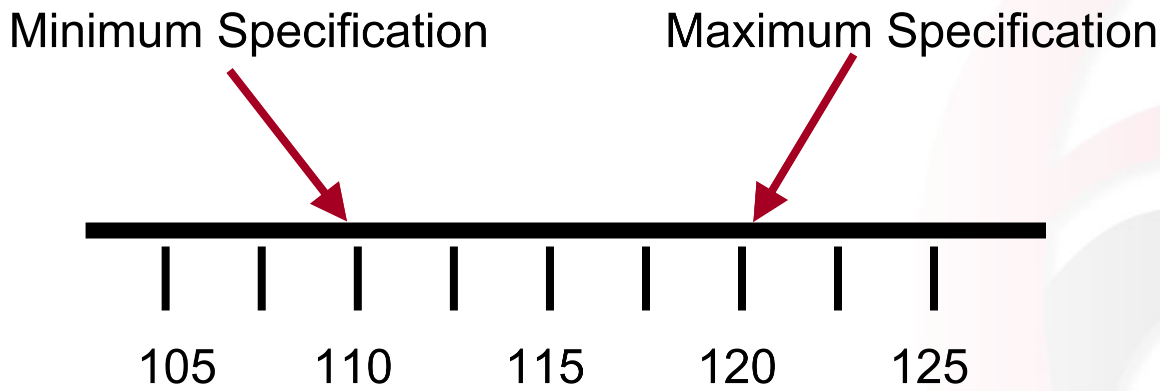
- Allows us to quantify the nature of the problem we will attack as one of the following:
  - Are the specifications correct for the parameter (Y) of interest (process or performance output variable)?
  - Is the location of the central tendency of the parameter (Y) centered within the appropriate specifications?
  - Is the process variation in the parameter greater than allowed by the specifications?
  - Is the measurement system affecting our ability to assess true process capability?
- Allows the organization to predict defect levels.

A Practical Illustration

A popular coffee bar has started receiving complaints from customers about the coffee temperature.

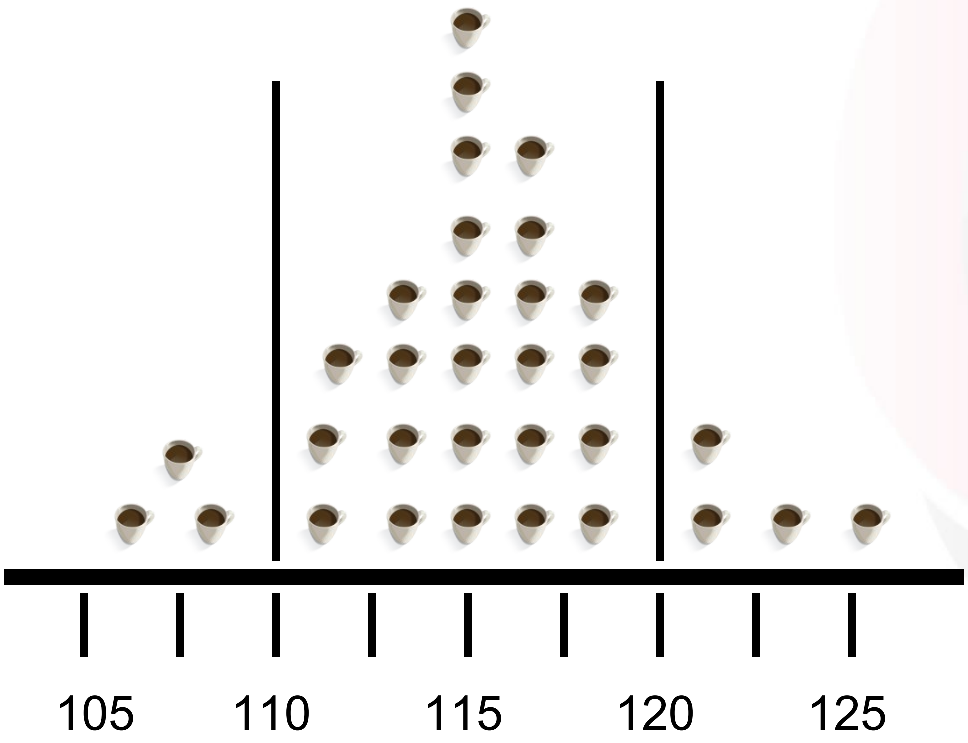
Some customers say the coffee is too hot, but others have complained it is too cold.

A Practical Illustration



Customer surveys and industry benchmarking indicate that customers will be satisfied if the temperature is between 110 and 120 degrees F.

A Practical Illustration



Capability Indices

A capability index uses both the process variability and the process specification limits to quantify whether or not a process is capable of meeting customer expectations.

Cp	Cpk
Indicates how well the process distribution fits within its specification limits. This index reflects how capable the process would be if centered	Incorporates information on spread as well as the process mean so it is an indicator of how well the process is actually performing.

If Cp = Cpk, the process is centered. If Cp > Cpk the process is not centered.

Capability Indices

- Capability indices can be divided into two categories:
  - within (short-term) and
  - overall (long-term).
  - Within or Short-term capability studies are based on measurements collected from one operating run.
  - Overall or Long-term capability studies consist of measurements which are collected over a longer period of time. It is assumed that data collected over a long period of time includes both common cause and special cause variation.

Estimation of Capability Indices

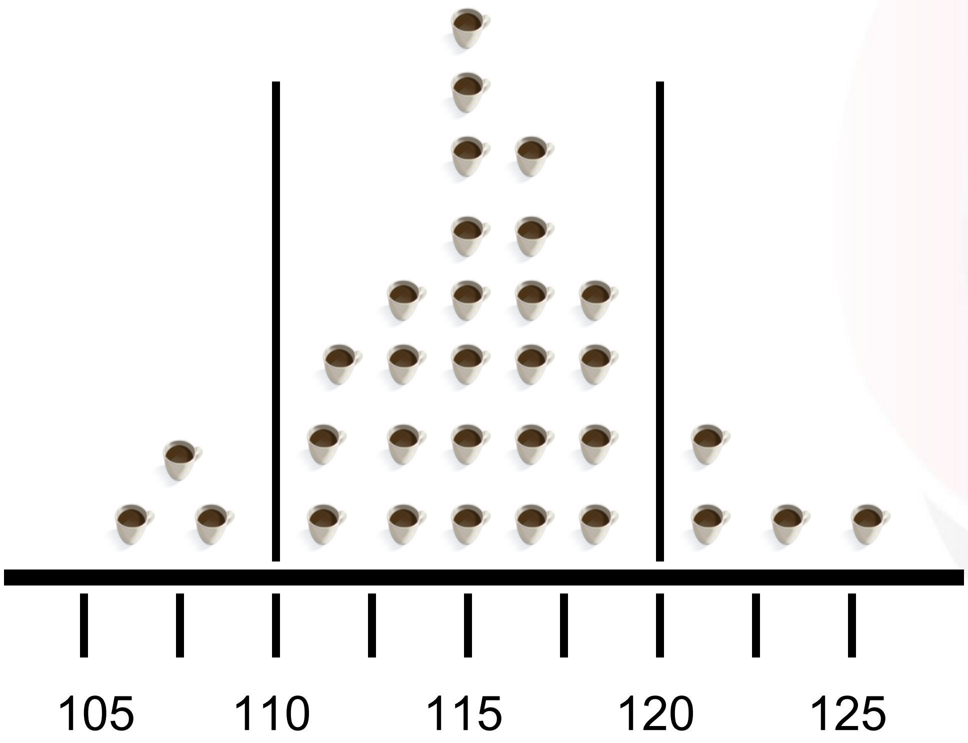
Short-Term Capability Indices

Long-Term Capability Indices

Assumptions

- The process data is normally distributed
- The process is in-control – no special cause variation is present

A Practical Illustration



How capable is the coffee shop?

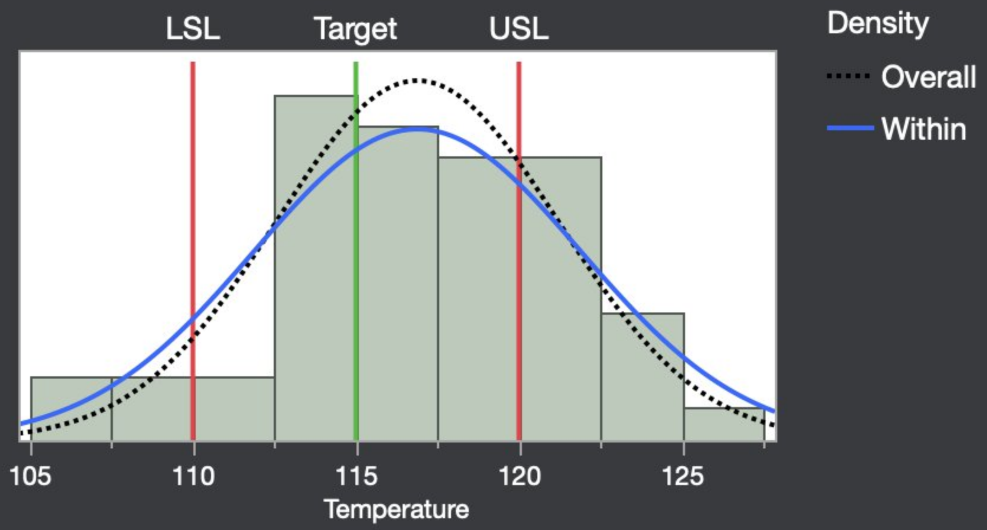
Example – Coffee Capability.jmp

1. Open the file **Coffee Capability.jmp**. from Wolfware for today
2. **Analyze → Distribution**
3. Select **Temperature → Y, Columns → OK**.
4. Click the red triangle next to **Temperature** and select **Process Capability**.
5. Lower spec limit is 110
6. Upper spec limit is 120
7. Target is 115
8. Select **OK**.

Process Capability

Temperature Capability

Histogram



Process Summary

LSL	110
Target	115
USL	120
N	50
Sample Mean	116.8856
Within Sigma	5.015138
Overall Sigma	4.338507
Stability Index	0.865082

Within sigma estimated by average moving range.

Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	0.207	0.101	0.313
Cpl	0.458	0.309	0.603
Cpu	0.207	0.100	0.312
Cp	0.332	0.249	0.415
Cpm	0.311	0.251	0.371

Overall Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Ppk	0.239	0.135	0.343
Ppl	0.529	0.388	0.667
Ppu	0.239	0.135	0.342
Pp	0.384	0.308	0.460
Cpm	0.352	0.287	0.424

Nonconformance

Portion	Observed %	Expected Within %	Expected Overall %
Below LSL	8.0000	8.4882	5.6246
Above USL	28.0000	26.7300	23.6425
Total Outside	36.0000	35.2182	29.2671

Process Sigma

The Sigma level is a measure of how often defects are expected to occur in a process.

Sigma and Capability

Cp	Parts Per Million Defects	σ
1.00	66,813	3.0
1.33	6,210	4.0
1.50	1,350	4.5
1.67	233	5.0
1.83	32	5.5
2.00	3.4	6.0

Example: Coffee

1. Open **Sigma Calculator.xls**.
2. Under Sigma Level-Continuous Data, type **116.88** in the Mean field.
3. Type **4.314** in the Standard Deviation field.
4. Type **110** in the LSL field.
5. Type **120** in the USL field.

Sigma Level - Continuous Data		
		Normal Distribution Only
Mean	116.88	
Standard Deviation	4.314	
Lower Spec Limit	110	leave blank if not applicable
Upper Spec Limit	120	leave blank if not applicable
Z Score Upper	0.723227	
% Out of Spec Upper	0.23477	
Z Score Lower	-1.594808	
% Out of Spec Lower	0.055378	
Total Out of Spec	29.01%	
DPM	290,148	
Sigma Level	2.05	
Yield	70.99%	

Is this process operating at an acceptable sigma level?

Example: Ischemia Time

1. Open **Sigma Calculator.xls**.
2. Under Sigma Level-Continuous Data, type **27.96** in the Mean field.
3. Type **8.094** in the Standard Deviation field.
4. Type **30** in the USL field.

Sigma Level - Continuous Data		
		Normal Distribution Only
Mean	27.96	
Standard Deviation	8.094	
Lower Spec Limit		leave blank if not applicable
Upper Spec Limit	30	leave blank if not applicable
Z Score Upper	0.252039	
% Out of Spec Upper	0.400506	
Z Score Lower		
% Out of Spec Lower		
Total Out of Spec	40.05%	
DPM	400,506	
Sigma Level	1.75	
Yield	59.95%	

Is this process operating at an acceptable sigma level?

Example: CRO Patient Recruiting

Background:

A CRO has started to experience long delays in completing the projects they have been awarded in the last 12 months. The executive team identified several areas of the process that might be leading to the long delays. Several Six Sigma teams were formed to tackle this project. One team is addressing the amount of time spent recruiting patients for a study.

Problem Statement:

The average number of weeks needed to recruit patients for new studies has increased from 6 weeks to 10 weeks in the last year, resulting in significant delays in starting new trials.

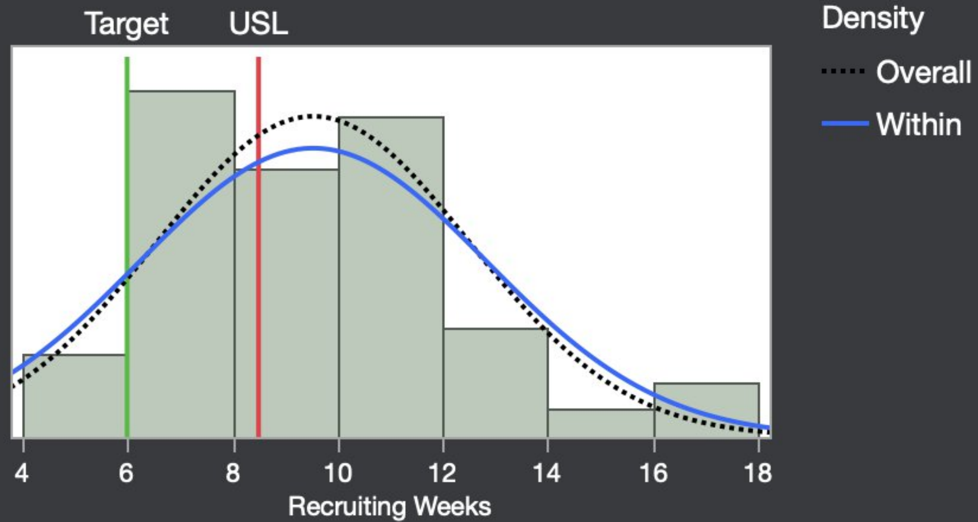
Example – Patient Recruiting.jmp

1. Open the file **Patient Recruiting.jmp**. from JMP File in today's Wolfware
2. **Analyze → Distribution**.
3. Select **Recruiting Weeks → Y, Columns, OK**.
4. Click the red triangle next to **Recruiting Weeks** and select **Process Capability**.
5. Upper spec limit is 8.5
6. Target is 6
7. Select **OK**.

Process Capability

Recruiting Weeks Capability

Histogram



Process Summary

Target	6
USL	8.5
N	45
Sample Mean	9.538963
Within Sigma	3.304872
Overall Sigma	2.976733
Stability Index	0.90071

Within sigma estimated by average moving range.

Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	-0.105	-0.205	-0.003
Cpu	-0.105	-0.205	-0.003
Cpm	0.172	.	.

Overall Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Ppk	-0.116	-0.216	-0.015
Ppu	-0.116	-0.216	-0.015
Cpm	0.180	.	.

Nonconformance

Portion	Observed %	Expected Within %	Expected Overall %
Above USL	57.7778	62.3381	63.6466
Total Outside	57.7778	62.3381	63.6466

Example: Bursting Strength

- One of the key quality characteristics of glass soda bottles is bursting strength (the pressure at which the bottle burst measured in psi).
- A manufacturer of bottles has set the lower specification limit on bursting strength at 200 psi. There is no upper specification limit.
- The bursting strength data is stored in **Bursting Strength.jmp**.

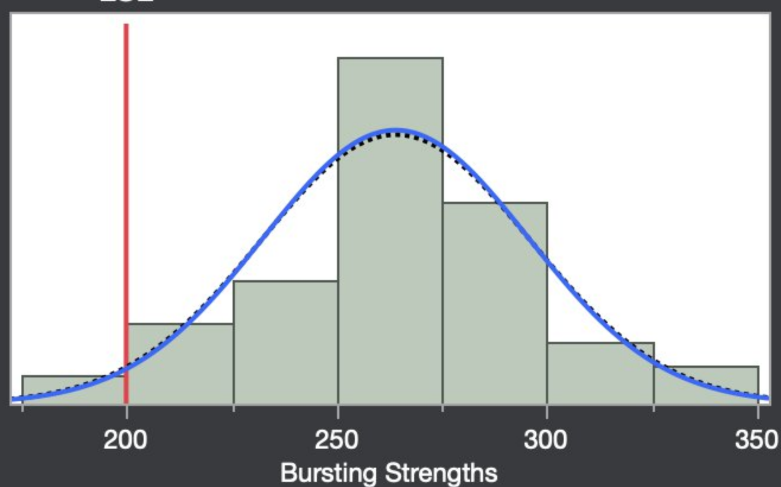
Example: Bursting Strength

1. Open the **Bursting Strength.jmp**. from JMP files in today's Wolfware
2. **Analyze → Distribution**.
3. Select **Bursting Strengths → Y, Columns, OK**.
4. Click the red triangle next to **Bursting Strengths** and select **Process Capability**.
5. Enter **200** as the **Lower Spec Limit**.
6. Select **OK**.

Process Capability

Bursting Strengths Capability

Histogram



Process Summary

LSL	200
N	100
Sample Mean	264.06
Within Sigma	31.49239
Overall Sigma	32.01793
Stability Index	1.016688

Within sigma estimated by average moving range.

Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	0.678	0.541	0.814
Cpl	0.678	0.541	0.814

Overall Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Ppk	0.667	0.553	0.780
Ppl	0.667	0.553	0.780

Nonconformance

Portion	Observed %	Expected Within %	Expected Overall %
Below LSL	3.0000	2.0969	2.2709
Total Outside	3.0000	2.0969	2.2709

How many defects will this process produce?

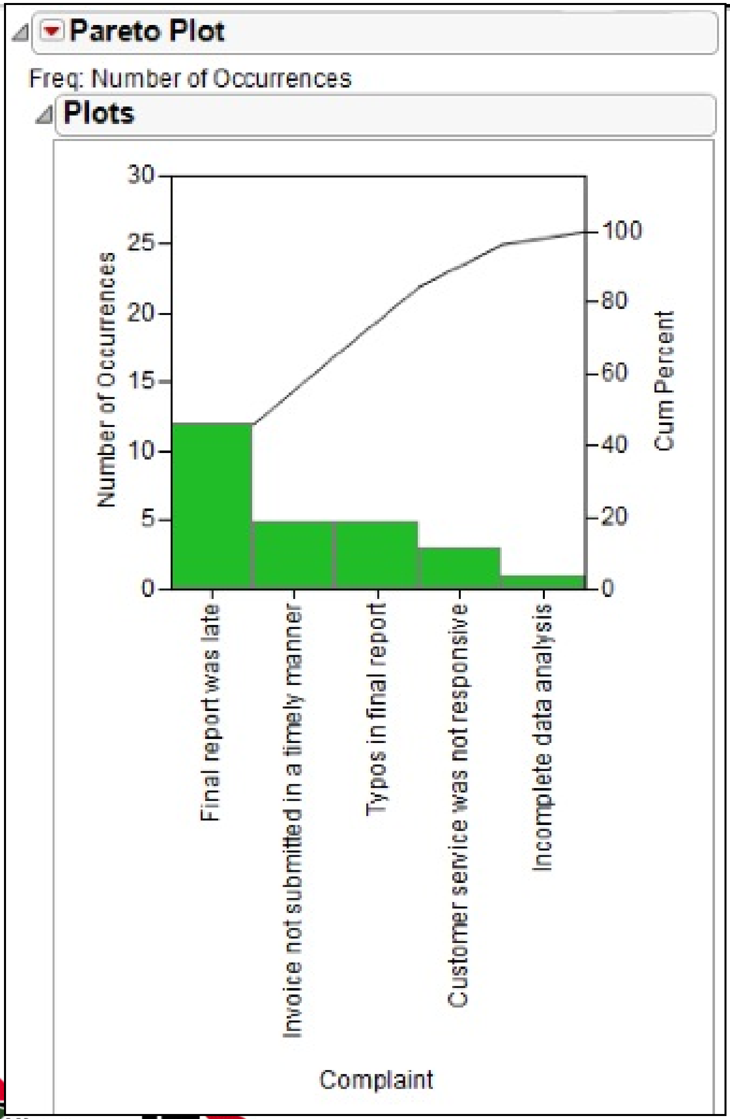
Graphing the Project Metric

- At the end of the Measure phase, the Lean Six Sigma project team should have a process baseline to add to the project charter.
- If a process, or product, has specification limits associated with it, capability indices are appropriate measures of the process baseline.
- For processes without specification limits, Pareto Plots, Histograms and Run Charts may be used to assess and report the current process baseline.

Pareto Plots

- Pareto Plots
  1. Open **Client Complaints.jmp**.
  2. Select **Analyze** → **Quality and Process** → **Pareto Plot**.
  3. Select **Complaint** → **Y, Cause**.
  4. Select **Number of Occurrences** → **Freq**.
  5. Select **OK**.

Pareto Plot

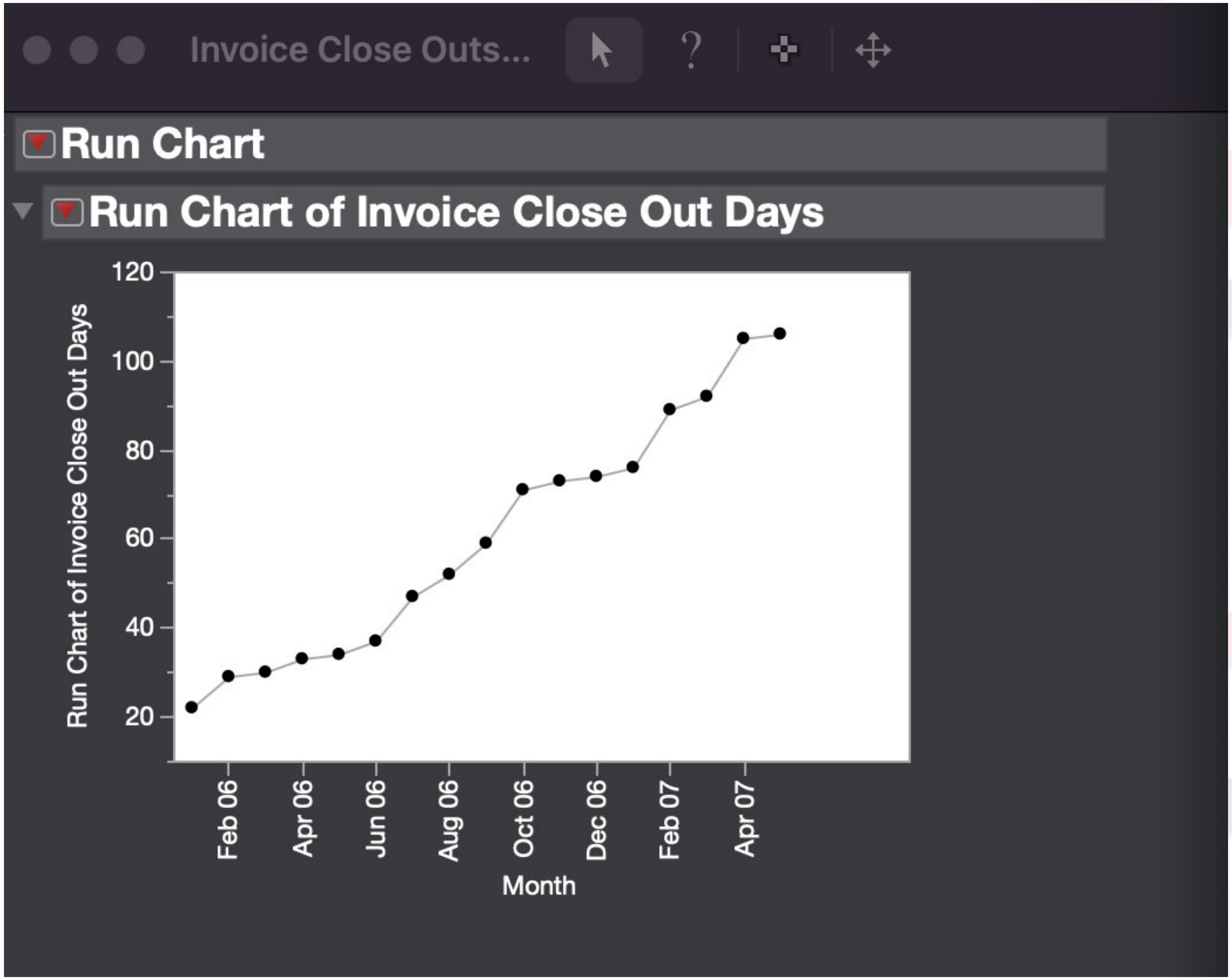


Which area should the Lean Six Sigma team target first?

Run Charts

- Run Charts
  1. Open **Invoice Close Outs.jmp**.
  2. Select **Analyze** → **Quality and Process** → **Legacy Control Charts** → **Runs Chart**.
  3. Select **Invoice Close Out Days** → **Process**.
  4. Select **OK**.

Run Chart


Invoice Close Outs...
Run Chart
Run Chart of Invoice Close Out Days
120
100
80
60
40
20
Run Chart of Invoice Close Out Days
Feb 06
Apr 06
Jun 06
Aug 06
Oct 06
Dec 06
Feb 07
Apr 07
Month

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

Measure Tollgate

- Determine project critical Ys and Xs
- Create the data collection plan
- Complete a measurement systems analysis
- Collect data
- Calculate process capability and baseline
- Update charter

PROCESS CAPABILITY

Objectives

- Discuss process capability terms
- Illustrate assessing process capability
- Understand the different capability indices
- Calculate process capability using JMP 17
- Discuss using run charts and Pareto charts to establish a process baseline
- Review the Measure Tollgate

Process Baseline

- The team's last task in Measure is to report the current process baseline.
- The team will continue to collect data on the project metric throughout the project and compare it to the baseline.
- Process capability is one way to report the process baseline.
- Graphically, the baseline may be reported with a run chart or even a Pareto plot.

Process Capability Terminology

- **Specification Limits**
  - Boundaries, usually set by management, engineering or customers, within which a process must operate
  - Voice of the customer
  - Is the service or product meeting the customer's expectations?
- **Process Capability**
  - Compares the output of an in-control process to specification limits using capability indices
  - Answers the question of how well a process meets a customer's expectations

Why Assess Process Capability?

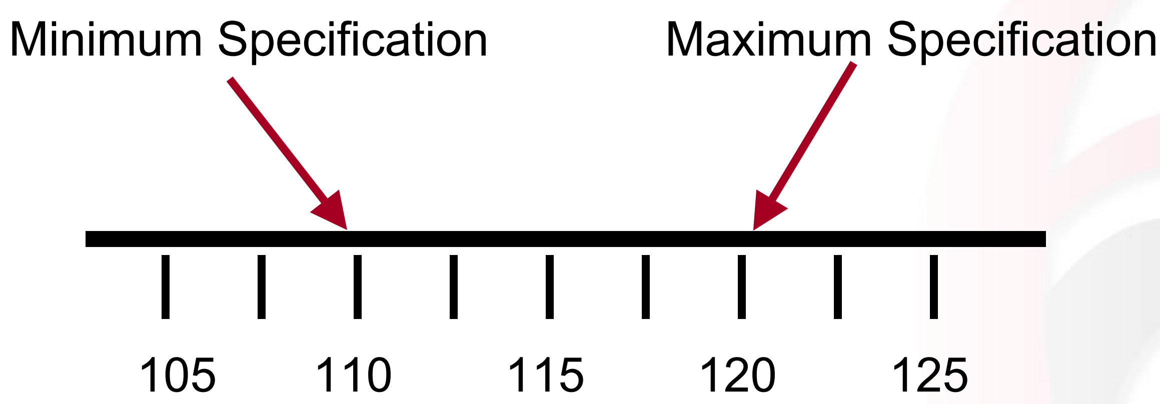
- Allows us to quantify the nature of the problem we will attack as one of the following:
  - Are the specifications correct for the parameter (Y) of interest (process or performance output variable)?
  - Is the location of the central tendency of the parameter (Y) centered within the appropriate specifications?
  - Is the process variation in the parameter greater than allowed by the specifications?
  - Is the measurement system affecting our ability to assess true process capability?
- Allows the organization to predict defect levels.

A Practical Illustration

A popular coffee bar has started receiving complaints from customers about the coffee temperature.

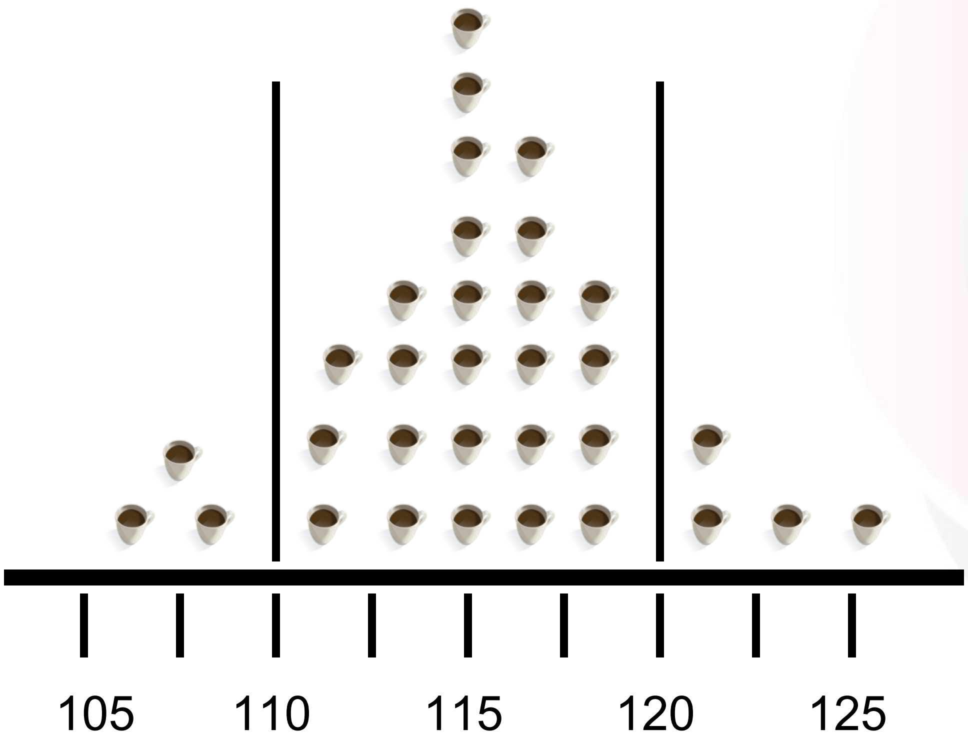
Some customers say the coffee is too hot, but others have complained it is too cold.

A Practical Illustration



Customer surveys and industry benchmarking indicate that customers will be satisfied if the temperature is between 110 and 120 degrees F.

A Practical Illustration



Capability Indices

A capability index uses both the process variability and the process specification limits to quantify whether or not a process is capable of meeting customer expectations.

Cp	Cpk
Indicates how well the process distribution fits within its specification limits. This index reflects how capable the process would be if centered	Incorporates information on spread as well as the process mean so it is an indicator of how well the process is actually performing.

If Cp = Cpk, the process is centered. If Cp > Cpk the process is not centered.

Capability Indices

- Capability indices can be divided into two categories:
  - within (short-term) and
  - overall (long-term).
  - Within or Short-term capability studies are based on measurements collected from one operating run.
  - Overall or Long-term capability studies consist of measurements which are collected over a longer period of time. It is assumed that data collected over a long period of time includes both common cause and special cause variation.

Estimation of Capability Indices

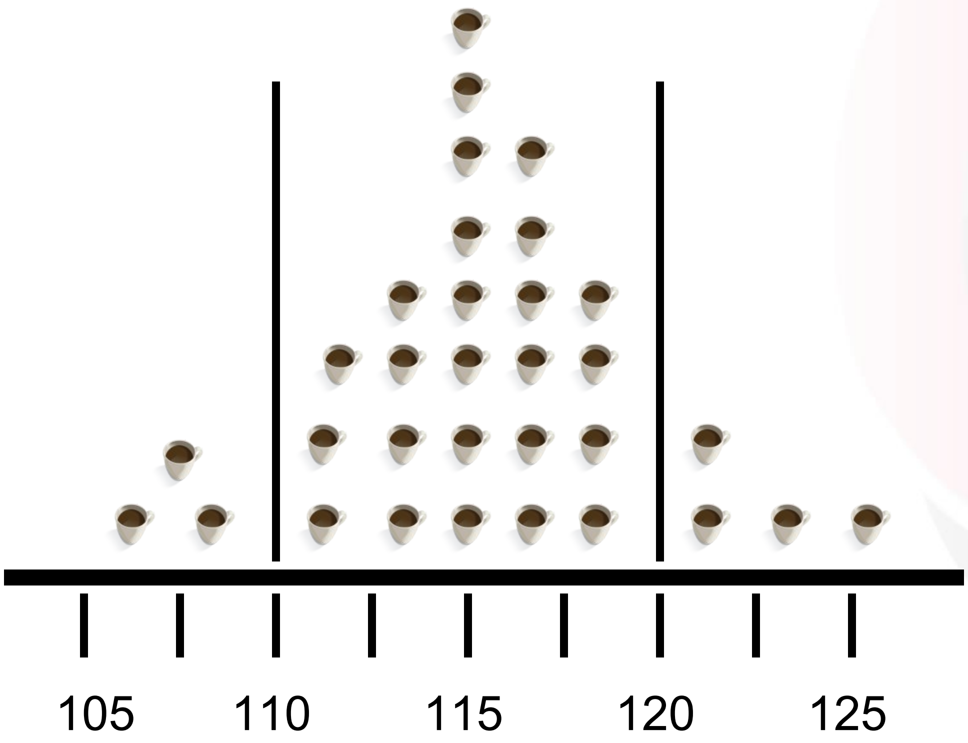
Short-Term Capability Indices

Long-Term Capability Indices

Assumptions

- The process data is normally distributed
- The process is in-control – no special cause variation is present

A Practical Illustration



How capable is the coffee shop?

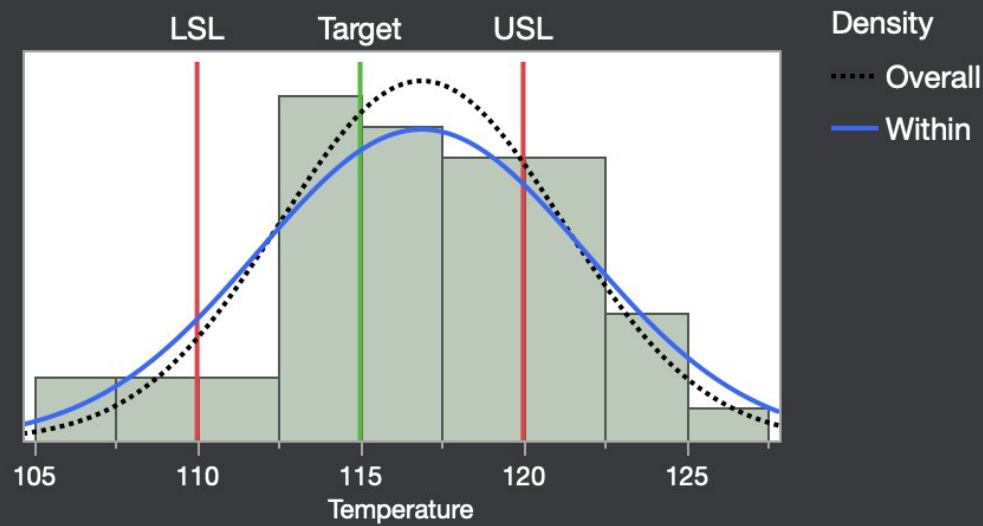
Example – Coffee Capability.jmp

1. Open the file **Coffee Capability.jmp**. from Wolfware for today
2. **Analyze → Distribution**
3. Select **Temperature → Y, Columns → OK**.
4. Click the red triangle next to **Temperature** and select **Process Capability**.
5. Lower spec limit is 110
6. Upper spec limit is 120
7. Target is 115
8. Select **OK**.

Process Capability

Temperature Capability

Histogram



Process Summary

LSL	110
Target	115
USL	120
N	50
Sample Mean	116.8856
Within Sigma	5.015138
Overall Sigma	4.338507
Stability Index	0.865082

Within sigma estimated by average moving range.

Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	0.207	0.101	0.313
Cpl	0.458	0.309	0.603
Cpu	0.207	0.100	0.312
Cp	0.332	0.249	0.415
Cpm	0.311	0.251	0.371

Overall Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Ppk	0.239	0.135	0.343
Ppl	0.529	0.388	0.667
Ppu	0.239	0.135	0.342
Pp	0.384	0.308	0.460
Cpm	0.352	0.287	0.424

Nonconformance

Portion	Observed %	Expected Within %	Expected Overall %
Below LSL	8.0000	8.4882	5.6246
Above USL	28.0000	26.7300	23.6425
Total Outside	36.0000	35.2182	29.2671

Process Sigma

The Sigma level is a measure of how often defects are expected to occur in a process.

Sigma and Capability

Cp	Parts Per Million Defects	σ
1.00	66,813	3.0
1.33	6,210	4.0
1.50	1,350	4.5
1.67	233	5.0
1.83	32	5.5
2.00	3.4	6.0

Example: Coffee

1. Open **Sigma Calculator.xls**.
2. Under Sigma Level-Continuous Data, type **116.88** in the Mean field.
3. Type **4.314** in the Standard Deviation field.
4. Type **110** in the LSL field.
5. Type **120** in the USL field.

Sigma Level - Continuous Data		
		Normal Distribution Only
Mean	116.88	
Standard Deviation	4.314	
Lower Spec Limit	110	leave blank if not applicable
Upper Spec Limit	120	leave blank if not applicable
Z Score Upper	0.723227	
% Out of Spec Upper	0.23477	
Z Score Lower	-1.594808	
% Out of Spec Lower	0.055378	
Total Out of Spec	29.01%	
DPM	290,148	
Sigma Level	2.05	
Yield	70.99%	

Is this process operating at an acceptable sigma level?

Example: Ischemia Time

1. Open **Sigma Calculator.xls**.
2. Under Sigma Level-Continuous Data, type **27.96** in the Mean field.
3. Type **8.094** in the Standard Deviation field.
4. Type **30** in the USL field.

Sigma Level - Continuous Data		
		Normal Distribution Only
Mean	27.96	
Standard Deviation	8.094	
Lower Spec Limit		leave blank if not applicable
Upper Spec Limit	30	leave blank if not applicable
Z Score Upper	0.252039	
% Out of Spec Upper	0.400506	
Z Score Lower		
% Out of Spec Lower		
Total Out of Spec	40.05%	
DPM	400,506	
Sigma Level	1.75	
Yield	59.95%	

Is this process operating at an acceptable sigma level?

Example: CRO Patient Recruiting

Background:
A CRO has started to experience long delays in completing the projects they have been awarded in the last 12 months. The executive team identified several areas of the process that might be leading to the long delays. Several Six Sigma teams were formed to tackle this project. One team is addressing the amount of time spent recruiting patients for a study.

Problem Statement:
The average number of weeks needed to recruit patients for new studies has increased from 6 weeks to 10 weeks in the last year, resulting in significant delays in starting new trials.

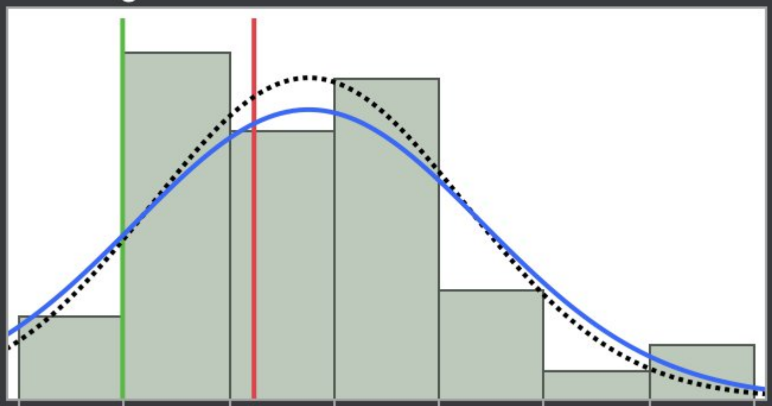
Example – Patient Recruiting.jmp

1. Open the file **Patient Recruiting.jmp**. from JMP File in today's Wolfware
2. **Analyze → Distribution**.
3. Select **Recruiting Weeks → Y, Columns, OK**.
4. Click the red triangle next to **Recruiting Weeks** and select **Process Capability**.
5. Upper spec limit is 8.5
6. Target is 6
7. Select **OK**.

Process Capability

Recruiting Weeks Capability

Histogram



Process Summary

Target	6
USL	8.5
N	45
Sample Mean	9.538963
Within Sigma	3.304872
Overall Sigma	2.976733
Stability Index	0.90071

Within sigma estimated by average moving range.

Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	-0.105	-0.205	-0.003
Cpu	-0.105	-0.205	-0.003
Cpm	0.172	.	.

Overall Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Ppk	-0.116	-0.216	-0.015
Ppu	-0.116	-0.216	-0.015
Cpm	0.180	.	.

Nonconformance

Portion	Observed %	Expected Within %	Expected Overall %
Above USL	57.7778	62.3381	63.6466
Total Outside	57.7778	62.3381	63.6466

Example: Bursting Strength

- One of the key quality characteristics of glass soda bottles is bursting strength (the pressure at which the bottle burst measured in psi).
- A manufacturer of bottles has set the lower specification limit on bursting strength at 200 psi. There is no upper specification limit.
- The bursting strength data is stored in **Bursting Strength.jmp**.

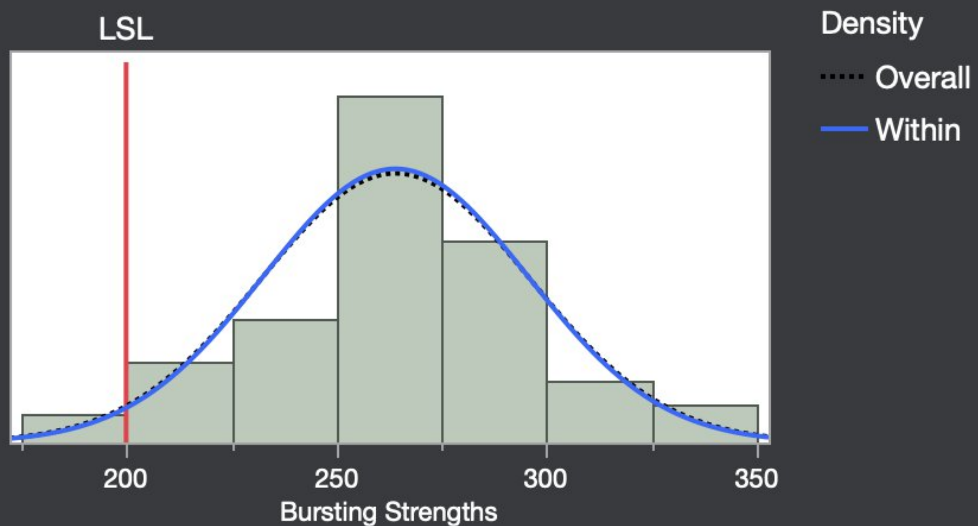
Example: Bursting Strength

1. Open the **Bursting Strength.jmp**. from JMP files in today's Wolfware
2. **Analyze → Distribution**.
3. Select **Bursting Strengths → Y, Columns, OK**.
4. Click the red triangle next to **Bursting Strengths** and select **Process Capability**.
5. Enter **200** as the **Lower Spec Limit**.
6. Select **OK**.

Process Capability

Bursting Strengths Capability

Histogram



Process Summary

LSL	200
N	100
Sample Mean	264.06
Within Sigma	31.49239
Overall Sigma	32.01793
Stability Index	1.016688

Within sigma estimated by average moving range.

Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	0.678	0.541	0.814
Cpl	0.678	0.541	0.814

Overall Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Ppk	0.667	0.553	0.780
Ppl	0.667	0.553	0.780

Nonconformance

Portion	Observed %	Expected Within %	Expected Overall %
Below LSL	3.0000	2.0969	2.2709
Total Outside	3.0000	2.0969	2.2709

How many defects will this process produce?

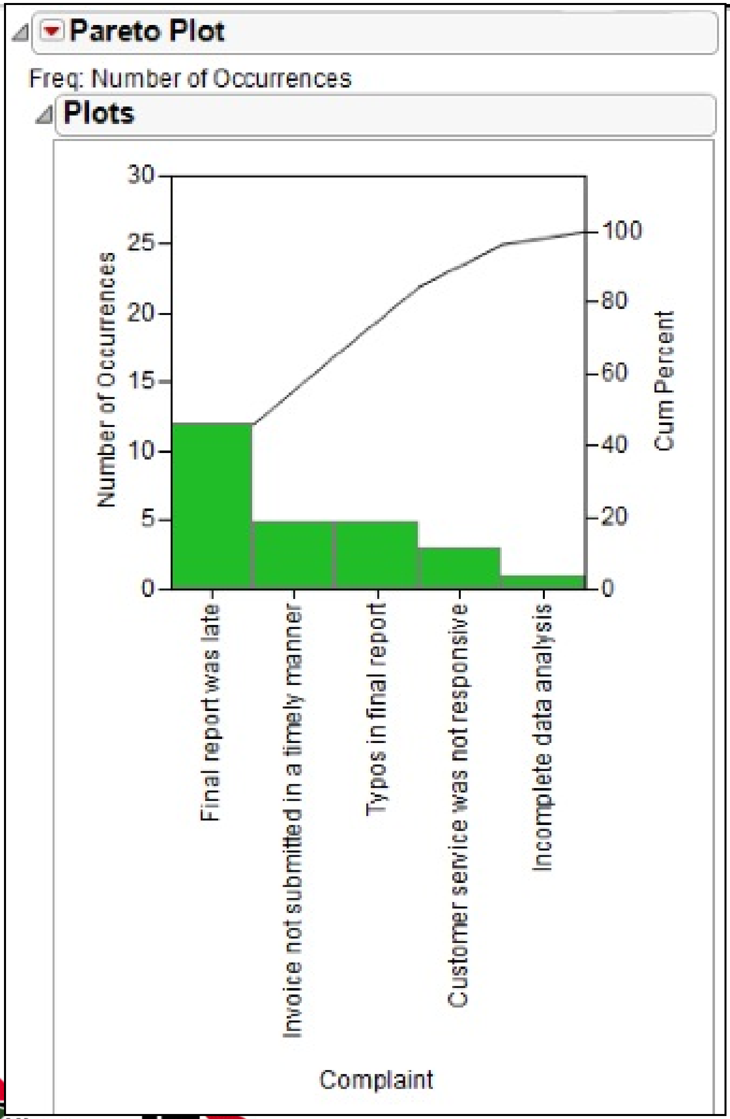
Graphing the Project Metric

- At the end of the Measure phase, the Lean Six Sigma project team should have a process baseline to add to the project charter.
- If a process, or product, has specification limits associated with it, capability indices are appropriate measures of the process baseline.
- For processes without specification limits, Pareto Plots, Histograms and Run Charts may be used to assess and report the current process baseline.

Pareto Plots

- Pareto Plots
  1. Open **Client Complaints.jmp**.
  2. Select **Analyze** → **Quality and Process** → **Pareto Plot**.
  3. Select **Complaint** → **Y, Cause**.
  4. Select **Number of Occurrences** → **Freq**.
  5. Select **OK**.

Pareto Plot



Which area should the Lean Six Sigma team target first?