# Measurement Systems Analysis

## *MSA for Suppliers*

# MSA Objective

Raytheon
Customer Success Is Our Mission

Qualification of a measurement system for use by quantifying its accuracy, precision, and stability

- Understand the quality characteristics of measurement
- Understand the method for establishing measurement capability
- Define the requirements of the measurement system

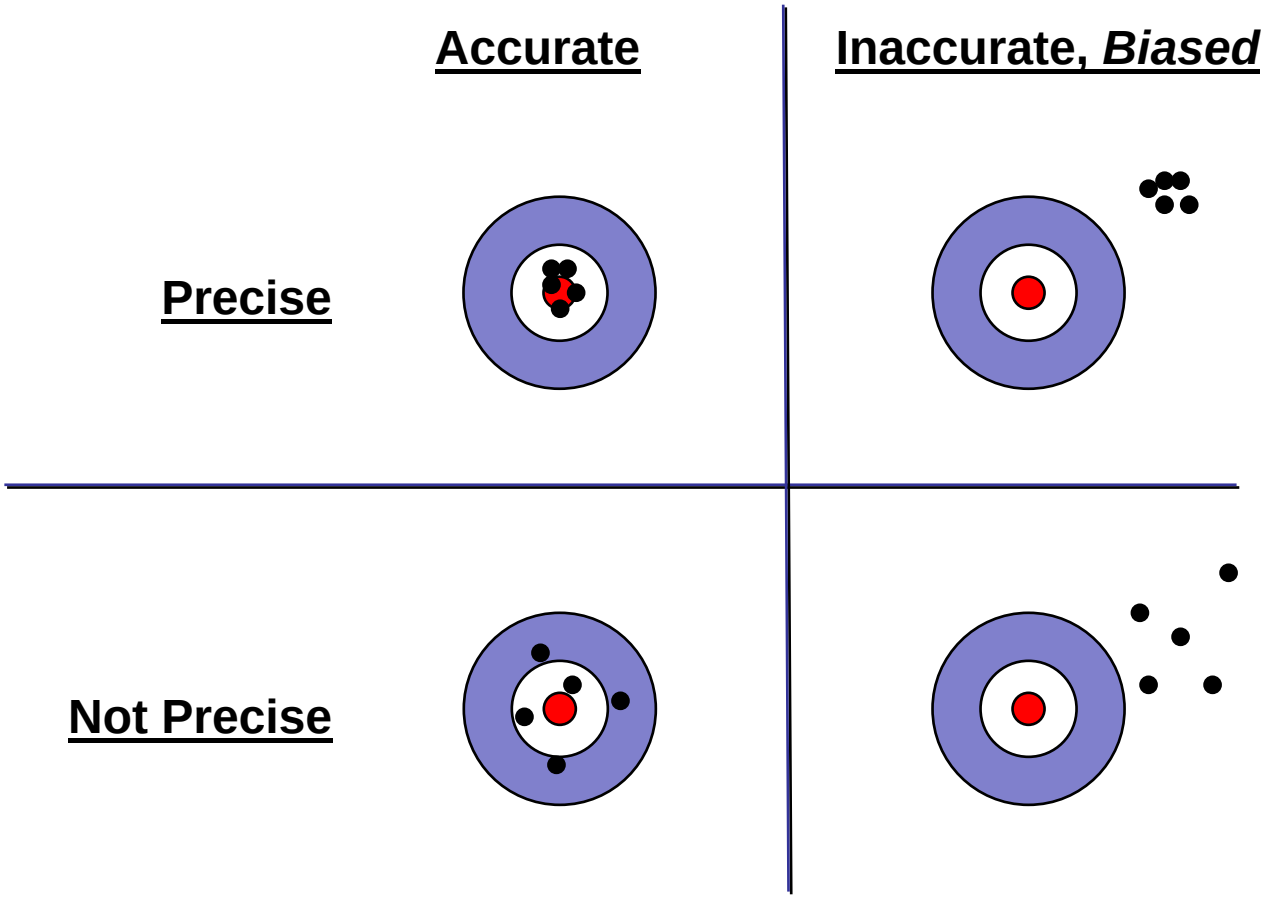




R6σ Raytheon Six Sigma

# The Importance of Good Measurement

Raytheon
Customer Success Is Our Mission




*You cannot improve what you cannot measure*





R6σ Raytheon Six Sigma

# The Qualities of Measurement

Raytheon
Customer Success Is Our Mission

- Resolution
- Accuracy (Bias)
- Linearity
- Repeatability
- Reproducibility
- Stability





R6σ Raytheon Six Sigma

# Resolution



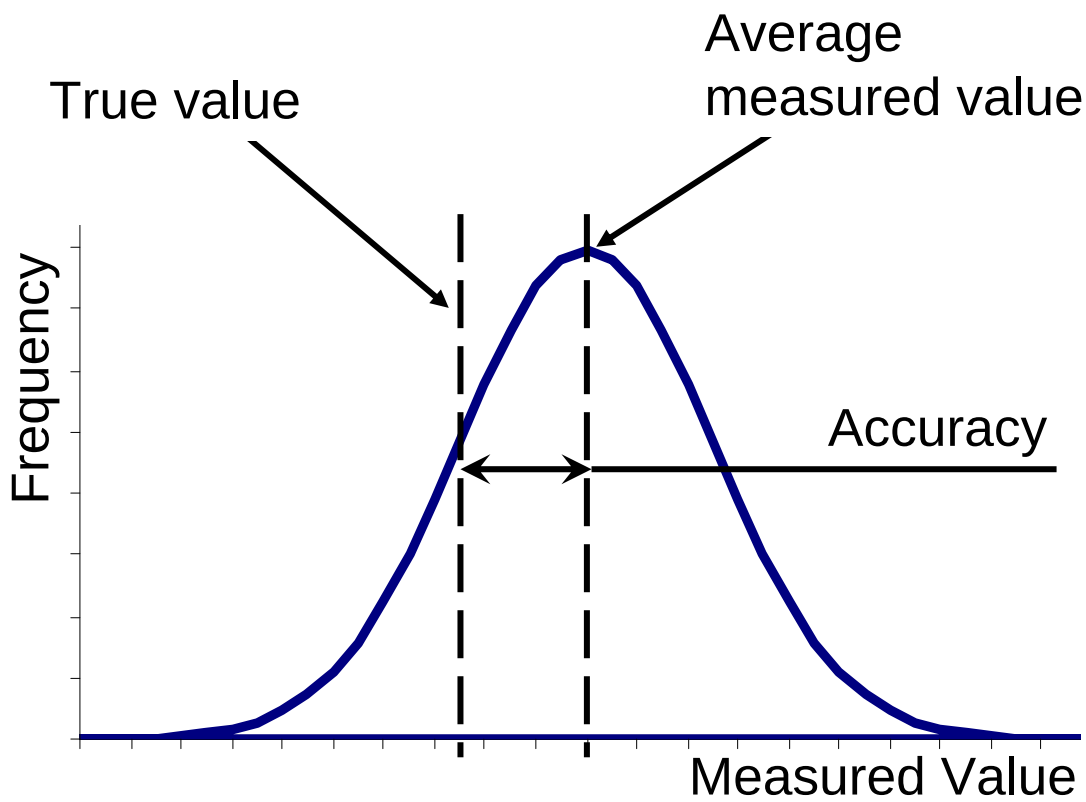

**Resolution** is the incremental ability of a measurement system to discriminate between measurement values.

The measurement system should have a **minimum of 20 measurement increments** within the product tolerance (e.g, for a full tolerance of 1, minimum resolution is .05)

# Accuracy



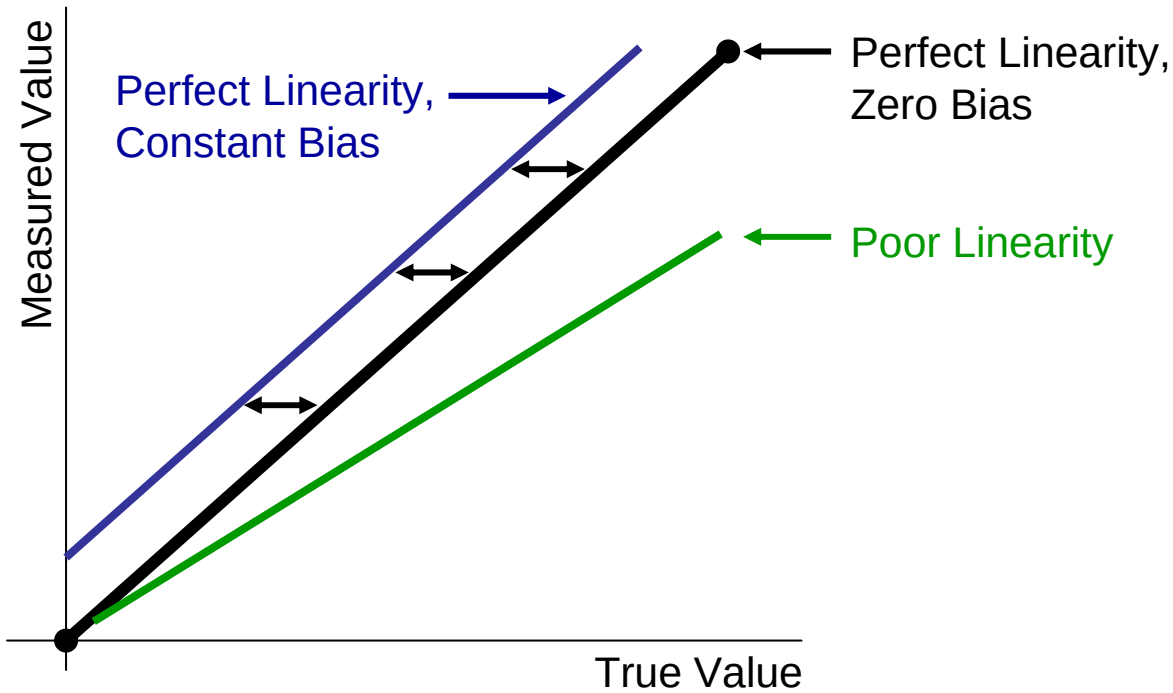
**Accuracy**—or **bias**—is a measure of the distance between the average value of the measurement of a part and the True, certified, or assigned value of a part



# Linearity

Raytheon
Customer Success Is Our Mission

**Linearity** is the consistency of **accuracy (bias)** over the range of measurement; a slope of one (unity) between measured and true value is perfect





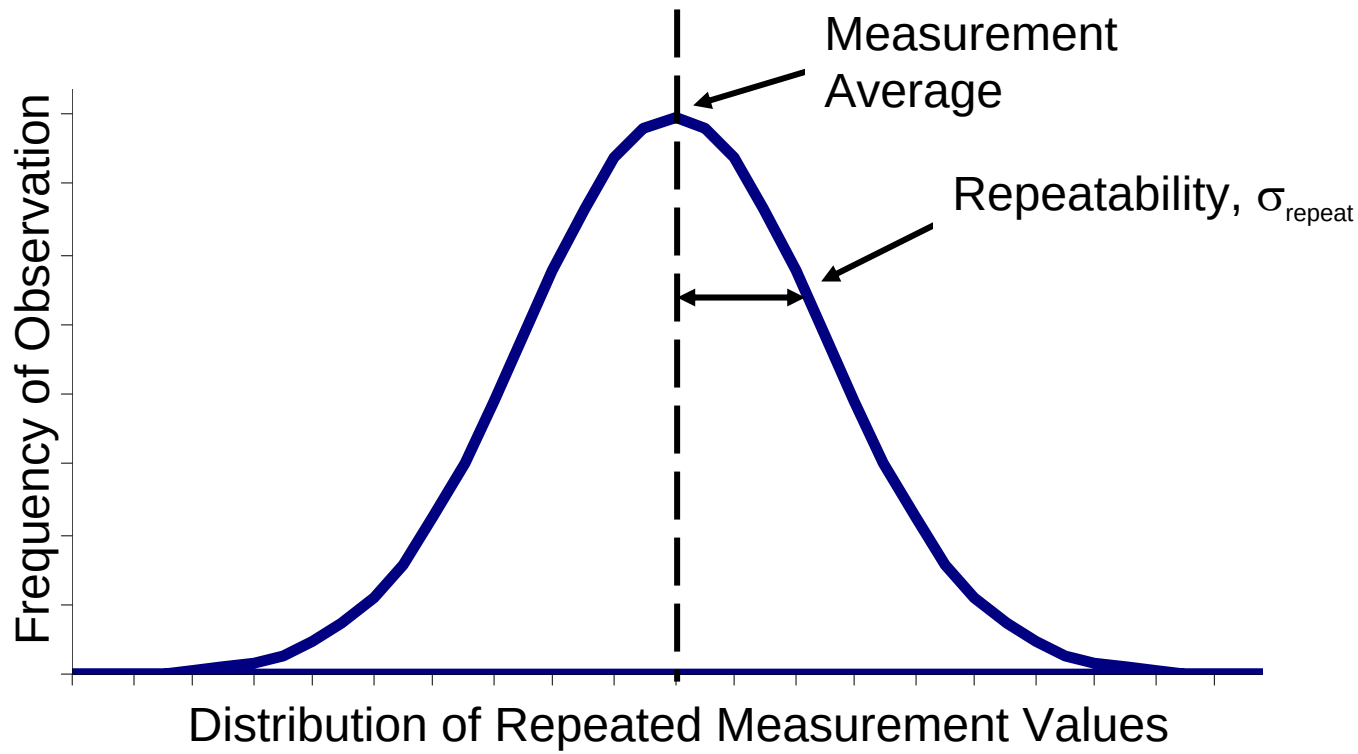



R6σ Raytheon Six Sigma

# Repeatability



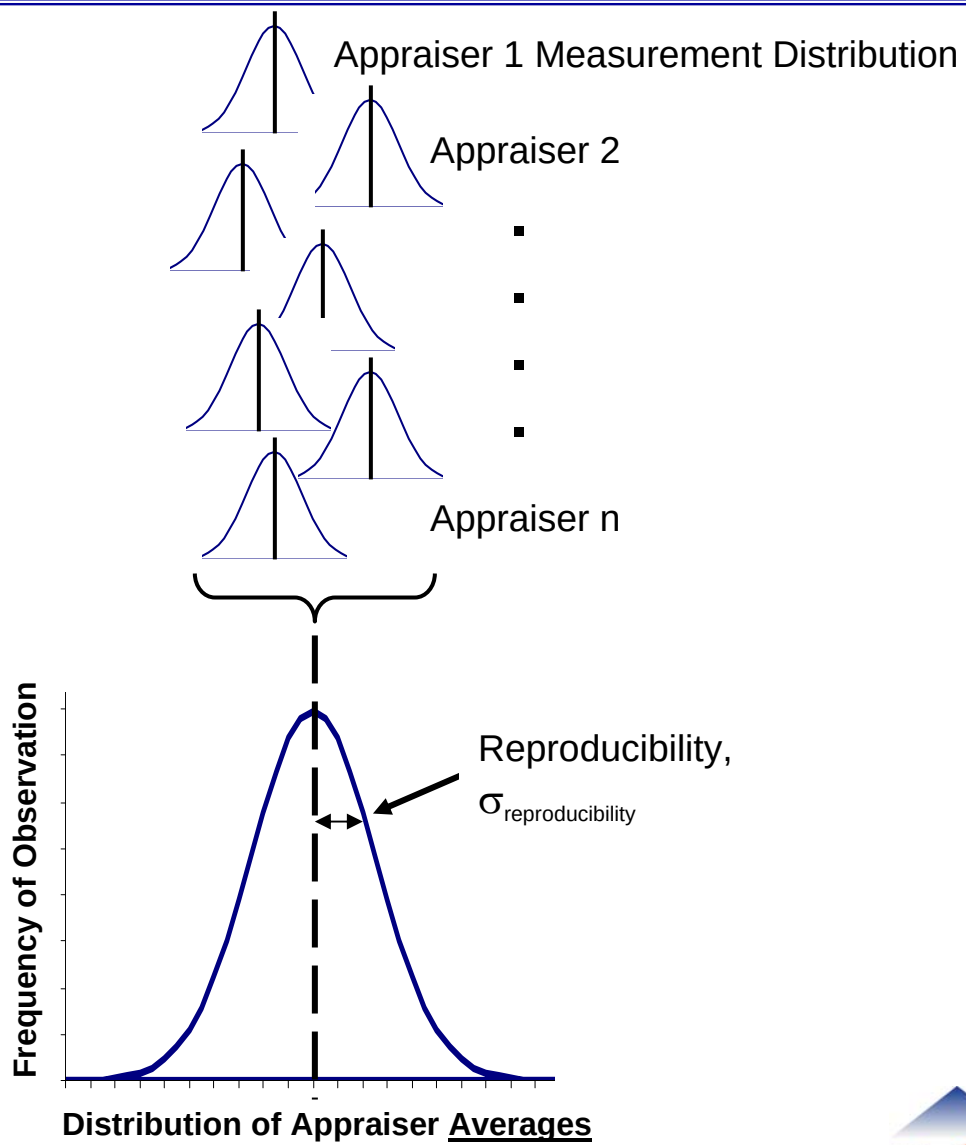
**Repeatability** is the consistency of a single appraiser to measure the same part multiple times with the same measurement system; it is related to the standard deviation of the measured values



# Reproducibility

Raytheon
Customer Success Is Our Mission

**Reproducibility** is the consistency of different appraisers in measuring the same part with the same measurement system; it is related to standard deviation of the distribution of appraiser averages





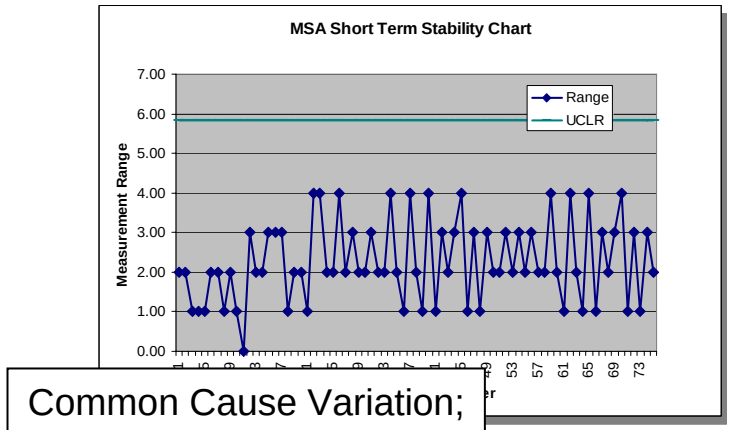



R6σ Raytheon Six Sigma

# Stability

Raytheon
Customer Success Is Our Mission

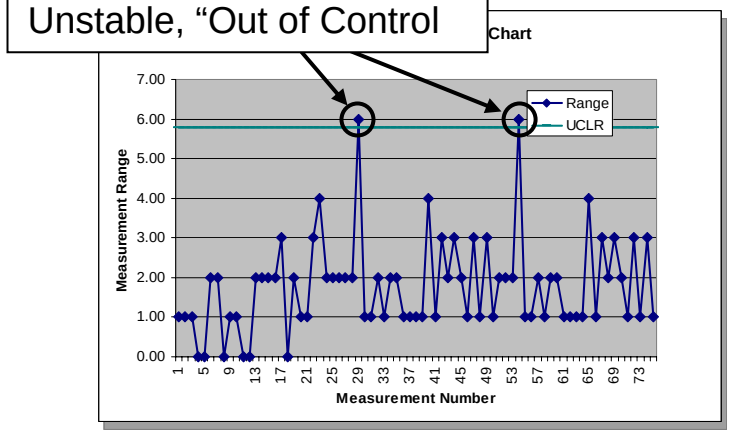
**Stability** is the ability of a measurement system to produce the same values over time when measuring the same sample




Common Cause Variation;
Stable, “In Control”

As with statistical process control charts, **stability means the absence of “Special Cause Variation”** which is indicated by an “in control” condition, leaving only "Common Cause” or random variation

Special Cause Variation;
Unstable, “Out of Control








R6σ Raytheon Six Sigma

# Measurement Systems Metrics

Raytheon
Customer Success Is Our Mission

- Generally, **precision is the principle concern**; inaccuracy due to linearity or constant bias can typically be corrected through calibration
- **Measurement Error** is the statistical summing of the error generated by Repeatibility (the variation within an appraiser) and Reproducibility (the variation between appraisers)
  - $\sigma_{error} = \sqrt{(\sigma_{repeability})^2 + (\sigma_{reproducibility})^2}$
- **Total Measurement Error** spans the interval that contains 99% of probable measurement values from a measurement system, using a single part
  - Total Measurement Error = $5.15 * \sigma_{error}$
- Measurement system **precision** is defined by the **Precision/Tolerance Ratio**, the ratio between Total Measurement Error and the part tolerance
  - P/T Ratio = $5.15 * \sigma_{error}$ / (Upper Spec Limit – Lower Spec Limit)





R6σ Raytheon Six Sigma

# Measurement Systems Metrics

Raytheon
Customer Success Is Our Mission

- **Error Independence** is defined by the **lack of a relationship between measurement error and the measurement value**; error generated by the measurement process should be independent of the measured value
- **Stability** is defined by the **randomness of the measurement error**; purely random measurement error is evidence of good stability
- **Linearity** is defined by the slope of measured value vs. true value; a slope of 1 (a 1:1 relationship) is perfect
- **Bias Offset** is defined by the average difference between the measured value and the true value at the specification target; a value of zero is perfect
  - The combination Bias Offset and Linearity define the amount of systematic measurement error across the entire measurement range; they are typically corrected through calibration





R6σ Raytheon Six Sigma

# Measurement System Requirements

Raytheon
Customer Success Is Our Mission

| MSA Parameter | Requirement |
|---|---|
| Precision/Tolerance Ratio | P/T<10% **Accept**<br>10%<P/T<30% **Marginal Accept**<br>>30% **Fail** |
| Error Independence | **Pass** the hypothesis test that error is independent of measured value |
| Stability | Measurement error is **in control** when plotted on a control chart |
| Bias | **Pass** the hypothesis test that no offset exists between true and measured value at the spec target |
| Linearity | **Pass** the hypothesis test that slope between the true and measured values is equal to one (unity) |





R6σ Raytheon Six Sigma

# Conducting the MSA

Raytheon
Customer Success Is Our Mission

- Raytheon provides two template versions for the MSA
  - **Short Study,** which **requires 10 parts** to be measured a minimum of two repetitions by two different operators (or up to three times with three operators)
  - **Standard Study,** which **requires 25 parts** to be measured a minimum of two repetitions by two different operators (or up to three times with three operators)
- For the purposes of analysis, **a part is equivalent to a dimension**
  - 25 different (but similar) dimensions on a single part is equivalent to a single dimension on 25 parts
- Parts selected for use in the MSA should **span the full tolerance range**
- The **measurement system being assessed must be properly calibrated** using standard operating practice prior to the MSA
- The quality of the assessment is related to the number of parts, repetitions and operators, thus **we recommend the standard study**
- Randomizing the order of measurement during the MSA is a best practice


MSA Standard Study


MSA Short Study





R6σ Raytheon Six Sigma

# Using the MSA Study Template

Raytheon
Customer Success Is Our Mission

- Use the MSA Form worksheet in the MSA Excel file to capture measurement data on the parts
- **The "True Value" of a part is necessary to assess system linearity and accuracy**; parts with values that span the tolerance should be used; we recommend a minimum of six parts with true values for the linearity analysis
- **A minimum of two repeated measures of each part is required**; this is the minimum number needed to establish a measurement range for an individual part; three is recommended
- **A minimum of two appraisers is required**; this allows us to estimate reproducibility; three is recommended

**MSA Data Acquisition Form** Raytheon Customer Success Is Our Mission

| | |
|---|---|
| Appraiser Name: | |
| Gage Name: | |
| Gage Type: | |
| Gage Number: | |
| Calibration Date | |
| Date: | |

| Part # | True Value | Trial 1 | Trial 2 | Trial 3 |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 10 | | | | |
| 11 | | | | |
| 12 | | | | |
| 13 | | | | |
| 14 | | | | |
| 15 | | | | |
| 16 | | | | |
| 17 | | | | |
| 18 | | | | |
| 19 | | | | |
| 20 | | | | |
| 21 | | | | |
| 22 | | | | |
| 23 | | | | |
| 24 | | | | |
| 25 | | | | |





R6σ Raytheon Six Sigma

# Using the MSA Study Template

Raytheon
Customer Success Is Our Mission

Raytheon
Customer Success Is Our Mission

**Data Input Sheet for Measurement Systems Analysis**

Input data into green boxes

| | | | |
|---|---|---|---|
| Gage Name: | AMS100 | Characteristic: | Gap |
| Gage Type: | Line Width Measurement | Upper Specification Limit: | 50 |
| Gage Number: | 23 | Lower Specification Limit: | 10 |
| Date: | 24-Oct-07 | Number of Appraisers | 3 |
| Appraiser 1 Name: | Jim | Trials/Appraiser | 3 |
| Appraiser 2 Name: | Larry | | |
| Appraiser 3 Name: | Brian | | |

| Jim | | | | | | |
|---|---|---|---|---|---|---|
| Part # | True Value | Trial 1 | Trial 2 | Trial 3 | Average | Range |
| 1 | 2.5 | 2 | 3 | 1 | 2.00 | 2.00 |
| 2 | | 3 | 2 | 4 | 3.00 | 2.00 |
| 3 | | 2 | 3 | 3 | 2.67 | 1.00 |
| 4 | | 3 | 4 | 3 | 3.33 | 1.00 |
| 5 | 4 | 4 | 4 | 3 | 3.67 | 1.00 |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | | | | | | |
| 9 | | | | | | |
| 10 | | | | | | |
| 11 | | | | | | |
| 12 | 5.2 | | | | | |
| 13 | | | | | | |
| 14 | | | | | | |
| 15 | | 6 | 4 | 3 | 4.33 | 3.00 |
| 16 | 5 | 4 | 2 | 5 | 3.67 | 3.00 |
| 17 | | 6 | 3 | 3 | 4.00 | 3.00 |
| 18 | | 5 | 5 | 6 | 5.33 | 1.00 |
| 19 | | 4 | 6 | 6 | 5.33 | 2.00 |
| 20 | | 6 | 5 | 4 | 5.00 | 2.00 |
| 21 | 4 | 5 | 4 | 4 | 4.33 | 1.00 |
| 22 | | 4 | 7 | 3 | 4.67 | 4.00 |
| 23 | | 2 | 6 | 5 | 4.33 | 4.00 |
| 24 | 4.5 | 4 | 6 | 6 | 5.33 | 2.00 |
| 25 | | 5 | 3 | 4 | 4.00 | 2.00 |
| Linearity Assessment Performed | | | | | | |

| Larry | | | | | |
|---|---|---|---|---|---|
| Part # | Trial 1 | Trial 2 | Trial 3 | Average | Range |
| 1 | 1 | 3 | 5 | 3.00 | 4.00 |
| 2 | 4 | 6 | 4 | 4.67 | 2.00 |
| 3 | 3 | 5 | 2 | 3.33 | 3.00 |
| 4 | 4 | 6 | 4 | 4.67 | 2.00 |
| 5 | 3 | 4 | 5 | 4.00 | 2.00 |
| 15 | 3 | 7 | 4 | 4.67 | 4.00 |
| 16 | 5 | 6 | 6 | 5.67 | 1.00 |
| 17 | 3 | 6 | 4 | 4.33 | 3.00 |
| 18 | 5 | 3 | 3 | 3.67 | 2.00 |
| 19 | 6 | 3 | 5 | 4.67 | 3.00 |
| 20 | 4 | 2 | 6 | 4.00 | 4.00 |
| 21 | 4 | 3 | 4 | 3.67 | 1.00 |
| 22 | 3 | 5 | 6 | 4.67 | 3.00 |
| 23 | 5 | 4 | 5 | 4.67 | 1.00 |
| 24 | 6 | 3 | 4 | 4.33 | 3.00 |
| 25 | 4 | 5 | 6 | 5.00 | 2.00 |

| Brian | | | | | |
|---|---|---|---|---|---|
| Part # | Trial 1 | Trial 2 | Trial 3 | Average | Range |
| 1 | 4 | 3 | 5 | 4.00 | 2.00 |
| 2 | 3 | 6 | 4 | 4.33 | 3.00 |
| 3 | 3 | 5 | 4 | 4.00 | 2.00 |
| 4 | 3 | 6 | 4 | 4.33 | 3.00 |
| 5 | 3 | 4 | 5 | 4.00 | 2.00 |
| | | | 2 | 3.67 | 3.00 |
| | | | 3 | 3.67 | 2.00 |
| | | | 2 | 3.00 | 2.00 |
| | | | 0 | 2.00 | 4.00 |
| | | | 4 | 4.00 | 2.00 |
| | | | 5 | 5.33 | 1.00 |
| | | | 3 | 5.33 | 4.00 |
| | | | 3 | 4.00 | 2.00 |
| | | | 5 | 4.67 | 1.00 |
| 15 | 3 | 7 | 4 | 4.67 | 4.00 |
| 16 | 5 | 6 | 6 | 5.67 | 1.00 |
| 17 | 3 | 6 | 4 | 4.33 | 3.00 |
| 18 | 5 | 3 | 3 | 3.67 | 2.00 |
| 19 | 6 | 3 | 5 | 4.67 | 3.00 |
| 20 | 4 | 2 | 6 | 4.00 | 4.00 |
| 21 | 4 | 3 | 4 | 3.67 | 1.00 |
| 22 | 3 | 4 | 6 | 4.33 | 3.00 |
| 23 | 5 | 4 | 5 | 4.67 | 1.00 |
| 24 | 6 | 3 | 4 | 4.33 | 3.00 |
| 25 | 4 | 5 | 6 | 5.00 | 2.00 |

Transcribe or import the measurement data into the green highlighted boxes on the MSA Input Sheet; the workbook calculates all of the MSA metrics from this data





R6σ Raytheon Six Sigma

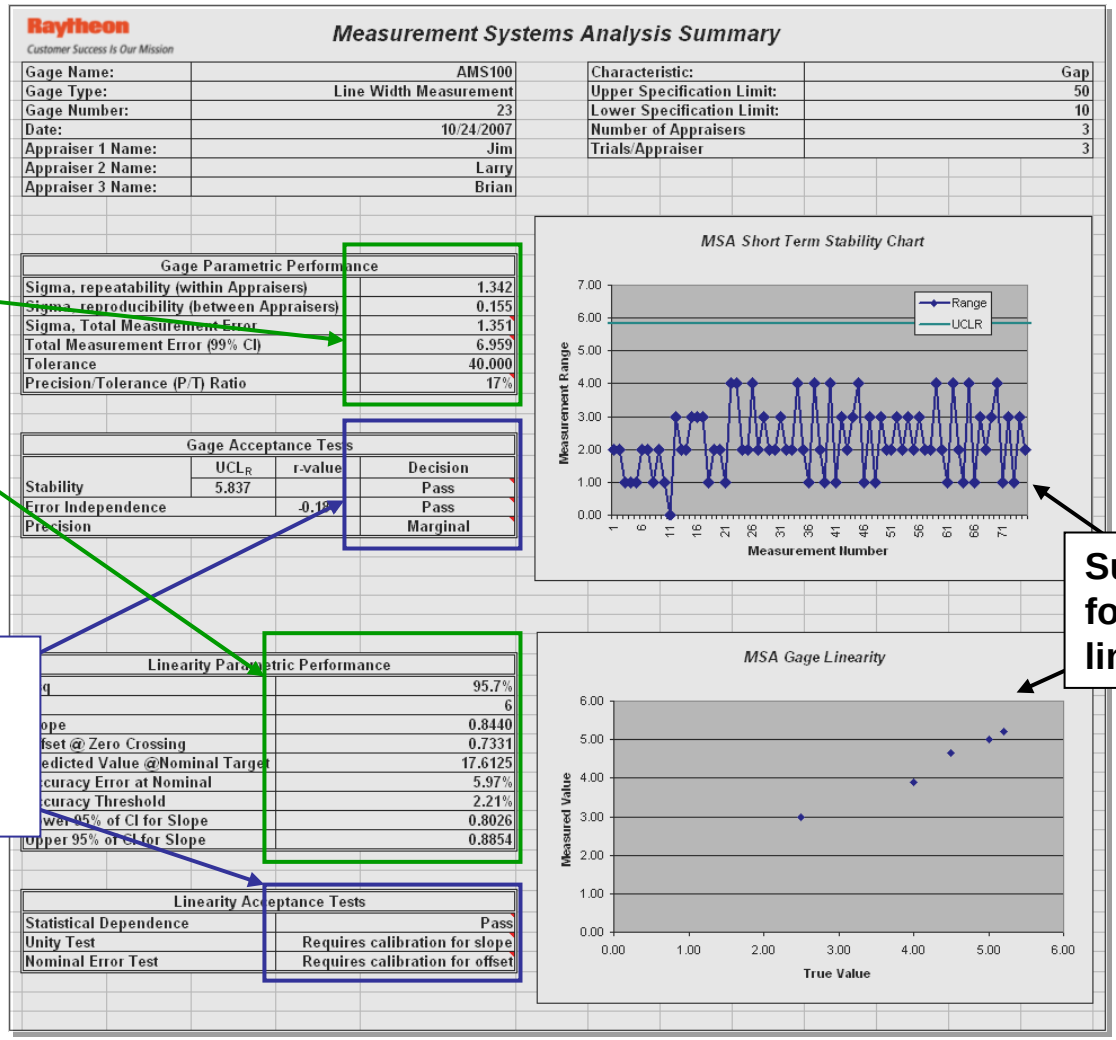
# Interpreting the Results

Raytheon
Customer Success Is Our Mission

**Precision and accuracy performance metrics for the gage**

**Acceptability results; based on requirements from slide 13**

**Supporting graphs for stability and linearity**



Raytheon
Customer Success Is Our Mission

*Measurement Systems Analysis Summary*

| | | | |
|---|---|---|---|
| Gage Name: | AMS100 | Characteristic: | Gap |
| Gage Type: | Line Width Measurement | Upper Specification Limit: | 50 |
| Gage Number: | 23 | Lower Specification Limit: | 10 |
| Date: | 10/24/2007 | Number of Appraisers | 3 |
| Appraiser 1 Name: | Jim | Trials/Appraiser | 3 |
| Appraiser 2 Name: | Larry | | |
| Appraiser 3 Name: | Brian | | |

| Gage Parametric Performance | |
|---|---|
| Sigma, repeatability (within Appraisers) | 1.342 |
| Sigma, reproducibility (between Appraisers) | 0.155 |
| Sigma, Total Measurement Error | 1.351 |
| Total Measurement Error (99% CI) | 6.959 |
| Tolerance | 40.000 |
| Precision/Tolerance (P/T) Ratio | 17% |

| Gage Acceptance Tests | | | |
|---|---|---|---|
| | $UCL_R$ | r-value | Decision |
| Stability | 5.837 | | Pass |
| Error Independence | | -0.19 | Pass |
| Precision | | | Marginal |

*MSA Short Term Stability Chart*




| Linearity Parametric Performance | |
|---|---|
| q | 95.7% |
| | 6 |
| ope | 0.8440 |
| fset @ Zero Crossing | 0.7331 |
| edicted Value @Nominal Target | 17.6125 |
| curacy Error at Nominal | 5.97% |
| curacy Threshold | 2.21% |
| wer 95% of CI for Slope | 0.8026 |
| Upper 95% of CI for Slope | 0.8854 |

| Linearity Acceptance Tests | |
|---|---|
| Statistical Dependence | Pass |
| Unity Test | Requires calibration for slope |
| Nominal Error Test | Requires calibration for offset |

*MSA Gage Linearity*








R6σ Raytheon Six Sigma

# Call to Action

Raytheon
Customer Success Is Our Mission

- MSA assures that the measurement equipment precision is aligned to the application requirement so that you don't pay for precision you don't need, or don't get the precision you do need
- Raytheon template is easy to use and requires no calculation or data manipulation from the user
- Utilizing MSA processes on production measurement equipment is an ISO requirement





R6σ Raytheon Six Sigma

# References and Resources

Raytheon
Customer Success Is Our Mission

Textbooks:

- Quality Through Statistical Thinking: Robertson, Gordon
- Statistics for Management: Levin, Richard

On the Web:

- http://www.moresteam.com/toolbox/t403.cfm

Questions? Ask the expert!





R6σ Raytheon Six Sigma

# End