Implementing an Expanded Gage R&R in Industrial Applications

Louis A. Johnson
Sr Training Specialist & Mentor
Minitab Inc

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Who’s using Expanded Gage R&R Studies?

- Coating Density
- Time to Gel
- Coating Thickness
- Gel Penetration
- Surface Roughness
- Fiber Density
- Pump Flow
- Voltage
- Capacitance
- Wind Direction
- Bolt Torque
- Peak Height
- Elasticity - Memory
- Flatness
Implementing an Expanded Gage R&R in Industrial Applications

Agenda:

- Expanded Gage R&R vs Standard Gage R&R
- NRG Renewable Systems – Demonstrating Capability
  - Estimates of Measurement System Capability
  - Wind Direction Expanded Gage R&R
  - Percent Tolerance Calculation
- Momentive Silicones – Comparing Gage Systems
  - Random vs Fixed Factors
  - Durometer Expanded Gage R&R
  - Measurement System Variability Comparison
- Restek Corporation – Exploring Sources of Variability
  - Determining an Efficient Sampling Plan
  - Chromatography Peak Height Expanded Gage R&R
  - Process Variability Reduction
- Questions & Discussion
All industrial experiments, results and scenarios are based on the authors’ actual experiences. Data units, variable names, etc. have been changed for demonstration purposes only.
Standard Gage R&R Study

Overall Process Variation

1. Part-to-Part Variation
2. Within Gage Variation (Repeatability)
3. Oper-to-Oper Variation
4. Operator * Part Interaction

Measurement System Variation

Variation due to the Measurement Procedure (Reproducibility)
Overall Process Variation

Part-to-Part Variation

Within Gage Variation

Gage to Gage Variation

Part * Gage Interaction

Variation due to Measurement Procedure

Operator * Gage Interaction

Oper-to-Oper Variation

Operator * Part Interaction

(Repeatability) ← (Gage Variation) → (Reproducibility)
NRG Systems built six gages to enable monitoring of their turbine control products to tight specifications. Their goal was to determine the capability of the measurement system as well as the major sources of variation.

Founded in 1982, NRG Systems manufactures products that help customers measure and better understand the renewable energy resources that serve the wind and solar energy industries. Their customers range from turbine manufacturers to electric utilities and renewable energy researchers.
Sampling Plan for NRG Systems Study

- 10 sensors are randomly selected to represent the typical process
- 2 operators are randomly selected
- 6 gages represent a random sample of all possible gages
- Each operator will measure each sensor with each gage twice

10 Parts X 2 Operators X 6 Gages X 2 Replicates
Analysis with Missing Data

Missing data prevents the analysis of a standard study dataset.

Missing data in an expanded study is automatically accounted for in the expanded study analysis.
### Expanded Gage R&R: Directional Current-Results

**Table 2. - Variance Components and Percent Contribution**

<table>
<thead>
<tr>
<th>Source</th>
<th>Variance Component</th>
<th>%Contribution (of Variance Component)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Gage R&amp;R</td>
<td>0.0027380</td>
<td>8.76</td>
</tr>
<tr>
<td><strong>Repeatability</strong></td>
<td>0.0006975</td>
<td>2.23</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>0.0020405</td>
<td>6.53</td>
</tr>
<tr>
<td>Operator</td>
<td>0.0000582</td>
<td>0.19</td>
</tr>
<tr>
<td><strong>Gage</strong></td>
<td>0.0018313</td>
<td>5.86</td>
</tr>
<tr>
<td>Sensor*Operator</td>
<td>0.000000</td>
<td>0.00</td>
</tr>
<tr>
<td>Sensor*Gage</td>
<td>0.0000453</td>
<td>0.14</td>
</tr>
<tr>
<td>Operator*Gage</td>
<td>0.0001057</td>
<td>0.34</td>
</tr>
<tr>
<td>Part-To-Part</td>
<td>0.0285278</td>
<td>91.24</td>
</tr>
<tr>
<td>Sensor</td>
<td>0.0285278</td>
<td>91.24</td>
</tr>
<tr>
<td>Total Variation</td>
<td>0.0312658</td>
<td>100.00</td>
</tr>
</tbody>
</table>

- Gage-to-Gage (Meter) variability is the strongest contributor to the measurement variation at 5.86%.
- The Repeatability of the gage is the second strongest contributor to the measurement variation at 2.23%.
The Gage Variation between the 6 gages is shown here. Variability between gages was much larger than between operators.
Estimates of Measurement System Capability

\[
\sigma^2_{Total} = \sigma^2_P + \left( \left( \sigma^2_O + \sigma^2_{PO} \right) + \sigma^2_e \right)
\]

\[
\sigma^2_{Total} = \sigma^2_P + \left( \sigma^2_{repeatability} + \sigma^2_{reproducibility} \right)
\]

\[
\sigma^2_{Total} = \sigma^2_P + \sigma^2_{measurement}
\]

\[
\% Study Variation = \frac{\sigma_{measurement}}{\sigma_{total}} \times 100\%
\]

\[
\% Tolerance = \frac{6 \times \sigma_{measurement}}{USL - LSL} \times 100\%
\]

\[
\% Process Variation = \frac{\sigma_{measurement}}{\sigma_{Historical}} \times 100\%
\]
Calculation of Measurement System Capability

\[ \%Tolerance = \frac{6 \times \sigma_{measurement}}{USL - LSL} \times 100\% \]

\[ \frac{6 \times \sqrt{(.002738)}}{(6 - 4) \text{ m-amp}} \times 100 = 15.7\% \]

% Tolerance Guidelines by AIAG

- Less than 10% – the measurement system is good to determine if parts are in specification.
- Between 10% and 30% – the measurement system is acceptable depending on the application.
- Greater than 30% – the measurement system is unacceptable and should be improved.
Application 2 – Comparing Measurement Systems

For more than 35 years, Momentive’s advanced silicone technology has been helping to provide long-lasting protection to the solar arrays of satellites in space and now in solar panels, hydro generating stations and windmills on earth, even under harsh weather conditions.

Measurement variation can’t be allowed to interfere with meeting exact durometer requirements. Is the automated system worth the cost and time?
Random vs Fixed Factors in Expanded Gage R&R

**Random Factor** – the operators, gages or parts tested are considered random samples from a normal population. The goal is to estimate the size of the variation caused by the factor.

**Fixed Factor** – the operators, gages or parts tested are the levels specifically of interest. The goal is to compare the mean response at the levels of the fixed variable.
Durometer Expanded Gage R&R – Sampling Plan

Manual Gage  X 10 Parts X 3 Operators X Repeats

Auto Gage  X 10 Parts X 3 Operators X Repeats

Screenshot of Minitab software for Gage R&R Study (Expanded)
## Expanded Gage R&R: Durometer - Results

### ANOVA Table with All Terms

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part</td>
<td>9</td>
<td>34.1400</td>
<td>34.1400</td>
<td>3.7933</td>
<td>56.25</td>
<td>0.000</td>
</tr>
<tr>
<td>Operator</td>
<td>2</td>
<td>2.7036</td>
<td>2.7036</td>
<td>1.3518</td>
<td>0.55</td>
<td>0.644</td>
</tr>
<tr>
<td>Gage</td>
<td>1</td>
<td>42.1610</td>
<td>42.1610</td>
<td>42.1610</td>
<td>17.04</td>
<td>0.052</td>
</tr>
<tr>
<td>Part*Operator</td>
<td>18</td>
<td>0.8220</td>
<td>0.8220</td>
<td>0.0457</td>
<td>0.76</td>
<td>0.738</td>
</tr>
<tr>
<td>Part*Gage</td>
<td>9</td>
<td>0.7333</td>
<td>0.7333</td>
<td>0.0815</td>
<td>1.36</td>
<td>0.210</td>
</tr>
<tr>
<td>Operator*Gage</td>
<td>2</td>
<td>4.9055</td>
<td>4.9055</td>
<td>2.4527</td>
<td>41.08</td>
<td>0.000</td>
</tr>
<tr>
<td>Repeatability</td>
<td>138</td>
<td>8.2396</td>
<td>8.2396</td>
<td>0.0597</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>179</td>
<td>93.7049</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- The average reading is different between the Manual gage and the Auto gage. They are calibrated differently.
- The difference between the two gages is consistent among the 10 parts used in the study.
- The difference between the two gages is not consistent among the three operators used in the study.
The average measurement is different between the two gages. They are calibrated differently.
The difference between the two gages is not the same for each of the operators. There is an Operator X Gage interaction.
## Comparison of Variation of the Two Gage Systems

<table>
<thead>
<tr>
<th>Source</th>
<th>StdDev</th>
<th>(6 × SD)</th>
<th>(%Study Var)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Gage R&amp;R</td>
<td>0.124145</td>
<td>0.74487</td>
<td>25.92</td>
</tr>
<tr>
<td>Repeatability</td>
<td>0.070683</td>
<td>0.42410</td>
<td>14.76</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>0.102058</td>
<td>0.61235</td>
<td>21.31</td>
</tr>
<tr>
<td>Operator</td>
<td>0.102058</td>
<td>0.61235</td>
<td>21.31</td>
</tr>
<tr>
<td>Part-To-Part</td>
<td>0.462551</td>
<td>2.77530</td>
<td>96.58</td>
</tr>
<tr>
<td>Total Variation</td>
<td>0.478921</td>
<td>2.87352</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Number of Distinct Categories = 5

<table>
<thead>
<tr>
<th>Source</th>
<th>StdDev</th>
<th>(6 × SD)</th>
<th>(%Study Var)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Gage R&amp;R</td>
<td>0.472978</td>
<td>2.83787</td>
<td>72.35</td>
</tr>
<tr>
<td>Repeatability</td>
<td>0.333434</td>
<td>2.00060</td>
<td>51.00</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>0.335455</td>
<td>2.01273</td>
<td>51.31</td>
</tr>
<tr>
<td>Operator</td>
<td>0.335455</td>
<td>2.01273</td>
<td>51.31</td>
</tr>
<tr>
<td>Part-To-Part</td>
<td>0.451301</td>
<td>2.70780</td>
<td>69.03</td>
</tr>
<tr>
<td>Total Variation</td>
<td>0.653744</td>
<td>3.92246</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Number of Distinct Categories = 1
The variability and therefore the % Tolerance for the Manual gage is more than double that of the Auto gage.
Chromatography columns are used to analyze trace amounts of fragrances, pesticides, flavorings, residue, pharmaceuticals and many other chemicals used by companies around the world.
Problem: A column has just been measured out-of-spec

- Issue with the measurement technician?
- Instrument issue?
- Bad column?
- Within-gage variation?

Which of these potential issues is most likely the problem?
What Measurement Sampling Plan Works Best?

- Repeatability >>> replicating Operator/Gage/Part combinations
- Operator, Gage and Part Variation >>> measuring different operators, parts and gages

Replicates Required to Estimate Repeatability

Roughly 35 to 45 degrees of freedom are required to estimate repeatability within +/- 20% of the true value.

How many Operators & Gages to Sample?

1) Save runs by not sampling 10 Parts
2) Increasing the # of Operators/Gages will decrease the Margin of Error
Expanded Gage R&R: Chromatography Peak Height

- 4 columns used to run the four meters and techs in parallel
- 2 replicates

<table>
<thead>
<tr>
<th>4 Chromatographs (Gage)</th>
<th>4 Techs (Operator)</th>
<th>4 Columns (Part)</th>
</tr>
</thead>
</table>

4 columns used to run the four meters and techs in parallel.
% Tolerance of 47% indicates that there is too much variability to use this system to measure columns against the customer spec.

The Repeatability of the gage is a strong contributor to the overall variation.

Gage-to-Gage (Meter) variability is also a strong contributor.
The Meter variation is larger than variation due to Technician.
Expanded Gage R&R: Peak Height - Implement Results

Based on the results of the Measurement Study

- All gages calibrated to the same standard column.
- Modifications to the instruments to improve repeatability.
- Automated injection was lowered in priority.

Project results:

- 60% drop in first pass reject columns
- Increased QA capacity (previously a bottleneck)
- Decreased measurement costs
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References


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Louis A. Johnson - ljohnson@minitab.com
Cheryl Pammer – cpammer@minitab.com

Thank you for your time and participation. Questions?