Measurement Systems Analysis

Components

and

Acceptance Criteria
Purpose

- To understand key concepts of measurement systems analysis
- To understand potential sources of measurement error and its affect on both process and part quality
Why Do We Care About Measurement Systems Analysis (MSA)?

• Ensures measurement is accurate and precise
• Eliminates false data that can impact decisions about the process
• Provides information about the gage(s) being used to evaluate our parts and processes
• Reduces risk in calling good parts bad (Type I Error)
  **Impacts internal throughput, scrap and rework
• Reduces risk in calling bad parts good (Type II Error)
  **Impacts customer
• Data you can trust = Good Decisions
Which line has less variation?

Line 1

Line 2
Which line has less variation?

Line 1

Line 2

Gage Variation

Total Variation
Which line has less variation?

Part Variation

Line 1

Line 2

Part Variation

Gage Variation

Total Variation

Line 2 has Less variation

Part Variation

Gage Variation

Total Variation (Observed)
Understanding Variation

What is the best course of action?
Assume the total observed variation is below 1.33 Ppk for an initial process study on a starred dimension (1.67 Ppk or greater required)

A. Measure a different sample of parts (Gather more data)
B. Investigate process changes to reduce process variation
C. Investigate gage changes to reduce measurement variation
How do you decide what to do?

• What are typical reactions to measuring a part out of tolerance?
  • Adjust processes / implement additional detection methods
  • Quarantine / Sort / Scrap parts
  • Review PFMEAs and Control Plans

• Before doing all this verify the measurement system
MSA Components

• What does a measurement system analysis consist of?
MSA Components

- Resolution (Discrimination)
- Accuracy
- Linearity
- Stability
- Repeatability (Test / Retest)
- Reproducibility
Sources of Variation

• Location of the Measurements
  • Accuracy / Bias
  • Stability
  • Linearity

• Variation of Measurement
  • Repeatability
  • Reproducibility

• Resolution / Discrimination

Each source of variation can result in incorrect measurements.
Resolution

- Can the gage detect change?
- Which logo below is larger?
- How is the measurement different?
Resolution - Response

- Select gages that have greater levels of discrimination (smaller increments)
- Record all measurement data, i.e. if a gage measures to 3 decimal points record all three
- As a general rule gage discrimination should be 1/10th of the product tolerance
  - Product tolerance: 0.100
  - Gage tolerance: 0.010 (Recommended minimum)
Accuracy

What is accuracy?

- The difference between the measured average value and the master value or the ‘Shift’ from ‘True’ value
- The master value needs to come from a traceable measurement source (ex. CMM)
- Although accuracy and bias are often used interchangeably it is best practice to refer to this difference in values as bias
Accuracy

- What is accuracy?

In this case the accuracy of the gage is ‘bias’ by 0.5 above the master.

Let’s assume the master value is 5.

Let’s also assume the average measurement is 5.5.

Master value (reference standard) Measured values
How to Determine Bias

• Take three samples
  • Ideally these samples would be at the high, middle and low ends of the process
• Determine the reference value for each sample using a traceable measurement method (CMM, calibrated height gage, etc.)
• Measure each sample at least 10 times. Calculate the average and subtract from the reference value
• Determine if the accuracy is acceptable or needs to be corrected
  • This is to be determined by the working team
Bias Example

Note: With multiple samples a linearity study may be completed.
Potential Bias Causes

- Gage needs calibration
- Worn gage, equipment or fixture
- Error in master part (worn or damaged)
- Improper setting of master in gage
- Differing measurement methods (set, loading, clamping, technique, etc.)
- Environment (temperature, humidity, vibration, cleanliness, etc.)
Bias - Response

• Increase calibration schedule
• Implement gage operating instructions
• Verify gage was made to correct specifications
• Check gage for wear
• Cleaning of gage
• Evaluate gage environment
Linearity

• What is linearity?
  • Linearity is the change in bias across the operating range of the gage
Linearity

(Difference between the measured average value and the master value)

No Bias
(Master value equals measured average value)

Note the bias and increasing variance
How to Determine Linearity

• Pick 5 parts covering the entire product tolerance
• Determine reference value of each part (ex. CMM)
• Measure each part 10 times or more and determine averages
• Subtract the average values from the determined reference values and decide if linearity is acceptable
Linearity Calculation (Minitab)

1. Enter Part Number, Measurement and Reference Value in the Worksheet


3. Fill in column ID’s for Part Number, Reference Values and Measurement Data. Don’t forget to fill in the Gage Info!
Linearity Analysis (Minitab)

This gage has little bias between 1.0 and 1.2

However, there is significant bias (P<0.05) at 1.31 and 1.35
Linearity - Acceptance Criteria

- Study must use 5 or more parts
- Parts must cover entire operating range of gage
- A p-value of less than 0.05 ($P<0.05$) indicates statistically significant bias
Linearity – Response

- Implement correction factor / table / curve
- Review gage and adjust
- Restrict use of range (Need to consider specification limits)
- Verify proper calibration (through entire operating range)
- Verify part / fixture is not distorted with change in part size
Linearity Question

Question: Is this linearity study acceptable?

A. Yes, all points are statistically acceptable across the range
B. No, at 1.355 there is significant bias
C. No, at 1.315 and 1.355 there is significant bias
D. There is no bias, this is a linearity study
Stability

• What is stability?
  • The variation in measurements obtained with the same master part(s) on a single feature over a period of time
  • Also known as ‘measurement drift’ and the ‘change in bias over time’
Measurement results are changing over time. Gage is not stable.
How to Determine Stability

• Select a master part
  • Part may be a reference part (master) or a production part
  • You can select multiple parts (low, middle and high end of expected range) and track stability for each

• Determine the reference value for each part via a master measurement method

• Measure each part 3 – 5 times at a chosen interval (daily, weekly, etc.)
  • Frequency should be determined based on knowledge of the gage. If frequency is unclear you should start at a high frequency and reduce over time as deemed acceptable.

• Plot the ongoing data on a Xbar & R chart
Stability – Potential Causes

- Calibration issues
- Gage wear
- Poor maintenance
- Master part damage / wear
Stability – Response

- Increase frequency of calibration
- Increase frequency of PM
- Change / Adjust gage
- Establish ‘life’ of gage or master part
Stability Question

Question: Assuming the same part was measured is this gage stable? Can this gage be used? Process tolerance is 9.0/6.0

A. Yes, the process is stable. Use the gage.
B. No, the gage is not stable. Do not use the gage.
C. No, the gage is not stable. Develop calibration schedule and use the gage.

The gage is not stable. Larger ‘jumps’ appear to happen every other day. The team should decide how often calibration should take place.
Precision

• What is precision?
  • According to AIAG it is “the net effect of discrimination, sensitivity and repeatability over the operating range of the measurement system.” (AIAG MSA Third Edition)

• So what does that mean?
  • Precision quantifies how close repeated measurements are to each other
Precision - Components

• **Repeatability**
  • Best known as within user variation
  • Also encompasses all ‘within’ variation
    • Within part
    • Within gage
    • Within standard
    • Within method
    • Within user
    • Within environment

• **Reproducibility**
  • Best known as between user variation
  • Also encompasses all ‘between’ variation
    • Between systems
    • Between conditions
    • Between methods
    • Between Environment
Precision - Components

Repeatability
(Within Variation)

Operator 1

Operator 2

Operator 3

Reproducibility
(Between Variation)
Variable Data GRR
Variable Data Gage R&R

How do you conduct a Variable Gage R&R?

1. Determine the need for the study. What do you want to accomplish?
   - %Study – For process control
   - %Tolerance – For product control

2. Determine specifics about the study (number of appraisers, number of trials, etc.)

3. Select appraisers
   - Appraisers should be selected that will used the gage in production

4. Select the sample parts to be used
   - Based upon chosen need from study
   - If for process control parts must be chosen from process range
Variable Data Gage R&R

5. Verify gage resolution is acceptable
6. Measure parts in **random** order to prevent ‘measurement memory’

7. The standard measurement process should be observed by all users (gage instructions)
8. The study should be observed by the engineer to ensure reliability of the data
Variable Data Gage R&R

General Rules

• Three appraisers
• Ten parts
• Three measurements per part per appraiser (Ninety total measurements)
• Parts should make use of the entire range of process variation
  • This does not mean the entire product tolerance
  • A capability study should accompany a completed GRR
• Parts should be collected over time
  • Parts collected in a row will usually have low between part variation
• Use ANOVA method if possible
• Xbar & R method does not account for operator interaction
• Report %Study or %Tolerance (whichever applies)
Variable GRR Calculation (Minitab)

1. Enter Appraiser, Part number and Measurement in the Worksheet


“Crossed” is when the same parts are used between trials

“Nested” is when different parts are used between trials
Variable GRR Calculation (Minitab)

Fill in part number, Operators and Measurement Data and select ANOVA

Complete Gage Info

Click Options
Variable GRR Calculation (Minitab)

Fill in upper and lower limits and include a title of the GRR

Click OK
Gage R&R (ANOVA) for IDC

Gage name: OGP FLASH
Date of study: 27 April 2012

Components of Variation

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<tr>
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<td>Part-to-Part</td>
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<td>9</td>
<td>10.95</td>
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<td>10</td>
<td>10.90</td>
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IDC by Operator

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<td>EB</td>
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<td>JC</td>
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Part * Operator Interaction

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<tr>
<td>10</td>
<td>10.90</td>
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Reported by: J Cole
Tolerance: 10.76 - 11.14
Misc:

Gage R&R (ANOVA) for IDC

- Components of Variation:
  - Gage R&R: 10%
  - Repeat: 9%
  - Reprod: 8%
  - Part-to-Part: 7%

- IDC by Part:
  - Part 1: 10.95
  - Part 2: 10.90
  - Part 3: 10.85
  - Part 4: 10.86
  - Part 5: 10.89

- IDC by Operator:
  - DK: blank
  - EB: blank
  - JC: blank

- Part * Operator Interaction:
  - Part 1: 10.86
  - Part 2: 10.92
  - Part 3: 10.89
  - Part 4: 10.92
  - Part 5: 10.90
  - Part 6: 10.90
  - Part 7: 10.90
  - Part 8: 10.95
  - Part 9: 10.90
  - Part 10: 10.90
Variable GRR - Analysis

Gage R&R (ANOVA) for IDC

- Gage name: OGP FLASH
- Date of study: 27 April 2012

Components of Variation

Pay attention to the overall sample range to understand ‘scale’ of error

Inside the Xbar r Chart control limits is the blind spot of the gage
Variable GRR - Analysis

Gage R&R (ANOVA) for IDC

Gage name: OGP FLASH
Date of study: 27 April 2012

Reported by: J Cole
Tolerance: 10.76 - 11.14
Misc:

Components of Variation

- % Contribution
- % Study Var
- % Tolerance

Part to part variation should be the largest contributor

R Chart should have all points in control. An out of control condition indicates poor repeatability

Xbar r Chart should be 50% out of control. This indicates each operator can tell a good part from a bad part

Want:
Small spread around mean
Similar mean and spread by operator
Lines to be close to being on top of each other
Variable GRR – Graphical Metrics

- Components of Variation
  - Indicates repeatability / reproducibility / parts
  - Want low Gage R&R, High part to part variation

- R Chart
  - Indicates repeatability / resolution
  - No outliers are permitted, helps to I.D. unusual measurements
  - Plateaus or steps indicate resolution limitation

- Xbar r Chart
  - Reproducibility / Sensitivity
  - Want to see similar patterns for each operator
Variable GRR – Numerical Metrics

Gage R&R Study - ANOVA Method

Gage R&R for IDC

Gage name: OGP FLASH
Date of study: 27 April 2012
Reported by: J Cole
Tolerance: 10.76 – 11.14
Misc:

Two-Way ANOVA Table With Interaction

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<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
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<tr>
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Alpha to remove interaction term = 0.25

Two-Way ANOVA Table Without Interaction

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Gage R&R

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<td>Total Variation</td>
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Process tolerance = 0.38

Study Var (6 * SD)

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<tr>
<th>Source</th>
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<th>%Study Var (SV)</th>
<th>%Tolerance (SV/Toler)</th>
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Number of Distinct Categories = 14

Report %Study or %Tolerance (Whatever applies) More on this later…
Variable GRR – Numerical Metrics

- %Study or %Tolerance should be below 10%
  - Between 10% and 30% may be acceptable
  - Above 30% is not acceptable
- Number of distinct categories must be at least 5
Why ANOVA?
Xbar/R GRR

### Components of Variation

- **% Contribution**
- **% Study Var**
- **% Tolerance**

### R Chart by Operator

- **Sample Range**
- **Average**

### IDC by Part

- **DK**
- **EB**
- **JC**

### Xbar Chart by Operator

- **Average**

### Table: Study Var & Tolerance

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<th>3(SD)</th>
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**Number of Distinct Categories = 8**
ANOVA GRR

Components of Variation

IDC by Part

R Chart by Operator

Xbar Chart by Operator

Part * Operator Interaction

Number of Distinct Categories: 3
Xbar/R & ANOVA Comparison

• The same data was used for both studies
• The only difference is method used to analyze the gage

• WHY?
• The Xbar/R method ignores operator to part interaction and as a result can appear to ‘boost’ gage performance
### Xbar/R & ANOVA Comparison

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<th>%Study Var</th>
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Number of Distinct Categories = 8

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<td>Part-To-Part</td>
<td>0.0255137</td>
<td>0.153082</td>
<td>92.87</td>
<td>40.28</td>
</tr>
<tr>
<td>Total Variation</td>
<td>0.0274731</td>
<td>0.164839</td>
<td>100.00</td>
<td>43.38</td>
</tr>
</tbody>
</table>

Number of Distinct Categories = 3

**Xbar/R Method**

- Operator interaction is ignored using the Xbar/R method

**ANOVA Method**

- Repeatability
  - Total Gage R&R
  - Repeatability
  - Reproducibility
  - Operator
  - Operator*Part
  - Part-To-Part
  - Total Variation

**Note:**
- The table shows the standard deviation, study variance, and percentage of variance for each category, along with the tolerance percentage.
Understanding %Tolerance

\[ \% \text{Tolerance} = \frac{6 \times \sigma_{R&R}}{\text{Tolerance}} \times 100 \]

- %Tolerance is the measurement error as a percent of the product specification (tolerance)
- %Tolerance determines if the gage can be used for product control (determining a good part from a bad)
- If the gage cannot pass %Tolerance it cannot determine if a part within specification
Understanding %Study

\[
\text{% Study Variation} = \frac{\sigma_{R&R}}{\sigma_{\text{TOTAL}}} \times 100
\]

- %Study is the measurement error as a percent of total variation (standard deviation)
- %Study determines if the gage can be used for process control
- If the gage cannot pass %Study it cannot distinguish one part from another within normal process variation or monitor process improvements / process changes
Specification vs. Total Variation
Outlier Effect on %Study

Adding an outlier will increase total variation

This will reduce the reported %Study and can make the gage look acceptable when it really isn’t

% Study Variation = \frac{\sigma_{R&R}}{\sigma_{TOTAL}} \times 100
Outlier Effect on %Tolerance

Adding an outlier will not affect %Tolerance

\[ \text{%Tolerance} = \frac{6 \times \sigma_{R&R}}{\text{Tolerance}} \times 100 \]

%Tolerance relies upon the USL-LSL in its calculation. An outlier does not affect the product specification.
Minimizing %Study by Part Selection

• %Study is heavily dependent on the parts selected for the study
• The more variation between parts selected for the study the lower %Study will be

• When selecting parts be sure to include parts across the entire process variation
  • Do not select parts outside of the process variation as this can mislead you to think the gage is better than it is
Part Selection for GRR

%Study is a measure of how well the gage sees inside the range of parts selected. Part selection is critical.

%Tolerance is not affected by part selection.
Confidence Interval and Distinct Categories

The actual size of a measured part can be anywhere within the confidence interval.

Confidence Interval

Measurement    Actual Size
Distinct Categories

\[
\text{Number of Distinct Categories} = \sqrt{2 \left( \frac{\sigma_{\text{ProcessOutput}}^2}{\sigma_{\text{R&R}}^2} \right)}
\]

- Distinct categories is the number of confidence intervals (divisions) that the measurement system can accurately measure across the process variation.
- Also known as effective resolution (not gage resolution)
Distinct Categories

- Number of distinct categories is an indication of how well a measurement system can detect product variation
- Used to establish if the measurement system has acceptable resolution (discrimination)
Confidence Interval and Distinct Categories

Confidence Interval surrounding a measurement

Number of Distinct Categories is roughly four

Looking at the measurements what is your estimate of the number of distinct categories?

Conceptually the number of distinct categories is equal to the number of confidence intervals that span the distribution.
When to Report %Tolerance

- There are cases when you want to report %Tolerance instead of %Study
  - When the manufacturing process is stable, in control, and...
  - When the parts selected for the GRR cover the entire range of process variation, and...
  - When the distribution is not close to the specification limits, and...
  - When the process is highly capable (Ppk>=2.5)
  - When the dimension is not a SC/CC/☆ and severity <8
What Does That Look Like?

Feature # 59: Ø48.42 - 48.52

**Xbar Chart**
- Sample Mean: UCL = 48.459167
- LCL = 48.455443

**R Chart**
- Sample Range: UCL = 0.00937
- LCL = 0

**Last 12 Subgroups**

**Capability Histogram**
- Specifications:
  - LSL = 48.42
  - USL = 48.52

**Normal Prob Plot**
- AD: 0.398, P: 0.350

**Capability Plot**

<table>
<thead>
<tr>
<th>Within</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>StDev</td>
<td>0.002150</td>
</tr>
<tr>
<td>Cp</td>
<td>7.75</td>
</tr>
<tr>
<td>Cpk</td>
<td>6.07</td>
</tr>
<tr>
<td>PPM</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specs</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPM</td>
</tr>
</tbody>
</table>
Troubleshooting Variable GRR

Repeatability Issues

• Verify / Review gage instructions
• Verify clamping sequence
• Verify part is not loose in gage
• Verify measuring location is the same between trials
• Verify sufficient gage resolution
• Verify maintenance schedule is sufficient
• Verify operator method does not vary
• Review environmental impact (heat, vibration, etc.)
Troubleshooting Variable GRR

Reproducibility Issues

- Verify / Review gage instructions
- Verify clamping sequence is the same
- Verify appraiser to appraiser methods are the same
- Appraiser ergonomics (size, strength, etc.)
- Review environmental impact (heat, vibration, etc.)
Reducing Variation – Multiple Readings

- If improving of gage instructions and appraiser training fail to provide an acceptable outcome you can use multiple readings to gain a better result.
- One drawback to this is that it can take significantly longer to conduct the study and this method will need to be used until further gage improvements can be made.
Reducing Variation – Multiple Readings

- Variation may be reduced by taking multiple measurements of a part and averaging the readings.
- This average can then be substituted for the individual measurement

\[
\text{Gauge Variation} = \sqrt{N}
\]

Where \( N = \text{Sample size} \)
Multiple Readings – Why?

Confidence Interval

Measurement

Actual Size

Average Measurement
### Multiple Readings - Example

#### %Contribution

<table>
<thead>
<tr>
<th>Source</th>
<th>VarComp (of VarComp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Gage R&amp;R</td>
<td>0.0002313</td>
</tr>
<tr>
<td>Repeatability</td>
<td>0.0002173</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>0.000140</td>
</tr>
<tr>
<td>Operator</td>
<td>0.000140</td>
</tr>
<tr>
<td>Part-To-Part</td>
<td>0.0022083</td>
</tr>
<tr>
<td>Total Variation</td>
<td>0.0024396</td>
</tr>
</tbody>
</table>

Process tolerance = 0.4

#### Study Var

<table>
<thead>
<tr>
<th>Source</th>
<th>StdDev (SD)</th>
<th>6 * SD</th>
<th>Study Var</th>
<th>%Study Var</th>
<th>%Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Gage R&amp;R</td>
<td>0.0152075</td>
<td>0.091245</td>
<td>30.79</td>
<td>22.81</td>
<td></td>
</tr>
<tr>
<td>Repeatability</td>
<td>0.0147414</td>
<td>0.088449</td>
<td>29.85</td>
<td>22.11</td>
<td></td>
</tr>
<tr>
<td>Reproducibility</td>
<td>0.0037359</td>
<td>0.022416</td>
<td>7.56</td>
<td>5.60</td>
<td></td>
</tr>
<tr>
<td>Operator</td>
<td>0.0037359</td>
<td>0.022416</td>
<td>7.56</td>
<td>5.60</td>
<td></td>
</tr>
<tr>
<td>Part-To-Part</td>
<td>0.0469928</td>
<td>0.281957</td>
<td>95.14</td>
<td>70.49</td>
<td></td>
</tr>
<tr>
<td>Total Variation</td>
<td>0.0493922</td>
<td>0.296353</td>
<td>100.00</td>
<td>74.09</td>
<td></td>
</tr>
</tbody>
</table>

Number of Distinct Categories = 4
## Multiple Readings - Example

<table>
<thead>
<tr>
<th>Source</th>
<th>VarComp (of VarComp)</th>
<th>%Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Gage R&amp;R</td>
<td>0.0000552</td>
<td>2.65</td>
</tr>
<tr>
<td>Repeatability</td>
<td>0.0000430</td>
<td>2.07</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>0.0000121</td>
<td>0.58</td>
</tr>
<tr>
<td>Operator</td>
<td>0.0000059</td>
<td>0.28</td>
</tr>
<tr>
<td>Operator*Part No</td>
<td>0.0000063</td>
<td>0.30</td>
</tr>
<tr>
<td>Part-To-Part</td>
<td>0.0020259</td>
<td>97.35</td>
</tr>
<tr>
<td>Total Variation</td>
<td>0.0020811</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Process tolerance = 0.4

<table>
<thead>
<tr>
<th>Source</th>
<th>StdDev (SD)</th>
<th>Study Var (6 * SD)</th>
<th>%Study Var (%SV)</th>
<th>%Tolerance (SV/Toler)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Gage R&amp;R</td>
<td>0.0074277</td>
<td>0.044566</td>
<td>16,28</td>
<td>11,14</td>
</tr>
<tr>
<td>Repeatability</td>
<td>0.0065591</td>
<td>0.039355</td>
<td>14,38</td>
<td>9,84</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>0.0034854</td>
<td>0.020913</td>
<td>7.64</td>
<td>5,23</td>
</tr>
<tr>
<td>Operator</td>
<td>0.0024191</td>
<td>0.014514</td>
<td>5.30</td>
<td>3,63</td>
</tr>
<tr>
<td>Operator*Part No</td>
<td>0.0025092</td>
<td>0.015055</td>
<td>5.50</td>
<td>3,76</td>
</tr>
<tr>
<td>Part-To-Part</td>
<td>0.0450103</td>
<td>0.270062</td>
<td>98,67</td>
<td>67,52</td>
</tr>
<tr>
<td>Total Variation</td>
<td>0.0456190</td>
<td>0.273714</td>
<td>100,00</td>
<td>68,43</td>
</tr>
</tbody>
</table>

Initial GRR (1 Measurement) | 30.79 %Study
Repeat GRR (5 Measurements) | 16.82 %Study

Five measurements were taken and averaged to help reduce variation

Number of Distinct Categories = 8
Attribute Data GRR
Attribute GRR

What is the goal of an attribute GRR?

- 100% match within and between operators measurement and the correct (master) attribute
- To have all Kappa values greater than 0.75
Attribute GRR

What you need

1. At least 50 parts
2. At least 3 appraisers
3. Each appraiser should measure each part 3 times
Attribute GRR Part Selection

- 25% close to the LSL
- 30% from normal process variation
- 25% close to the USL
- 10% outside of USL
- 10% outside of LSL
Attribute GRR

How to conduct an attribute GRR

1. Select parts for study (50 minimum)
2. Select appraisers for study (recommend 3)
3. Measure all 50 parts on a master measurement system (ex. CMM)
4. Build a master truth table
   This table lists the known disposition of each part (pass/fail) as well as associated variable data
Attribute GRR

5. Conduct the GRR study (Measure parts in random order, observe study while in progress.

6. Input data into Minitab

<table>
<thead>
<tr>
<th>Part S/N</th>
<th>Master Meas</th>
<th>Truth</th>
<th>Trial</th>
<th>Operator</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>4.350</td>
<td>P</td>
<td>1</td>
<td>1</td>
<td>P</td>
</tr>
<tr>
<td>15</td>
<td>4.342</td>
<td>P</td>
<td>1</td>
<td>1</td>
<td>P</td>
</tr>
<tr>
<td>16</td>
<td>4.258</td>
<td>P</td>
<td>1</td>
<td>1</td>
<td>P</td>
</tr>
<tr>
<td>17</td>
<td>4.325</td>
<td>P</td>
<td>1</td>
<td>1</td>
<td>P</td>
</tr>
</tbody>
</table>

Input part number, master measurement and truth

Input trial number, appraiser and outcome
Attribute GRR


Don’t forget to fill in the gage information!

If appraiser data is in multiple columns fill in here

Select the appropriate columns for each field.
Assessment Agreement - Attribute

Date of study: 03/20/2012
Reported by: Dan W.
Name of product: 19 - Alignment Pin Height
Misc: Less than 6.8mm

Within Appraisers

Appraiser vs Standard

How well each appraiser agrees with themself

How well each appraiser agrees with the truth
### Attribute Agreement Analysis for Pass/Fail

**Date of study:** 03/20/2012  
**Reported by:** D. W.  
**Name of product:** 19 - Alignment Pin Height  
**Misc:**

#### Within Appraisers

(Repeatability)

**Assessment Agreement**

<table>
<thead>
<tr>
<th>Appraiser</th>
<th># Inspected</th>
<th># Matched</th>
<th>Percent</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>50</td>
<td>100.00</td>
<td>(94.18, 100.00)</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>50</td>
<td>100.00</td>
<td>(94.18, 100.00)</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>50</td>
<td>100.00</td>
<td>(94.18, 100.00)</td>
</tr>
</tbody>
</table>

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

#### Fleiss’ Kappa Statistics

| Appraiser | Response | Kappa | SE Kappa | Z | P(>|Z|) |
|-----------|----------|-------|----------|---|---------|
| 1         | F        | 1     | 0.0816497| 12.2474 | 0.0000 |
| 2         | F        | 1     | 0.0816497| 12.2474 | 0.0000 |
| 3         | F        | 1     | 0.0816497| 12.2474 | 0.0000 |

### Each Appraiser vs Standard

#### Assessment Agreement

<table>
<thead>
<tr>
<th>Appraiser</th>
<th># Inspected</th>
<th># Matched</th>
<th>Percent</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>50</td>
<td>100.00</td>
<td>(94.18, 100.00)</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>50</td>
<td>100.00</td>
<td>(94.18, 100.00)</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>50</td>
<td>100.00</td>
<td>(94.18, 100.00)</td>
</tr>
</tbody>
</table>

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

#### Assessment Disagreement

<table>
<thead>
<tr>
<th>Appraiser</th>
<th># P / F</th>
<th>Percent</th>
<th># F / P</th>
<th>Percent</th>
<th># Mixed</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0.00</td>
<td>0</td>
<td>0.00</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0.00</td>
<td>0</td>
<td>0.00</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0.00</td>
<td>0</td>
<td>0.00</td>
<td>0</td>
<td>0.00</td>
</tr>
</tbody>
</table>

# P / F: Assessments across trials = P / standard = F.  
# F / P: Assessments across trials = F / standard = P.  
# Mixed: Assessments across trials are not identical.

#### Fleiss’ Kappa Statistics

| Appraiser | Response | Kappa | SE Kappa | Z | P(>|Z|) |
|-----------|----------|-------|----------|---|---------|
| 1         | F        | 1     | 0.0816497| 12.2474 | 0.0000 |
| 2         | F        | 1     | 0.0816497| 12.2474 | 0.0000 |
| 3         | F        | 1     | 0.0816497| 12.2474 | 0.0000 |

Kappa Values (Must be greater than 0.75)
### Between Appraisers

(Reproducibility)

**Assessment Agreement**

<table>
<thead>
<tr>
<th># Inspected</th>
<th># Matched</th>
<th>Percent</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>50</td>
<td>100.00</td>
<td>(94.18, 100.00)</td>
</tr>
</tbody>
</table>

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

**Fleiss' Kappa Statistics**

<table>
<thead>
<tr>
<th>Response</th>
<th>Kappa</th>
<th>SE Kappa</th>
<th>Z</th>
<th>P(vs &gt; 0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>1</td>
<td>0.0235702</td>
<td>42.4264</td>
<td>0.0000</td>
</tr>
<tr>
<td>P</td>
<td>1</td>
<td>0.0235702</td>
<td>42.4264</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

### All Appraisers vs Standard

**Assessment Agreement**

<table>
<thead>
<tr>
<th># Inspected</th>
<th># Matched</th>
<th>Percent</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>50</td>
<td>100.00</td>
<td>(94.18, 100.00)</td>
</tr>
</tbody>
</table>

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

**Fleiss' Kappa Statistics**

<table>
<thead>
<tr>
<th>Response</th>
<th>Kappa</th>
<th>SE Kappa</th>
<th>Z</th>
<th>P(vs &gt; 0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>1</td>
<td>0.0471405</td>
<td>21.2132</td>
<td>0.0000</td>
</tr>
<tr>
<td>P</td>
<td>1</td>
<td>0.0471405</td>
<td>21.2132</td>
<td>0.0000</td>
</tr>
</tbody>
</table>
Kappa Value

What is a kappa value?

• Fleiss’ kappa value is used to measure the level of agreement between two appraisers rating the same data set

\[
Kappa = \frac{P_{observed} - P_{chance}}{1 - P_{chance}}
\]

• This equation is comparing the proportion of agreement between appraisers after removing chance
Attribute Agreement

How many Kappa values are calculated?

• Within Appraiser
• Between Appraiser
• Each Appraiser to Standard
• All Appraisers to Standard

• All Kappa values must be greater than 0.75
Attribute GRR – More Info

• There is an alternate method for calculating Kappa values for different types of attribute data
  • Nominal – Information is qualitative, not quantitative
    • Go / No Go, Gender, Race
    • Use Fleiss’ Kappa Statistic
  • Ordinal – Higher number represent higher values. The zero point is chosen arbitrarily.
    • Casting porosity rating
    • Use Kendall’s Coefficient of Concordance
Guard Banding
Guard Banding – General Rules

- Guard banding is shrinking the product acceptance limits from the product tolerance.
- This can only be done if a gage has repeatability issues. It will do nothing to correct a reproducibility concern.
- Typically used when a product is not capable and the part is measured 100%.
Guard Banding – How to Implement

Let’s assume a gauge has 20% Tolerance Variation measurement error (GRR). What would you do?

Both the LSL and USL should be shrunk by 10% (toward nominal)
Acceptance Criteria - Summary

Resolution

• Gage should be $1/10^{th}$ of product tolerance
• Range charts with 5 or less possible values (steps) could be an indicator of inadequate resolution
• Range charts where 25% or more points have 0 range values indicates poor resolution

Linearity

• Must include 5 or more samples
• Parts selected must cover entire product tolerance
• All p-values should be greater than 0.05 (P>0.05)
Acceptance Criteria - Summary

Variable GRR

- 10% or less %Study with 5 or more distinct categories (10%-30% may be acceptable)
- 10% or less %Tolerance with 5 or more distinct categories (10%-30% may be acceptable)
- If reporting %Tolerance process must have high capability (ex Ppk>2.5), be stable and in control. Number of distinct categories is not used when reporting %Tolerance with a high capability process
- R-Charts should have all points within control limits
- Xbar charts should have more than 50% of points outside of control limits.
- Part to part variation should account for almost all of the variation in the study
Acceptance Criteria - Summary

Attribute GRR

- All Kappa values must be greater than 0.75
  - Within Appraiser
  - Between Appraiser
  - Each Appraiser to Standard
  - All Appraisers to Standard