Introduction to Gage R&R Studies
The Key to Understanding Measurement Systems

By
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Speakers

- Hank Scutoski
  - VP Quality
  - 30 Years Experience
  - TI, Motorola, Cerprobe
  - Motorola University’s
    Six Sigma Research Institute
  - Certified Quality Engineer
  - Certified Quality Auditor

- Chander Sekar, Ph.D.
  - Corporate Statistician
  - 23 Years Experience
  - Professor of Statistics at
    the University of
    Madras, India
  - 3 Degrees in Statistics
  - Certified Quality Engineer
We must determine the uncertainty of our measurement systems before we can compare, control or optimize our manufacturing processes.
85 Studies to Date Including:

- Tip Diameter
- Tip Length
- Contact Force
- Probe Tip Alignment
- Planarity
- Contact Resistance
- Leakage
Benefits

- Validates consistent results between:
  - Cerprobe’s many manufacturing facilities
  - Cerprobe & customer sites

- Provides for “Dock to Stock” certification

- Provides feedback to Cerprobe’s suppliers.

- Able to provide customer with quality products with statistical consulting support.
Statistical Applications

- Gage R&R
  - Comparison of Metrology Tools
  - Design of Experiments
- SPC
- Scientific Guard Banding
Gage Repeatability

- The variation obtained from **one gage** and **one operator** when measuring the **same part** several times.

- Machine Variation

- Only Applies to ATE

\[
\text{Precision}_R = \text{Diameter} = 6 \text{ Std Dev}
\]

- Diagram showing the relationship between measurements and true value.
Gage Reproducibility

- The difference in the average of the measurements made by **different** operators using the **same** gage when measuring the **same** part.

- Operator-to-Operator Variation
No. of Operators: 3
No. of Parts: 32
No. of Trials: 3
No. of Operators: 3
No. of Parts: 32
No. of Trials: 3
Study #3

R&R Summary Plot

Video System

Operators

Deviation from Average

-0.00030
-0.00025
-0.00020
-0.00015
-0.00010
-0.00005
0.00000
0.00005
0.00010
0.00015
0.00020
0.00025
0.00030
Total Variation

- Process Variation
- Gage Variation
  - Repeatability
  - Reproducibility
Repeatability

Note:  
- One Gage
- 1 Operator
- Repeated Measurements
Reproducibility

Note:
- One Gage
- 2 Operators
- Repeated Measurements
- One Part
Measurement System Capability

- Precision-to-Tolerance Ratio (P/T)

  \[ P/T < 0.1 \quad \text{Acceptable System} \]

  \[ 0.1 < P/T < 0.3 \quad \text{Marginally Acceptable System} \]

  \[ P/T > 0.3 \quad \text{Unacceptable System} \]

Ref.: SEMATECH: Introduction to Measurement Capability Analysis

#91090709A-ENG
**Interpretation of P/T Ratios**

\[ P/T = 0.1 \]

* Measurement system consumes 10% of tolerance

* Effect of T on P/T

\[
\begin{align*}
P &= 1.2 & P &= 1.2 \\
T &= 4.0 & T &= 3.0 \\
P/T &= 0.3 & P/T &= 0.4
\end{align*}
\]
Repeatability Study

- Single operator performs multiple trials
- No change in the setup between trials
- Provides a quick estimate of measurement capability
- $P_{R/T}$
### Repeatability Study - Data

<table>
<thead>
<tr>
<th>Trial #1</th>
<th>Trial #2</th>
<th>Trial #3</th>
<th>Trial #4</th>
<th>Trial #5</th>
<th>S</th>
<th>R</th>
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<tbody>
<tr>
<td>0.0170</td>
<td>0.0180</td>
<td>0.0190</td>
<td>0.0070</td>
<td>0.0930</td>
<td>0.0351</td>
<td>0.0860</td>
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<td>0.1630</td>
<td>0.1540</td>
<td>0.1340</td>
<td>0.0297</td>
<td>0.0750</td>
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<tr>
<td>0.0790</td>
<td>0.1170</td>
<td>0.0600</td>
<td>0.0880</td>
<td>0.0970</td>
<td>0.0211</td>
<td>0.0570</td>
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<td>0.0770</td>
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<td>0.0820</td>
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<td>0.0322</td>
<td>0.0630</td>
</tr>
<tr>
<td>0.0840</td>
<td>0.0300</td>
<td>0.0730</td>
<td>0.0780</td>
<td>0.0240</td>
<td>0.0285</td>
<td>0.0600</td>
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<td>0.0299</td>
<td>0.0670</td>
</tr>
</tbody>
</table>

S: Standard Deviation  R: Range
Repeatability Study

P/T Calculations

\[ \frac{P_{R/T}}{T} = 6 \cdot \frac{\bar{R}}{d_2} \div (USL - LSL) \]
Gage R&R Study

- Involves multiple operators and trials
- Total tear down of the setup between trials
- Provides separate estimates of repeatability and reproducibility
- $P_{R&R}/T$
### Gage R&R Study - Data

<table>
<thead>
<tr>
<th>O1-T1</th>
<th>O1-T2</th>
<th>O1-T3</th>
<th>O2-T1</th>
<th>O2-T2</th>
<th>O2-T3</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.0050</td>
<td>0.0360</td>
<td>0.0330</td>
<td>0.0040</td>
<td>-0.0070</td>
<td>-0.0420</td>
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<tr>
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<tr>
<td>0.0070</td>
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<td>0.0090</td>
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<td>-0.0040</td>
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<td>-0.0820</td>
<td>-0.1060</td>
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<tr>
<td>-0.0620</td>
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<td>-0.1010</td>
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<td>-0.1290</td>
<td>-0.0900</td>
<td>-0.1650</td>
<td>-0.1780</td>
</tr>
</tbody>
</table>

O1, O2 - Operators 1 and 2  
T1, T2, T3 - Trials 1, 2 and 3
Gage R&R Study

- Repeatability
- Reproducibility
- Operator-Part Interaction
- Part-to-Part Variation
Operator-to-Part Interaction

- Significant Operator-to-Part Interaction
  - Bad Gage
  - Poor Operator Training
  - Improper Measurement Study Procedure
Data Analysis Methods

- Average Range Method
- Analysis of Variance (ANOVA) Method
Gage R&R Study

P/T Calculations

\[ \frac{P_{R&R}}{T} = 6 \times \frac{(R&R \text{ Sigma})}{(USL - LSL)} \]
Road Map to Success

Microscope
P/T 0.80

Video
P/T 0.23

Interaction with Suppliers
Feedback to Operators
Robust Data Collection
Advanced Statistical Techniques

Consistent Product Quality