MEASUREMENT SYSTEM ANALYSIS (MSA)

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WHAT IS MSA?

- A means to determine the percent of variation between operator, gauge, and process in a measuring procedure.
WHY?

- Variation exists in all measuring processes.
  - Operator performance will vary from day to day and operator to operator
  - Gauge may or may not be adequate for its intended use
  - Process may or may not be adequate for its intended use
FISHBONE EXERCISE

SWIPE

- Standard
- Workpiece
- Instrument
- Person/Process
- Environment
FISHBONE EXERCISE

Figure 2: Measurement System Variability Cause and Effect Diagram
BASICS

- Definition
  - Uncertainty
  - Discrimination
  - Linearity
  - Stability
  - True Value
  - Bias
  - Reference Value
  - Repeatability
  - Reproducibility
UNCERTAINTY

- Uncertainty is a quantified expression of measurement reliability that describes the range of a measurement result within a level of confidence.

- Estimating uncertainties is a vast subject which in itself can take quite a bit of effort to master. Suggested reading on this subject is ANSI/NCSL Z540.3 (appendix A is particularly helpful), and ISO/IEC Guide to the Expression of Uncertainty in Measurement (GUM). Also, the following documents can be found on the internet free of charge; NIST Technical Note 1297, EA 4/02, and M3003.
TYPE “A” AND TYPE “B”

- Type “A” uncertainties are quantified by statistic and include studies such as:
  - Accuracy
  - Linearity
  - Repeatability
  - Reproducibility

- Type “B” uncertainties **cannot** be evaluated by statistic and include:
  - Temperature
  - Errors
  - Fixture variation
  - Calibration
<table>
<thead>
<tr>
<th>Source</th>
<th>% Uncertainty</th>
<th>*Divisor</th>
<th>X</th>
<th>X²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeatability</td>
<td>1.3</td>
<td>1</td>
<td>1.3</td>
<td>1.69</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>4.02</td>
<td>1</td>
<td>4.02</td>
<td>16.1604</td>
</tr>
<tr>
<td>DUT Certification</td>
<td>.03</td>
<td>2</td>
<td>.015</td>
<td>.000225</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RSS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>**Expanded (K=2)</td>
</tr>
</tbody>
</table>
DISCRIMINATION (RESOLUTION)

- Smallest scale unit of measure for an instrument

- 10 to 1 rule +/- .005 inch?
  - .005/10 = .0005 inch
  - .005/4 = .00125 inch

- Requirement varies based on application
  - Cost of gage must be considered and weighed against ROI (Micrometer-$200, or optical comparator-$15,000)
    - Disposable toothbrushes – Airplane tires
DISCRIMINATION FOUND ON SPC RANGE CHART

Not recommended If:
3 or less values are displayed on the chart or
More that ¼ of the values are 0
NUMBER OF DISTINCT CATEGORIES

- This number represents the ability of your measurement device to segment the total range of values.

- AIAG recommends a minimum of 5 ndc

- If you require more ndc than the study determined
  - Run the study with more parts that represent the entire range
  - Improve the measurement tool to deliver more precision
NUMBER OF DISTINCT CATEGORIES

- There is a mathematic relation between ndc and % Total Variation
  - You will need less than approximately 27% Total Variation to have a minimum of 5 ndc
LINEARITY

- Collective variation over the range of measurement
  - If gage gains .1 inch per foot and you measure 6 inches then variation in linearity may be .05 of your range
  - This “may” be acceptable if tolerance is +/- 1 inch and total length measured is 6 inches.
  - This would not be acceptable if total length is over 10 feet
    \[ .1 \times 10 = 1 \]
LINEARITY STUDY

- Choose 5 parts representing the full range of values
- Determine each parts reference value
- Have best operator randomly measure each part 12 times
- Determine bias of each part
- Enter data in software to create linearity plot
LINEARITY PLOT

Linearity Example

\[ Y = 0.736667 - 0.131667X \]

R-Sq = 71.4 %

Figure 11: Linearity Study – Graphical Analysis
LINEARITY RESULTS

- Result is a linearity problem
- R-Sq is only 71.4\% (0 to 100\% - Larger better)
- Bias line intercepted by regression line (Unacceptable if significantly different than “0”)
- Distribution is bimodal (7 data points at value 4 & 6)
STABILITY (Drift)

- The change in the difference between measurement value and reference value over time
  - Electronic instruments may change over time due to the drifting of values
  - Operators may deviate in methods over time
  - Temperature may vary over time (or per day)
DETERMINING STABILITY

- Obtain a part to use as a master reference value
  - Can be done by averaging repetitive measurements of a master over time
  - Measure this master 5 times per shift over four weeks until at least 20 subgroups are obtained
- Plot the data on Xbar/R Chart
- Monitor using standard SPC analysis for special cause
DETERMINING STABILITY

Xbar/R Chart for Stability

Sample Mean

Subgroup

Sample Range

UCL=6.297

6.021

LCL=5.746

UCL=1.010

0.4779

LCL=0
REPEATABILITY

- Variation in measurements obtained with one measuring instrument when used several times by an operator while measuring the identical characteristic on the same part (AIAG).
  - Commonly referred to as Equipment Variation (E.V.)
  - Variation in the gage
POOR REPEATABILITY

- Part – Surface, position, consistency of part
- Instrument – Repair, wear, fixture, maintenance
- Standard – Quality, wear
- Method – Variation, technique
- Appraiser – Technique, experience, fatigue
- Environment – Temperature, humidity, vibration, lighting, cleanliness
- Assumptions – Stable
REPRODUCABILITY

- Variation in the average of the measurements made by different operators using the same gage when measuring a characteristic on one part
  - Commonly referred to as Appraiser variation (A.V.)
POOR REPRODUCABILITY

- Part – Between part variation
- Instrument – Between instrument variation
- Standard – Influence of different settings
- Method – Holding & clamping methods, zeroing
- Appraisers – Between appraiser variation, training, skill, experience
- Environment – Environmental cycles
- Assumptions – Stability of process
R & R ACCEPTABILITY

- Under 10% - Acceptable
- 10 – 30% - May be acceptable based on application
- Over 30% - Not acceptable
BIAS (ACCURACY)

- Bias is the difference between observed measurement and reference value (AIAG)
- True value is the actual value of the artifact
  - Unknown and unknowable
- Reference Value is the accepted value of an artifact
  - Artifacts or reference materials can be used to calibrate instruments or to validate measurement methods.
BIAS (ACCURACY)

• Possible causes
• Out of calibration
• Worn or damaged fixture, equipment, instrument
• Wrong gage
• Environmental conditions
• Operator skill level, performed wrong method
We received two complaints regarding the calculation used in this form.

### Gage R & R Study Worksheet

#### Part Number: 1.02

<table>
<thead>
<tr>
<th>Operator</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Trials</td>
<td>3</td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>

#### Operator A

<table>
<thead>
<tr>
<th>Trial</th>
<th>Part</th>
<th>Range</th>
<th>Average</th>
<th>Range</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.56</td>
<td>0.00</td>
<td>1.54</td>
<td>0.58</td>
<td>0.12</td>
</tr>
<tr>
<td>2</td>
<td>0.54</td>
<td>0.00</td>
<td>1.57</td>
<td>0.56</td>
<td>0.10</td>
</tr>
<tr>
<td>3</td>
<td>0.56</td>
<td>0.00</td>
<td>1.57</td>
<td>0.58</td>
<td>0.10</td>
</tr>
</tbody>
</table>

#### Operator B

<table>
<thead>
<tr>
<th>Trial</th>
<th>Part</th>
<th>Range</th>
<th>Average</th>
<th>Range</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.56</td>
<td>0.00</td>
<td>1.54</td>
<td>0.58</td>
<td>0.12</td>
</tr>
<tr>
<td>2</td>
<td>0.54</td>
<td>0.00</td>
<td>1.57</td>
<td>0.56</td>
<td>0.10</td>
</tr>
<tr>
<td>3</td>
<td>0.56</td>
<td>0.00</td>
<td>1.57</td>
<td>0.58</td>
<td>0.10</td>
</tr>
</tbody>
</table>

#### Operator C

<table>
<thead>
<tr>
<th>Trial</th>
<th>Part</th>
<th>Range</th>
<th>Average</th>
<th>Range</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.56</td>
<td>0.00</td>
<td>1.54</td>
<td>0.58</td>
<td>0.12</td>
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<tr>
<td>2</td>
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<td>0.00</td>
<td>1.57</td>
<td>0.56</td>
<td>0.10</td>
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<tr>
<td>3</td>
<td>0.56</td>
<td>0.00</td>
<td>1.57</td>
<td>0.58</td>
<td>0.10</td>
</tr>
</tbody>
</table>

### Notes

- No Operations: 3
- Tolerance: 1.02
- Number of Parts: 10

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http://thequalityportal.com/q_for ms.htm
**Jacket Line Measurement Analysis, ANOVA**

**Gage name:** Vision Microscope  
**Date of study:** 12-20-06

**Reported by:** Mike Parrillo  
**Tolerance:** +/- .001 inch  
**Misc:** Accuracy .0001 inch

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**Components of Variation**

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

---

**R Chart by Operator**

- **Harish**
- **Pankaj**
- **Pramod**

**Sample Range**

- **UCL = 0.001743**
- **R = 0.000533**
- **LCL = 0**

---

**Xbar Chart by Operator**

- **Harish**
- **Pankaj**
- **Pramod**

**Sample Mean**

**MSD = 0.001227**

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**Response by Part (Operator)**

- **Part Operator**

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**Response by Operator**

- **Part**
  - Harish
  - Pankaj
  - Pramod
Primary Line Measurement Analysis, ANOVA

Gage name: Vision Microscope
Date of study: 12-20-06

Components of Variation

<table>
<thead>
<tr>
<th>Percent</th>
<th>Gage R&amp;R</th>
<th>Repeat</th>
<th>Reprod</th>
<th>Part-to-Part</th>
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</thead>
<tbody>
<tr>
<td>100</td>
<td>10</td>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

% Contribution: % Study Var

R Chart by Operator

Sample Range

<table>
<thead>
<tr>
<th>Sample Range</th>
<th>Jay</th>
<th>Kirte</th>
<th>Nick</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0010</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

UCL=0.001307
\bar{R}=0.0004
LCL=0

Xbar Chart by Operator

Sample Mean

<table>
<thead>
<tr>
<th>Sample Mean</th>
<th>Jay</th>
<th>Kirte</th>
<th>Nick</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.020</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.016</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.012</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

UCL=0.01669
CL=0.01593
LCL=0.01318

Reported by: Mike Parrillo
Tolerance: +/- .001 inch
Misc: Accuracy .0001 inch
ATTRIBUTE STUDY

- A study comparing categories as opposed to measurements.
- Go/No Go gages, classifications such as good, fair, poor, unacceptable.
- Involves human judgment which may vary
ATTRIBUTE STUDY

- Collect minimum of 30 samples that span the entire range
- Determine reference value of each sample
- Have three operators measure each part 3x (Unaware of reference value, or part number). Total inspected 90
ATTRIBUTE STUDY

- Determine
  - How often did each appraiser pass the same part
  - How often did each appraiser fail the same part
  - How often did appraiser “A” pass and “B” fail
  - How often did appraiser “B” pass and “A” fail
  - Compare all appraisers in combinations (A & B, A & C, B & C)
- Determine expected CT/GT*RT (CT-Column Total, GT-Grand Total, RT-Row Total)
## ATTRIBUTE STUDY

<table>
<thead>
<tr>
<th>Appraiser “B”</th>
<th>Appraiser “A”</th>
<th>Pass</th>
<th>Fail</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Count</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pass</td>
<td></td>
<td>24</td>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.4</td>
<td>19.6</td>
<td>28</td>
</tr>
<tr>
<td>Fail</td>
<td></td>
<td>3</td>
<td>59</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18.6</td>
<td>43.4</td>
<td>90</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>27</td>
<td>63</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27</td>
<td>63</td>
<td>90</td>
</tr>
</tbody>
</table>
Cohen’s Kappa

- $P_{\text{observed}} - p_{\text{expected}}/1 - p_{\text{expected}}$
- From 0 to 1
  - 0 - no agreement
  - 1 - complete agreement
- .80 – 1 Very good
- .60 - .80 Good
- .40 - .60 Moderate
- .20 - .40 Fair
- > .20 Poor
Cohen’s Kappa

P observed (Agreement) = \((24 + 59)/90 = .922\)
P expected (Agreement) = \((8.4 + 43.9)/90 = .576\)
\(.922 - .576/1 - .576 = .82\)

- Calculate tables for each combination of appraisers.
- Calculate Cohen’s Kappa for each combination of appraisers.
- Review results and act appropriately
ATTRIBUTE STUDY

• If Cohen’s Kappa is under minimum requirement:
  • Appraiser – Interpretation, eyesight, skill level, method
  • Organization – Procedure, training, peer/management pressure, fatigue
Bibliography

- Minitab - Understanding "Number of distinct categories" in Gage R&R output - ID 276
- http://thequalityportal.com/q_forms.htm
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