Practical Tools for Measurement Systems Analysis

Created and presented by: Gabor Szabo
Practical Tools for Measurement Systems Analysis

Presentation Outline

• Conventional Gage R&R Metrics – basic familiarity assumed
• Thought process for Measurement Systems Analysis
• Practical approaches and tools
• Examples
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• Measurement Systems Analysis – Gage R&R
  • Assesses Repeatability and Reproducibility

• Metric-based way of drawing conclusions from Gage R&R Studies: percentages per AIAG MSA Handbook
  • %Study Variation: compares measurement system variation to overall variation (measurement system and part-to-part)
  • %Tolerance: compares measurement system variation to tolerance
  • Guidelines: 10/30% rule
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Measurement Systems Analysis Process

Decision
1. Results satisfactory – use measurement system as is
2. Collect more data
3. Make improvements to current system based on findings

- Define scope
- Measurement application
- Sample selection strategy
- Strategy for appraisers
- Define execution plan
- Data collection plan
- Assessment criteria

- Study results
- Assess if results are in line with expectations

- Execute study based on plan
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• “PGA” Approach
  • Practical
  • Graphical
  • Analytical
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Practical

• Going into the study: what is the purpose of the measurement?
  • How big of a difference am I trying to detect? “Signal to Noise”
  • What are my specification limits? Where is my process running?
• Is there anything about the raw data that visually stands out?
Graphical

• Graphical look
• Is there anything about the data that graphically stands out?
• Chart study results and look for clues – shifts, drifts, patterns, special causes etc.
Analytical

- This should be the last step of your analysis
- Be careful about what you choose to be the metric of the analysis
Example of PGA Approach: Gage R&R for optical wall thickness measurement

- Optical measurement
- Extruded components
- Specification: .012”-.013”
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### Practical

### Visual – Raw data

<table>
<thead>
<tr>
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Specification: .012”-.013”
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Graphical

Tool: Multi-Vari Chart

- Ability to compare variation across factors
- Bottom-up
- Ability to look for patterns in the data

Multi-Vari Chart for WT by Trial - Operator

Panel variable: Operator

Are these special causes?
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Graphical & Analytical I.

Tool: Xbar-R behavior chart

• Charts staged by operator

\[
\begin{align*}
UCL_R &= D_4 \times \bar{R} \\
LCL_R &= D_3 \times \bar{R}
\end{align*}
\]

\[
\begin{align*}
UCL_X &= \bar{X} + A_2 \times \bar{R} \\
LCL_X &= \bar{X} - A_2 \times \bar{R}
\end{align*}
\]

• Xbar chart shows repeatability vs. part-to-part variation

No special causes present
Graphical & Analytical II.

Tool: Xbar-R behavior chart

- Rbar: represents average repeatability error
- Ranges above control limit on R chart need to be investigated

Graphical – Multi-Vari Chart
Making a Decision

Scenario #1

Process running close to LSL causing yield issues. Engineer identifies critical process parameters and decides to run a DOE to bring process to nominal

- How big of a difference do you want to be able to detect?
- $Rbar = 0.0000567\,"$
- Is the measurement system acceptable for this scenario?
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Making a Decision

Scenario #2

Process running close to LSL causing yield issues. Engineer decides to perform 100% sorting

- What is the purpose of the inspection?
- Rbar = 0.0000567"
- %Tolerance = 25.53%Tol.
  - Repeatability = 20.85%Tol.
  - Reproducibility = 14.73%Tol.
- Is the measurement system acceptable for this scenario?
- What is the risk the engineer is running?
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Risk-Based Approach

- Risk of product misclassification
  - Good $\rightarrow$ Bad
  - Bad $\rightarrow$ Good

- The closer you are to the specification limits, the higher the risk of misclassification

- How does one quantify the risk of misclassification?
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Gage Performance Curve

- Visualizes and quantifies risk of misclassification
- Plotted for individual reference values covering the entire tolerance range and outside of it
- Uses Gage R&R results (StDev) and Z score-based probability calculations to quantify risk

Formula: 

\[ P_a = \phi \left( \frac{UL - (X_T + b)}{\sigma} \right) - \phi \left( \frac{LL - (X_T + b)}{\sigma} \right) \]

Gage Performance Curve

<table>
<thead>
<tr>
<th>Measurement System Variation</th>
<th>Value</th>
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<tbody>
<tr>
<td>LSL</td>
<td>0.455</td>
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<tr>
<td>USL</td>
<td>0.655</td>
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<tr>
<td>Sigma Interval</td>
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<tr>
<td>StdevGRR</td>
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<tr>
<td>Variance</td>
<td>0.000225</td>
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<tr>
<td>%Tolerance</td>
<td>42.15%</td>
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</tbody>
</table>

Probability of acceptance (Pa) – probability of measurements falling inside spec limits – calc. using Z scores*

Probability of acceptance (Pa) curve. Ideally, Pa should be as close to 1 as possible inside the specification, and as close to 0 as possible outside of it.

Measurement System Variation spread (StDev). Expected range of measurement variation for a reference value.

Measurement System Variation (GR&R)
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Gage Performance Curve

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<td>Variance</td>
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</tr>
<tr>
<td>%Tolerance</td>
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</tr>
</tbody>
</table>

How do you address the risk of misclassification?
through Guard Banding

Shaded area corresponds to Pa value of 0.5 for mean reference value
Shaded area corresponds to Pa value of 0.94 for mean reference value
Guard Banding

- Guard band applied around specification limits
- Guard band width a fraction of measurement system variation

Guard Banding Excel Tool – email me at gabor.attila.szabo@gmail.com to get a copy

<table>
<thead>
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<th>Guard Banding</th>
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<td>Guard banded USL</td>
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Examples

#1

Is there anything about the charted data that stands out?

Next slide
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Examples

#1

- R chart: none of the ranges appear to be above the UCL
- Repeatability error exceeds part-to-part variation

Next steps:
- Investigate and eliminate special causes
- Assess whether further reduction of repeatability error is necessary
Examples

#2

Is there anything about the charted data that stands out?
Examples

#2

- Resolution issue
- One of the operators (TN) rounded/truncated their measurement results

Next steps:
- Re-do study without rounding measurements
- Re-evaluate results
Is there anything about the raw data that stands out?

<table>
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Examples

#3

Is there anything about the charted data that stands out?

- R chart: none of the ranges appear to be above the UCL
- Repeatability error does not exceed part-to-part variation
Is there anything about the charted data that stands out?

- Decreasing pattern trial-to-trial

Next steps:
- Investigate the physics of the measurement or manufacturing process
- Investigate potential root causes
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Takeaways

• Don’t rely solely on your conventional Gage R&R metrics to tell you how your measurement system is behaving
• Use the Practical-Graphical-Analytical (PGA) approach to study your measurement systems analysis result, look for patterns and take action based on findings
• Quantify risks associated with measurement error

Feel free to reach out with any questions!
Gabor Szabo, CQE, CMQ/OE
(626) 733-5279
gabor.atttila.szabo@gmail.com