



pdf **Six Sigma**<sup>TM</sup>

Lean Six Sigma Black Belt Training  
Featuring Examples from Minitab 16

# 2.0 Measure Phase

# Black Belt Training: Measure Phase

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- 2.1.2 Process Mapping
- 2.1.3 X-Y Diagram
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- 2.2.2 Descriptive Statistics
- 2.2.3 Distributions & Normality
- 2.2.4 Graphical Analysis

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- 2.3.2 Bias, Linearity & Stability
- 2.3.3 Gage R&R
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## 2.4 Process Capability

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## 2.3.4 Variable & Attribute MSA

# Variable Gage R&R

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- Whenever something is measured repeatedly or by different people or processes, the results of the measurements will vary. Variation comes from 2 primary sources:
  1. Differences between the parts being measured
  2. The measurement system
- We can use a Gage R&R to conduct a measurement system analysis to determine what portion of the variability comes from the parts and what portion comes from the measurement system.
- There are key study results that help us determine the components of variation within our measurement system..

# Key Measure of a Variable Gage R&R

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- **% Contribution**: The %Contribution for a source is 100 times the variance component for that source divided by the Total Variation variance component.
- **% Study Var ( $6*SD$ )**: The %Study Variation for a source is 100 times the study variation for that source divided by the Total Variation study variation.
- **%Tolerance ( $SV/Tolerance$ )**: Percent of spec range taken up by the total width of the distribution of the data based on variation from that Source
- **Distinct Categories**: This number is the number of distinct categories of parts that the measurement system is able to distinguish. If a measurement system is not capable of distinguishing at least 5 types of parts, it is probably not adequate.

# Variable Gage R&R Guidelines (AIAG)

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- **%Tolerance and % Study Variation**
  - 10% or less – Acceptable
  - 10% to 30% - Marginal
  - 30% or greater – Unacceptable
- **%Contribution**
  - 1% or less – Acceptable
  - 1% to 9% - Marginal
  - 9% or greater – Unacceptable
- **Distinct Categories**
  - Look for 5 or more distinct categories to indicate that your measurement system is acceptable

# Guidelines for Distinct Categories

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**Distinct Categories** is the # of categories of parts that your measurement system can distinguish. If it's below 5 it's likely not able to distinguish between parts.

Number of Categories	Conclusion
Distinct Categories = 1	Measurement system can't discriminate between parts
Distinct Categories = 2	Measurement system can only distinguish between high/low or big/small
Distinct Categories = 3 or 4	Measurement system is of little or no value
Distinct Categories = 5+	According to AIAG the measurement system can acceptably discriminate parts

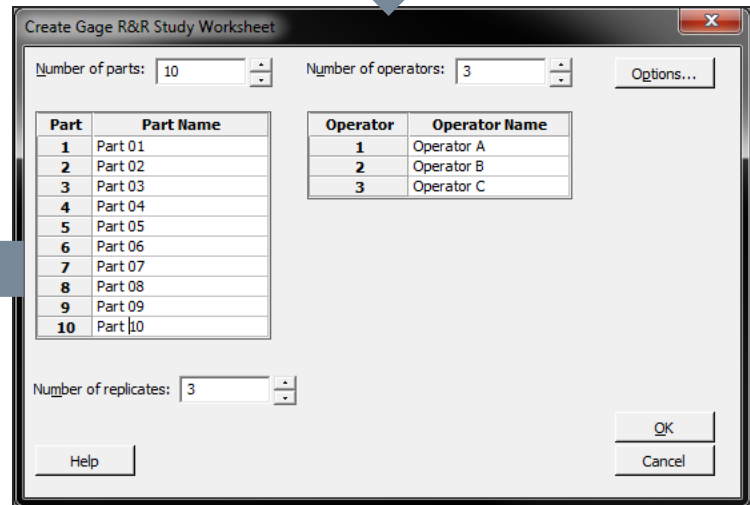
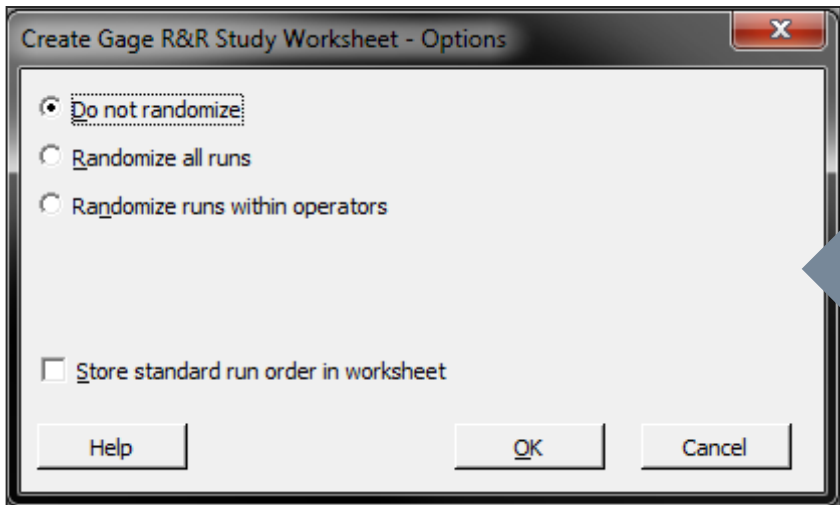
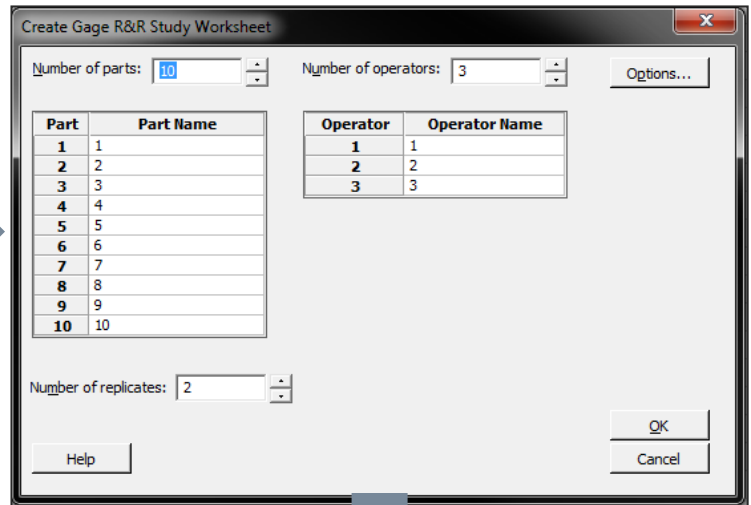
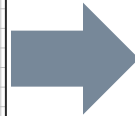
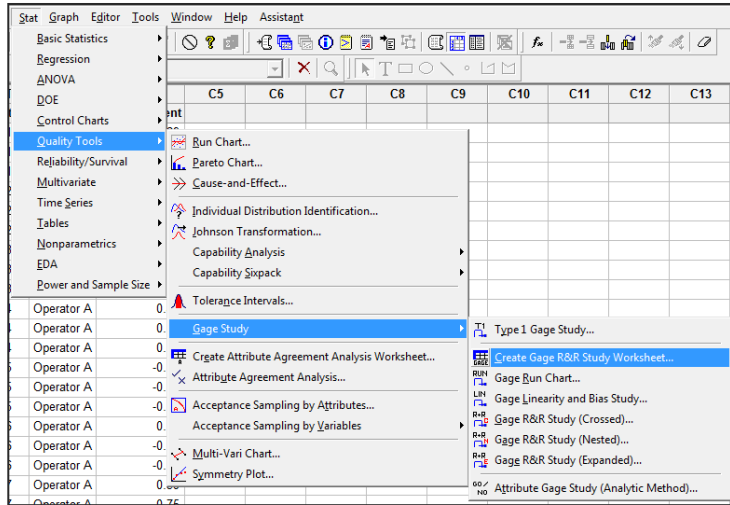


# Use Minitab to Implement a Variable MSA

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- Data File: “Variable MSA” tab in “Sample Data.xlsx” (an example in the AIAG MSA Reference Manual, 3rd Edition)
- **Step 1: Initiate the MSA study**
  - Click on Stat -> Quality Tools -> Gage R&R -> Create Gage R&R Study Worksheet
  - A new window named “Create Gage R&R Study Worksheet” pops up
  - Select 10 as the “Number of Parts”
  - Select 3 as the “Number of Operators”
  - Select 3 as the “Number of Replicates”
  - Enter the part name (e.g. Part 01, Part 02, Part 03, ...)
  - Enter the operator name (e.g. Operator A, Operator B, Operator C)
  - Click on the “Options” button and another window named “Create Gage R&R Study Worksheet – Options” pops up.
  - Select the radio button “Do not randomize”.
  - Click “OK” in the window “Create Gage R&R Study Worksheet – Options”.
  - Click “OK” in the window “Create Gage R&R Study Worksheet”.
  - A new data table is generated.

# Use Minitab to Implement a Variable MSA



# Use Minitab to Implement a Variable MSA

- Step 2: Data collection
  - In the newly generated data table, Minitab has provided the template where we organize the data
  - In the “Variable MSA” tab in “Sample Data.xlsx”, there are all the measurement data collected by three operators (i.e. operator A, B and C). The data are listed in the standardized order.

	A	B	C	D
1	Run Order	Part	Operator	Measurement
2		1 Part 01	Operator A	0.29
3		2 Part 01	Operator A	0.41
4		3 Part 01	Operator A	0.64
5		4 Part 02	Operator A	-0.56
6		5 Part 02	Operator A	-0.68
7		6 Part 02	Operator A	-0.58
8		7 Part 03	Operator A	1.34
9		8 Part 03	Operator A	1.17
10		9 Part 03	Operator A	1.27
11		10 Part 04	Operator A	0.47
12		11 Part 04	Operator A	0.5
13		12 Part 04	Operator A	0.64
14		13 Part 05	Operator A	-0.8
15		14 Part 05	Operator A	-0.92

# Use Minitab to Implement a Variable MSA

- **Step 3: Enter the data into the MSA template generated in Minitab**
  - Transfer the data from the “Measurement” column in “Variable MSA” tab of “Sample Data.xlsx” to the last column in the MSA template Minitab generates.
  - Although the run order in the “Variable MSA” tab of “Sample Data.xlsx” is different from the run order in the Minitab MSA template, we can directly use the raw data listed in the “Variable MSA” tab of “Sample Data.xlsx” for our MSA purpose.

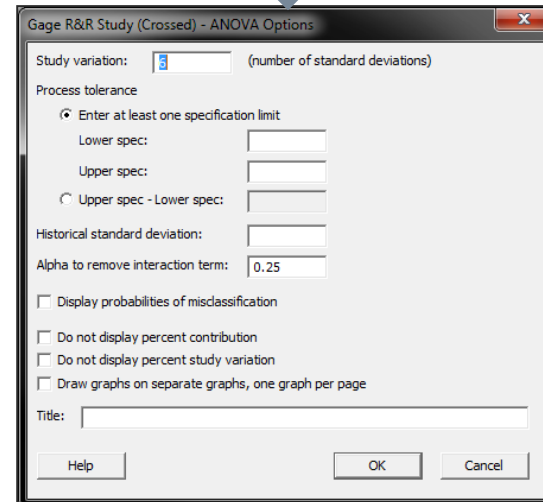
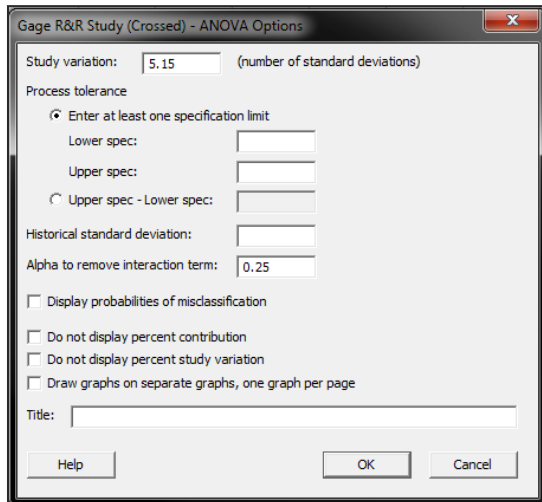
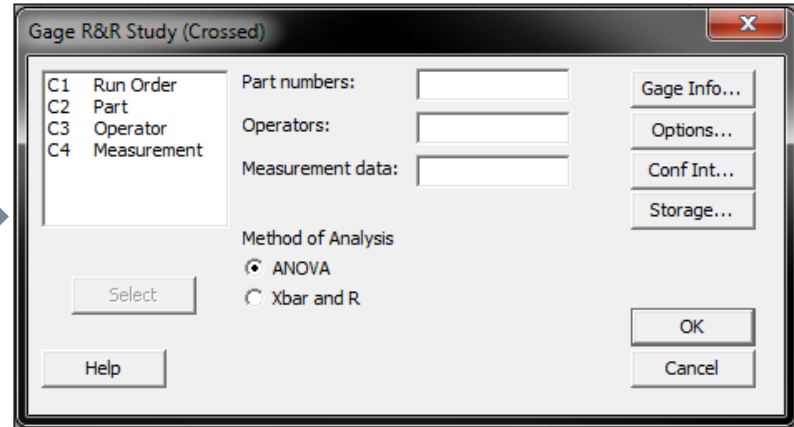
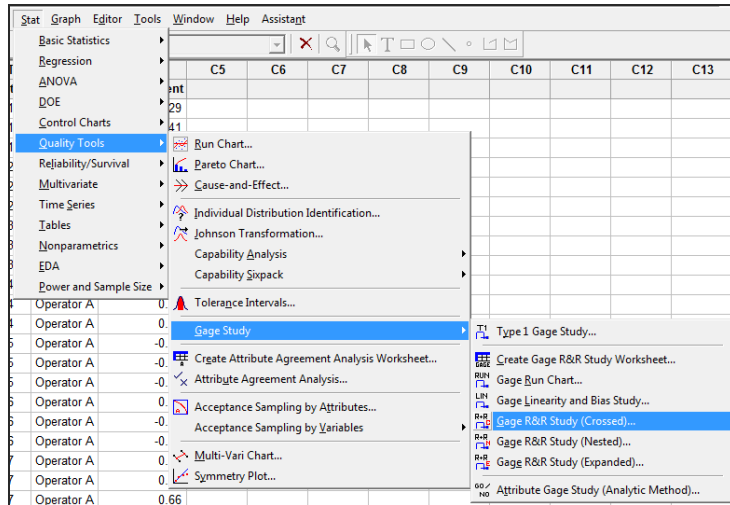
↓	C1	C2-T	C3-T	C4
	Run Order	Part	Operator	Measurement
1	1	Part 01	Operator A	0.29
2	2	Part 01	Operator A	0.41
3	3	Part 01	Operator A	0.64
4	4	Part 02	Operator A	-0.56
5	5	Part 02	Operator A	-0.68
6	6	Part 02	Operator A	-0.58
7	7	Part 03	Operator A	1.34
8	8	Part 03	Operator A	1.17
9	9	Part 03	Operator A	1.27
10	10	Part 04	Operator A	0.47
11	11	Part 04	Operator A	0.50
12	12	Part 04	Operator A	0.64
13	13	Part 05	Operator A	-0.80

# Use Minitab to Implement a Variable MSA

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- Step 4: Implement Gauge R&R
  - Click Stat -> Quality Tools -> Gage Study -> Gage R&R Study (Crossed)
  - A new window named “Gage R&R Study (Crossed)” appears.
  - Select “Part” as “Part numbers”
  - Select “Operator” as “Operators”
  - Select “Measurement” as “Measurement data”
  - Click on the “Options” button and another new window named “Gage R&R Study (Crossed) – ANOVA Options” pops up
  - Enter 5.15 as the “Study variation (number of standard deviations)”.
  - Click “OK” in the window “Gage R&R Study (Crossed) – ANOVA Options”.
  - Click “OK” in the window “Gage R&R Study (Crossed)”.
  - The MSA analysis results appear in the new window and the session window.

# Use Minitab to Implement a Variable MSA



# Use Minitab to Implement a Variable MSA

- 5.15 is the recommended standard deviation multiplier by the Automotive Industry Action Group (AIAG). It corresponds to 99% of data in the normal distribution. If we use 6 as the standard deviation multiplier, it corresponds to 99.73% of the data in the normal distribution.

Confidence Level	Sixma Multiplier
90%	3.29
95%	3.92
99%	5.15
99.73%	6

# Use Minitab to Implement a Variable MSA

- Step 4: Analyze the MSA results

Gage R&R			
Source	VarComp	%Contribution (of VarComp)	
Total Gage R&R	0.09143	7.76	
Repeatability	0.03997	3.39	
Reproducibility	0.05146	4.37	
Operator	0.05146	4.37	
Part-To-Part	1.08645	92.24	
Total Variation	1.17788	100.00	

Source	StdDev (SD)	Study Var (5.15 * SD)	%Study Var (%SV)
Total Gage R&R	0.30237	1.55721	27.86
Repeatability	0.19993	1.02966	18.42
Reproducibility	0.22684	1.16821	20.90
Operator	0.22684	1.16821	20.90
Part-To-Part	1.04233	5.36799	96.04
Total Variation	1.08530	5.58929	100.00

The percentage of variation R&R contributes to the total variation is 27.86% and the precision level of this measurement system is not good. Actions are required to calibrate the measurement system.



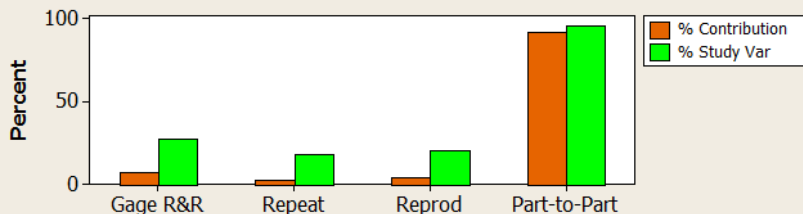
# Use Minitab to Implement a Variable MSA

## Gage R&R (ANOVA) for Measurement

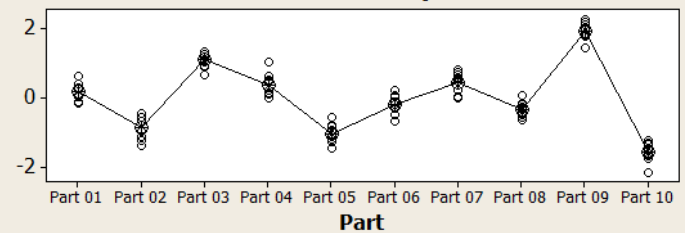
Gage name:  
Date of study:

Reported by:  
Tolerance:  
Misc:

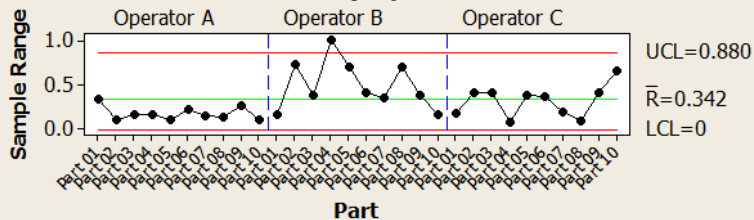
**Components of Variation**



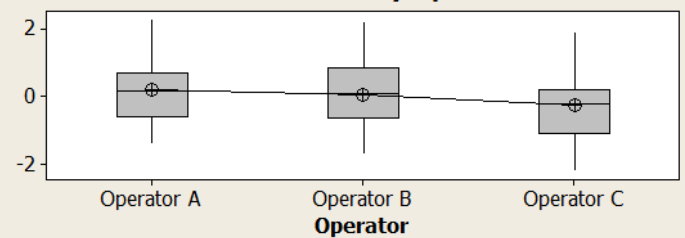
**Measurement by Part**



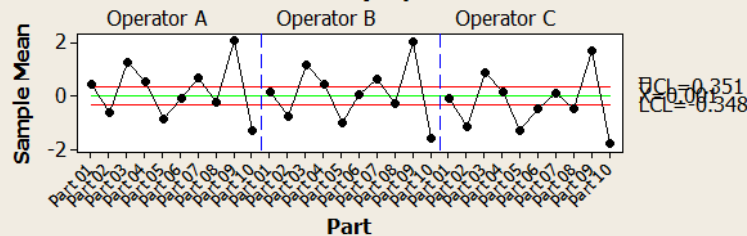
**R Chart by Operator**



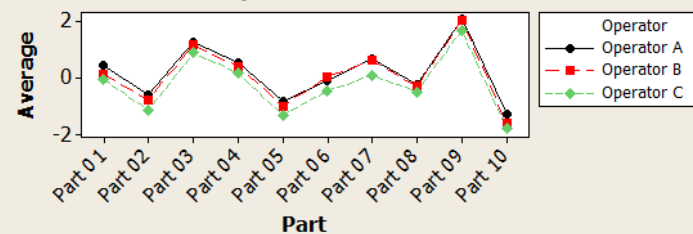
**Measurement by Operator**



**Xbar Chart by Operator**



**Part \* Operator Interaction**



# Use Minitab to Implement an Attribute MSA

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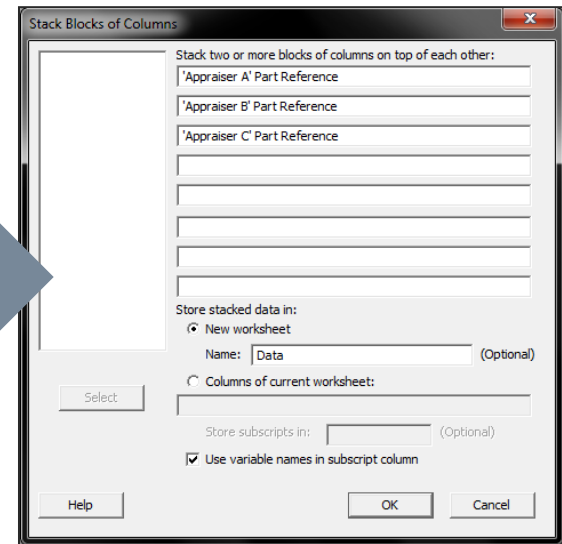
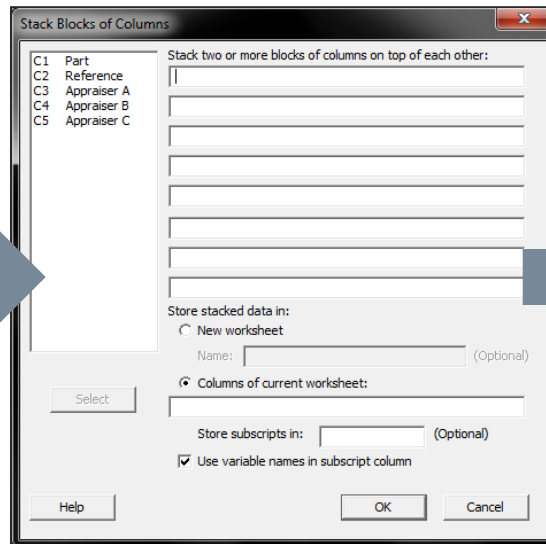
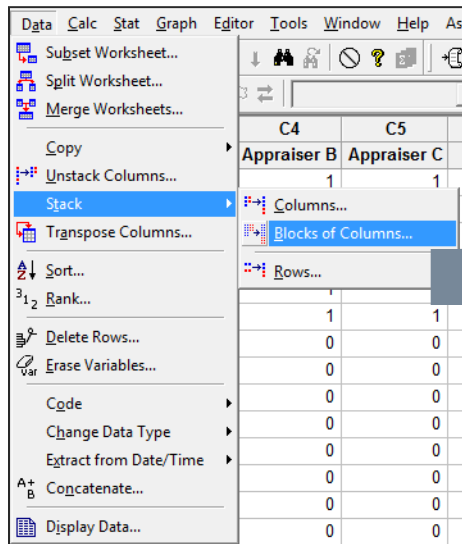
- Data File: “Attribute MSA” tab in “Sample Data.xlsx” (an example in the AIAG MSA Reference Manual, 3rd Edition)
- Steps in Minitab to run an attribute MSA

# Use Minitab to Implement an Attribute MSA

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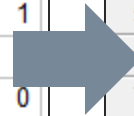
- **Step 1: Reorganize the original data into four new columns (i.e. Appraiser, Assessed Result, Part and Reference, ).**
  - Click Data -> Stack -> Blocks of Columns
  - A new window named “Stack Blocks of Columns” pops up
  - Select “Appraiser A”, “Part” and “Reference” as block one
  - Select “Appraiser B”, “Part” and “Reference” as block two
  - Select “Appraiser C”, “Part” and “Reference” as block three
  - Select the radio button of “New worksheet” and name the sheet “Data”
  - Check the checkbox “Use variable names in subscript column”
  - Click “OK”
  - The stacked columns are created in the new worksheet named “Data”
  - Name the four columns from left to right in worksheet “Data”: Appraiser, Assessed Result, Part and Reference.

# Use Minitab to Implement an Attribute MSA



# Use Minitab to Implement an Attribute MSA

↓	C1-T	C2	C3	C4
	<b>Subscripts</b>			
1	Appraiser A	1	1	1
2	Appraiser A	1	1	1
3	Appraiser A	1	1	1
4	Appraiser A	1	2	1
5	Appraiser A	1	2	1
6	Appraiser A	1	2	1
7	Appraiser A	0	3	0
8	Appraiser A	0	3	0
9	Appraiser A	0	3	0
10	Appraiser A	0	4	0
11	Appraiser A	0	4	0
12	Appraiser A	0	4	0
13	Appraiser A	0	5	0



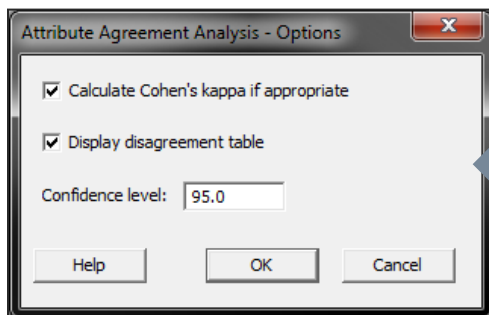
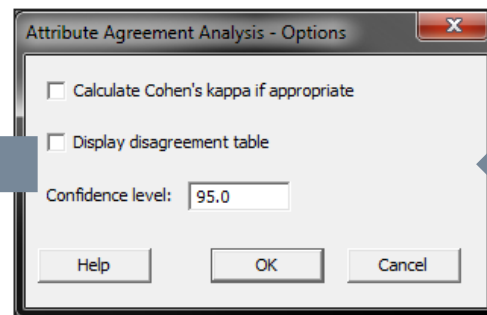
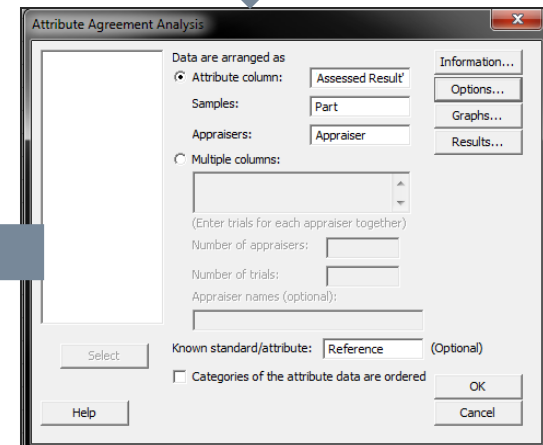
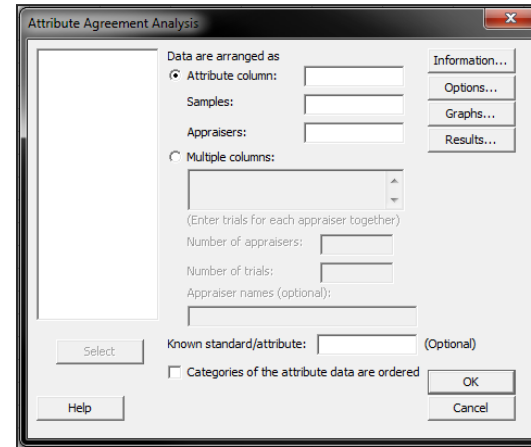
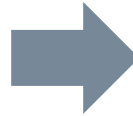
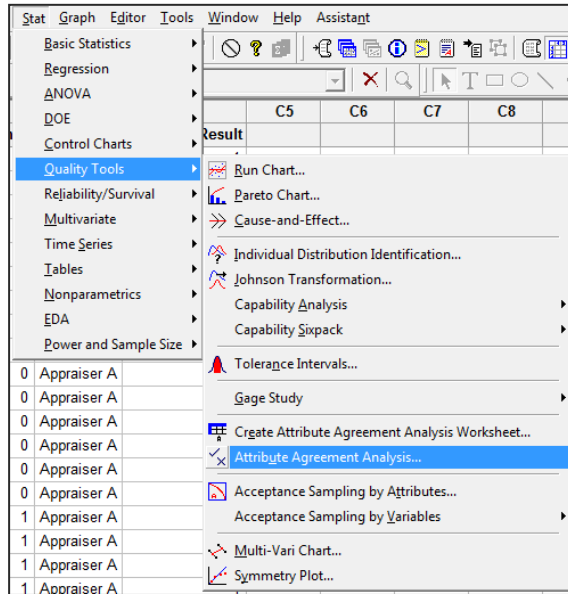
↓	C1-T	C2	C3	C4
	<b>Appraiser</b>	<b>Assessed Result</b>	<b>Part</b>	<b>Reference</b>
1	Appraiser A	1	1	1
2	Appraiser A	1	1	1
3	Appraiser A	1	1	1
4	Appraiser A	1	2	1
5	Appraiser A	1	2	1
6	Appraiser A	1	2	1
7	Appraiser A	0	3	0
8	Appraiser A	0	3	0
9	Appraiser A	0	3	0
10	Appraiser A	0	4	0
11	Appraiser A	0	4	0
12	Appraiser A	0	4	0
13	Appraiser A	0	5	0

# Use Minitab to Implement an Attribute MSA

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- **Step 2: Run MSA using Minitab**
  - Click Stat -> Quality Tools -> Attribute Agreement Analysis
  - A new window named “Attribute Agreement Analysis” pops up.
  - Click in the blank box next to “Attribute column” and the variables appear in the list box on the left.
  - Select “Assessed Result” as “Attribute column”
  - Select “Part” as “Sample”
  - Select “Appraiser” as “Appraisers”
  - Select “Reference” as “Known standard/attribute”
  - Click the “Options” button and another window named “Attribute Agreement Analysis – Options” pops up
  - Check the checkboxes of both “Calculate Cohen’s kappa if appropriate” and “Display disagreement table”.
  - Click “OK” in the window “Attribute Agreement Analysis – Options”.
  - Click “OK” in the window “Attribute Agreement Analysis”.
  - The MSA results appear in the newly generated window and the session window.

# Use Minitab to Implement an Attribute MSA



# Use Minitab to Implement an Attribute MSA

**Within Appraisers**

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
Appraiser A	50	42	84.00	(70.89, 92.83)
Appraiser B	50	45	90.00	(78.19, 96.67)
Appraiser C	50	40	80.00	(66.28, 89.97)

# Matched: Appraiser agrees with him/herself across trials.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
Appraiser A	0	0.760000	0.0816497	9.3081	0.0000
	1	0.760000	0.0816497	9.3081	0.0000
Appraiser B	0	0.845073	0.0816497	10.3500	0.0000
	1	0.845073	0.0816497	10.3500	0.0000
Appraiser C	0	0.702911	0.0816497	8.6089	0.0000
	1	0.702911	0.0816497	8.6089	0.0000

Within Appraiser Agreement Percent: the agreement percentage within each individual appraiser.



# Use Minitab to Implement an Attribute MSA

**Each Appraiser vs Standard**

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
Appraiser A	50	42	84.00	(70.89, 92.83)
Appraiser B	50	45	90.00	(78.19, 96.67)
Appraiser C	50	40	80.00	(66.28, 89.97)

# Matched: Appraiser's assessment across trials agrees with the known standard.

Assessment Disagreement

Appraiser	# 1 / 0	Percent	# 0 / 1	Percent	# Mixed	Percent
Appraiser A	0	0.00	0	0.00	8	16.00
Appraiser B	0	0.00	0	0.00	5	10.00
Appraiser C	0	0.00	0	0.00	10	20.00

# 1 / 0: Assessments across trials = 1 / standard = 0.  
# 0 / 1: Assessments across trials = 0 / standard = 1.  
# Mixed: Assessments across trials are not identical.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
Appraiser A	0	0.880236	0.0816497	10.7806	0.0000
	1	0.880236	0.0816497	10.7806	0.0000
Appraiser B	0	0.922612	0.0816497	11.2996	0.0000
	1	0.922612	0.0816497	11.2996	0.0000
Appraiser C	0	0.774703	0.0816497	9.4881	0.0000
	1	0.774703	0.0816497	9.4881	0.0000

Each Appraiser vs. Standard Agreement Percent: the agreement percentage between each appraiser and the standard. It reflects the accuracy of the measurement system.

# Use Minitab to Implement an Attribute MSA

```
Between Appraisers
Assessment Agreement
# Inspected # Matched Percent 95% CI
      50      39    78.00 (64.04, 88.47)
|
# Matched: All appraisers' assessments agree with each other.

Fleiss' Kappa Statistics
Response      Kappa    SE Kappa      Z    P(vs > 0)
0             0.793606  0.0235702  33.6698  0.0000
1             0.793606  0.0235702  33.6698  0.0000
```

Between Appraiser Agreement Percent: the agreement percentage between different appraisers.

All Appraisers vs. Standard Agreement Percent: overall agreement percentage of both within and between appraisers. It reflects how precise the measurement system performs.

```
All Appraisers vs Standard
Assessment Agreement
# Inspected # Matched Percent 95% CI
      50      39    78.00 (64.04, 88.47)
|
# Matched: All appraisers' assessments agree with the known standard.

Fleiss' Kappa Statistics
Response      Kappa    SE Kappa      Z    P(vs > 0)
0             0.859184  0.0471405  18.2260  0.0000
1             0.859184  0.0471405  18.2260  0.0000
```

# Use Minitab to Implement an Attribute MSA

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- Kappa statistic is a coefficient indicating the agreement percentage above the expected agreement by chance.
- Kappa ranges from -1 (perfect disagreement) to 1 (perfect agreement).
- When the observed agreement is less than the chance agreement, Kappa is negative.
- When the observed agreement is greater than the chance agreement, kappa is positive.
- Rule of Thumb: If Kappa is greater than 0.7, the measurement system is acceptable. If Kappa is greater than 0.9, the measurement system is excellent.

# Use Minitab to Implement an Attribute MSA

**Within Appraisers**

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
Appraiser A	50	42	84.00	(70.89, 92.83)
Appraiser B	50	45	90.00	(78.19, 96.67)
Appraiser C	50	40	80.00	(66.28, 89.97)

# Matched: Appraiser agrees with him/herself across trials.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
Appraiser A	0	0.760000	0.0816497	9.3081	0.0000
	1	0.760000	0.0816497	9.3081	0.0000
Appraiser B	0	0.845073	0.0816497	10.3500	0.0000
	1	0.845073	0.0816497	10.3500	0.0000
Appraiser C	0	0.702911	0.0816497	8.6089	0.0000
	1	0.702911	0.0816497	8.6089	0.0000

Kappa statistic of the agreement within each appraiser

Kappa statistic of the agreement between individual appraiser and the standard

**Each Appraiser vs Standard**

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
Appraiser A	50	42	84.00	(70.89, 92.83)
Appraiser B	50	45	90.00	(78.19, 96.67)
Appraiser C	50	40	80.00	(66.28, 89.97)

# Matched: Appraiser's assessment across trials agrees with the known standard.

Assessment Disagreement

Appraiser	# 1 / 0	Percent	# 0 / 1	Percent	# Mixed	Percent
Appraiser A	0	0.00	0	0.00	8	16.00
Appraiser B	0	0.00	0	0.00	5	10.00
Appraiser C	0	0.00	0	0.00	10	20.00

# 1 / 0: Assessments across trials = 1 / standard = 0.  
 # 0 / 1: Assessments across trials = 0 / standard = 1.  
 # Mixed: Assessments across trials are not identical.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
Appraiser A	0	0.880236	0.0816497	10.7806	0.0000
	1	0.880236	0.0816497	10.7806	0.0000
Appraiser B	0	0.922612	0.0816497	11.2996	0.0000
	1	0.922612	0.0816497	11.2996	0.0000
Appraiser C	0	0.774703	0.0816497	9.4881	0.0000
	1	0.774703	0.0816497	9.4881	0.0000

# Use Minitab to Implement an Attribute MSA

**Between Appraisers**

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
50	39	78.00	(64.04, 88.47)

# Matched: All appraisers' assessments agree with each other.

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
0	0.793606	0.0235702	33.6698	0.0000
1	0.793606	0.0235702	33.6698	0.0000

Kappa statistic of the agreement between appraisers

Kappa statistic of the overall agreement between appraisers and the standard

**All Appraisers vs Standard**

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
50	39	78.00	(64.04, 88.47)

# Matched: All appraisers' assessments agree with the known standard.

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
0	0.859184	0.0471405	18.2260	0.0000
1	0.859184	0.0471405	18.2260	0.0000



pdf **Six Sigma**<sup>TM</sup>

Lean Six Sigma Black Belt Training  
Featuring Examples from Minitab 16