Measurement Systems Correlation

MSC for Suppliers

MSC Objective

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Correlation of multiple measurement systems for use by quantifying accuracy relative to a Gold Standard Measurement System

- Understand the characteristics of correlation
- Understand the method for establishing measurement correlation
- Define the requirements for correlation between systems

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The Qualities of Correlation

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- A Gold Tester is the measurement system used to determine and assign specifications
- Correlation measures the ability of a measurement system to reproduce the measurement (and, therefore, acceptance) values obtained on an originating, or “Gold”, tester
- The state of correlation between testers is assessed by:
  - r^2: the Coefficient of Determination
  - Offset
  - Linearity
  - Repeatability

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The Importance of Correlation

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- **Establishes a relationship between the specification requirement and the test equipment at the supplier or manufacturing site**
  - Mitigates the risk that suppliers could produce and ship non-conforming units without knowing it
  - Mitigates the risk that suppliers could optimize their product distribution to the incorrect target
  - Mitigates schedule and cost risk due to specification requirements that are too tight without knowing it
- Acceptance criteria for correlation is a business risk decision
  - The less important the parameter, the more risk you can take and the looser the requirements can be
  - The more capable the product distribution, the more risk you can take and the looser the requirements can be
  - Looser correlation requirements can reduce the cost required for test verification equipment

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Coefficient of Determination: The r^2 Value

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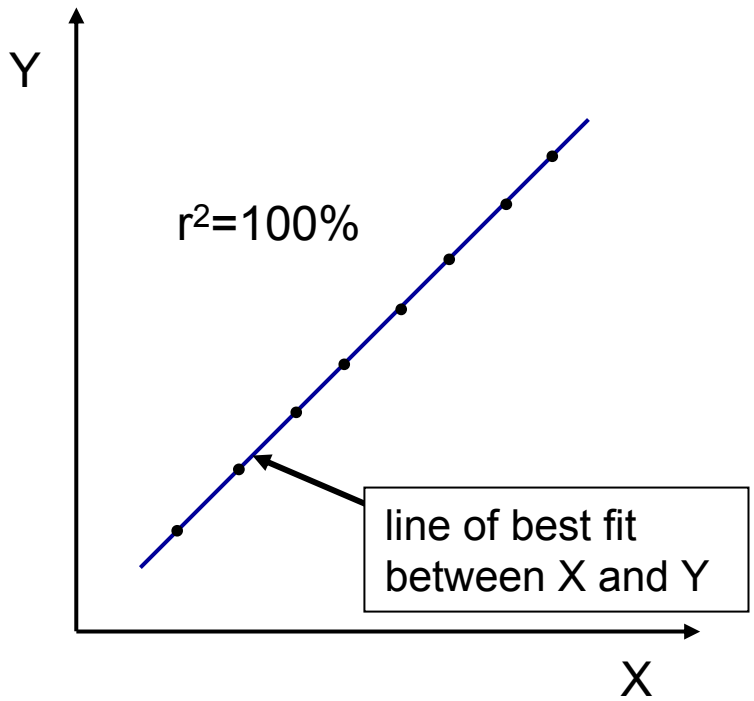
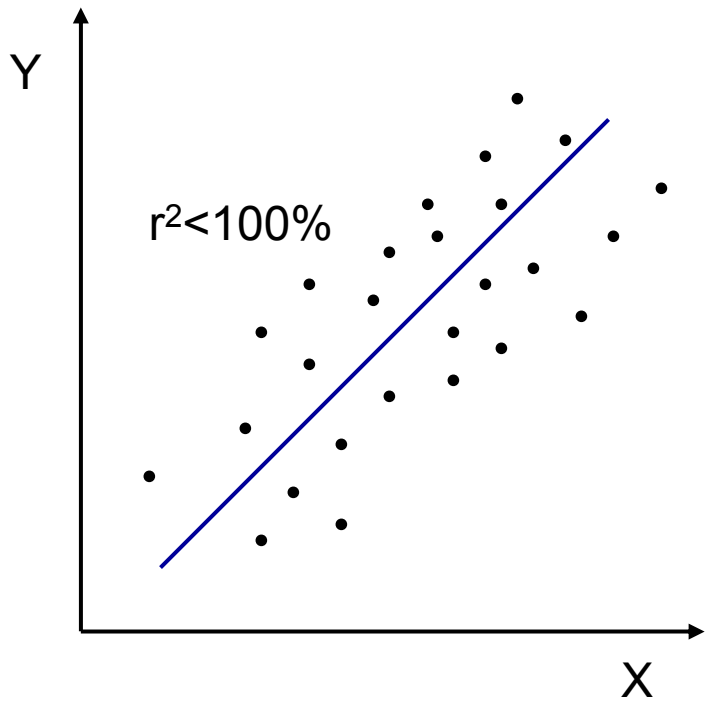
The r^2 value is usually expressed as a percentage; it represents **the amount of variation in Y that is explained by X.** r^2 is equal to 100% when every data point lies on the regression line





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Offset

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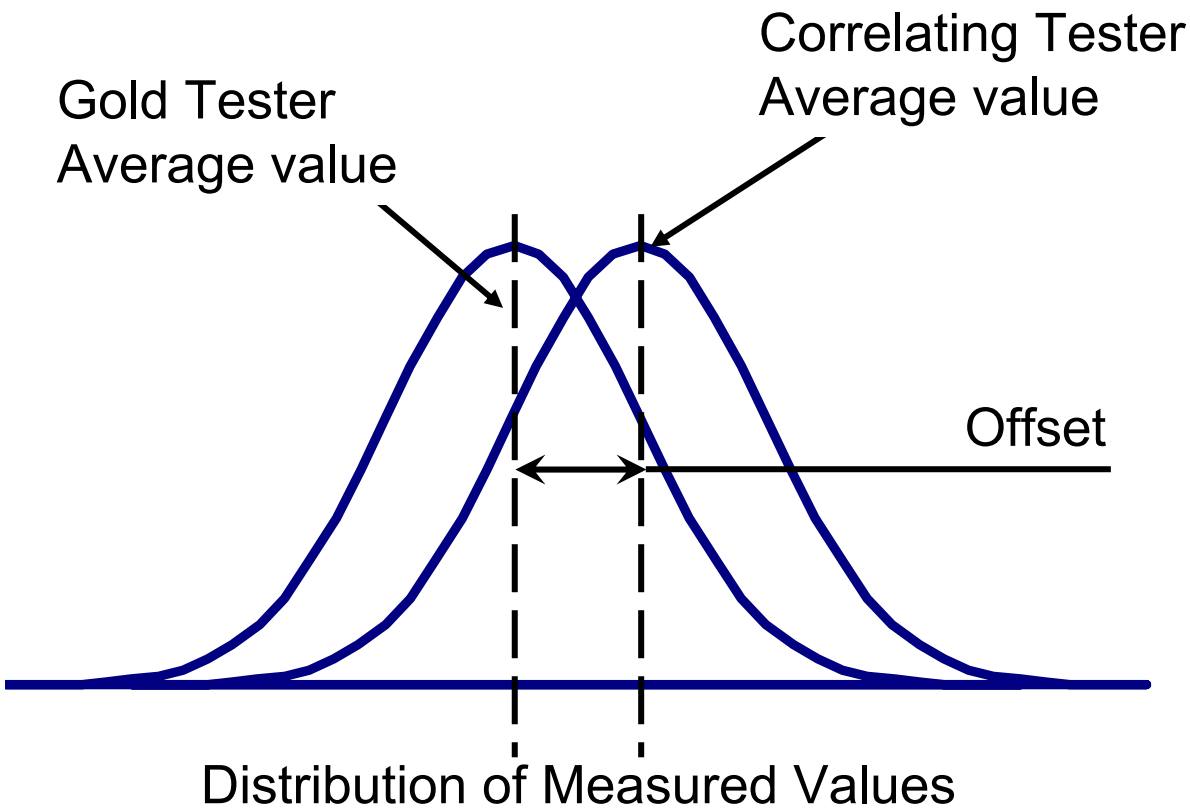
Offset is the difference between the average values of the Correlating Tester measurement and the Gold Tester measurement at a specific measurement value



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Linearity

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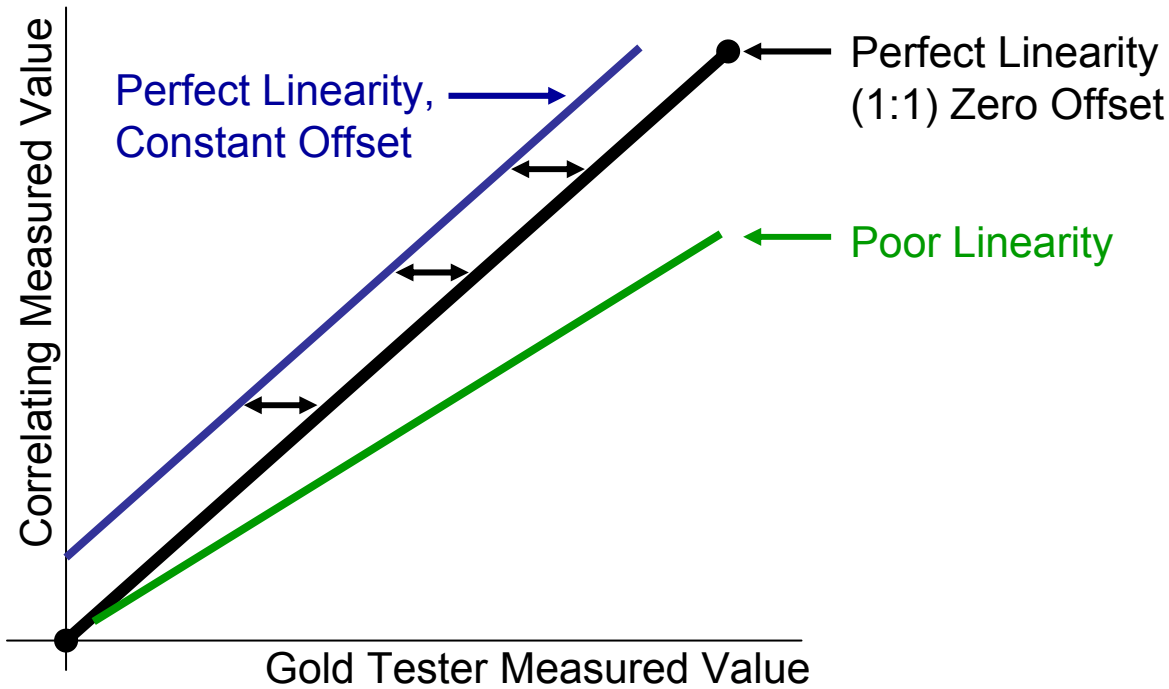
Linearity is the consistency of the **offset** over the range of measurement; a 1:1 slope between the correlating tester and gold tester is perfect



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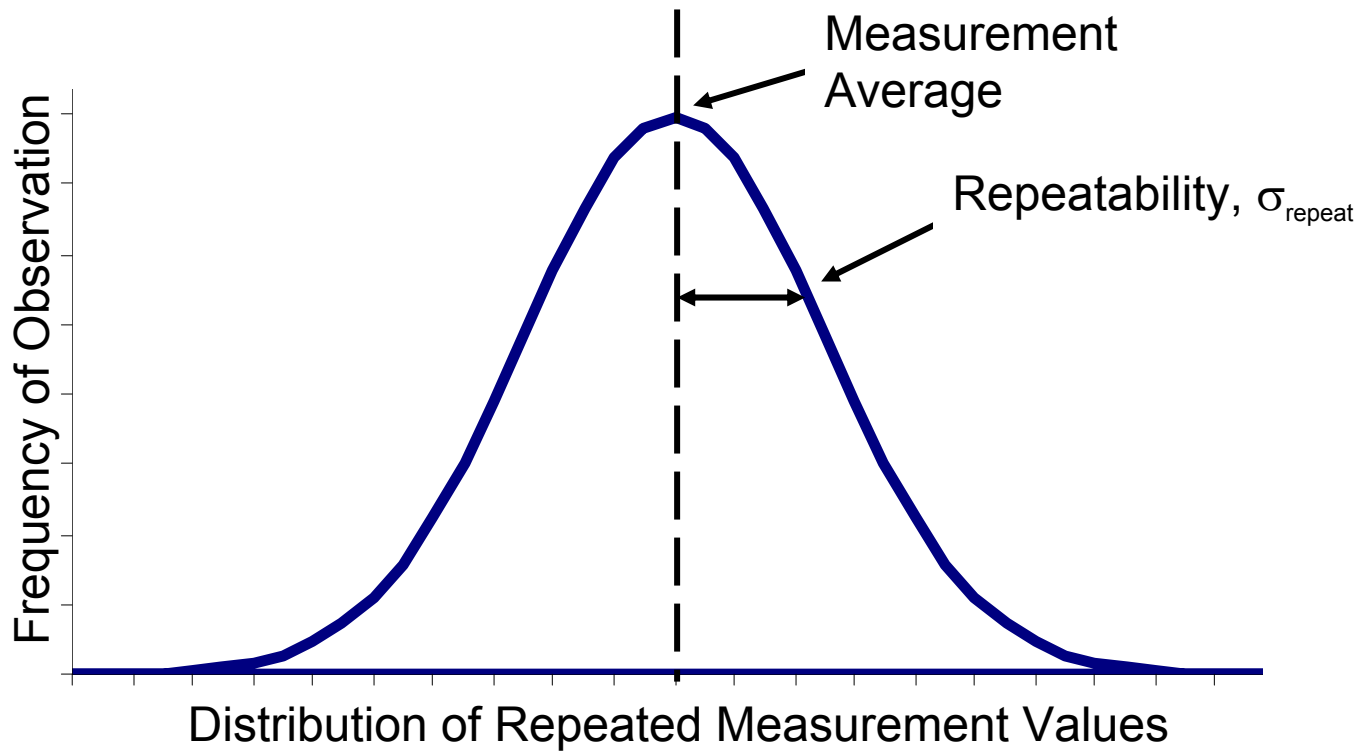
Repeatability

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



Measurement Systems Correlation Metrics

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- **R-squared** is the **Coefficient of Determination** between the measurement values of the Gold Tester and the Correlating Tester; it measures the strength of the correlation
- **Linearity** is defined by the slope between Gold Tester measured values and Correlating Tester measured values; a slope of 1 (representing a 1:1 relationship) is perfect
- **Offset** is defined by the average difference between the measured values of the Gold Tester and the Correlating Tester; a value of zero is perfect
  - The combination Offset and Linearity define the amount of systematic measurement error across the entire measurement range; they can generally be corrected through calibration
- **Precision** is the 99% confidence interval ($5.15*\sigma_{error}$) of single measurement repeatability of the measurement system
- **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

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Measurement Correlation Requirements

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MSC Parameter	Recommended Requirement
Coefficient of Determination, r^2	R^2>95% **Accept** 87%<R^2<95% **Marginal Accept**
Offset	<3% at USL and LSL **Accept** 3%<Offset<5% **Marginal Accept**
Linearity to Gold System	**Pass** the hypothesis test that slope between the Gold and Production system is equal to one (unity)
Precision (repeatability only)	<10% **Accept** 10%<P/T<30% **Marginal Accept**
Error Independence	**Pass** the hypothesis test that error is independent of measured value

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Threats to Achieving Acceptable Correlation

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- Measurement repeatability (process- or machine-related)
- Measurement system out-of-control (time-related repeatability)
- Clustering of values of the correlation sample
- Insufficient range of values represented by the sample used in the study
- Poor calibration
- Lack of standards available for the calibration process
- Insufficient resolution
- Algorithm differences between participating testers
- Noise floor differences between participating testers
- Tooling differences between participating testers
- Damage to correlation units during the study
- Mislabeled correlation sample

….and others

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Conducting the MSC

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- Raytheon provides one template for the MSC which **requires 25 parts** to be measured a minimum of two repetitions on two different measurement systems (or up to three times on three systems); one measurement system must be defined as "Gold" (typically the "originating" tester used to generate the specification)
- For the purposes of analysis, **a part is equivalent to a dimension**
  - 25 different (but similar) dimensions that span the measurement range-of-interest on a single part is equivalent to a single dimension on 25 parts
- Strategically select the parts used in the MSC: **parts should have values that are evenly distributed and span the full tolerance range**
- The **measurement system being assessed must be properly calibrated** using standard operating practice prior to the MSC
- Each participating measurement system must have adequate resolution
- Randomizing the order of measurement of the parts during the MSC is a best practice

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Using the MSC Study Template

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- Use the MSC Form worksheet in the MSC Excel file to capture measurement data on the parts
- **A minimum of two repeated measures for each part is required**; this is the minimum number needed to establish a measurement range for an individual part; three is recommended
- **A maximum of three systems can be evaluated** (one gold to two production testers)

RTN CorrIn Analysis

MSC Data Acquisition Form			
Appraiser Name:			
Parameter:			
Gage Name:			
Gage Type:			
Gage Number:			
Calibration Date:			
Date:			
Part #	Trial 1	Trial 2	Trial 3
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
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Using the MSC Study Template

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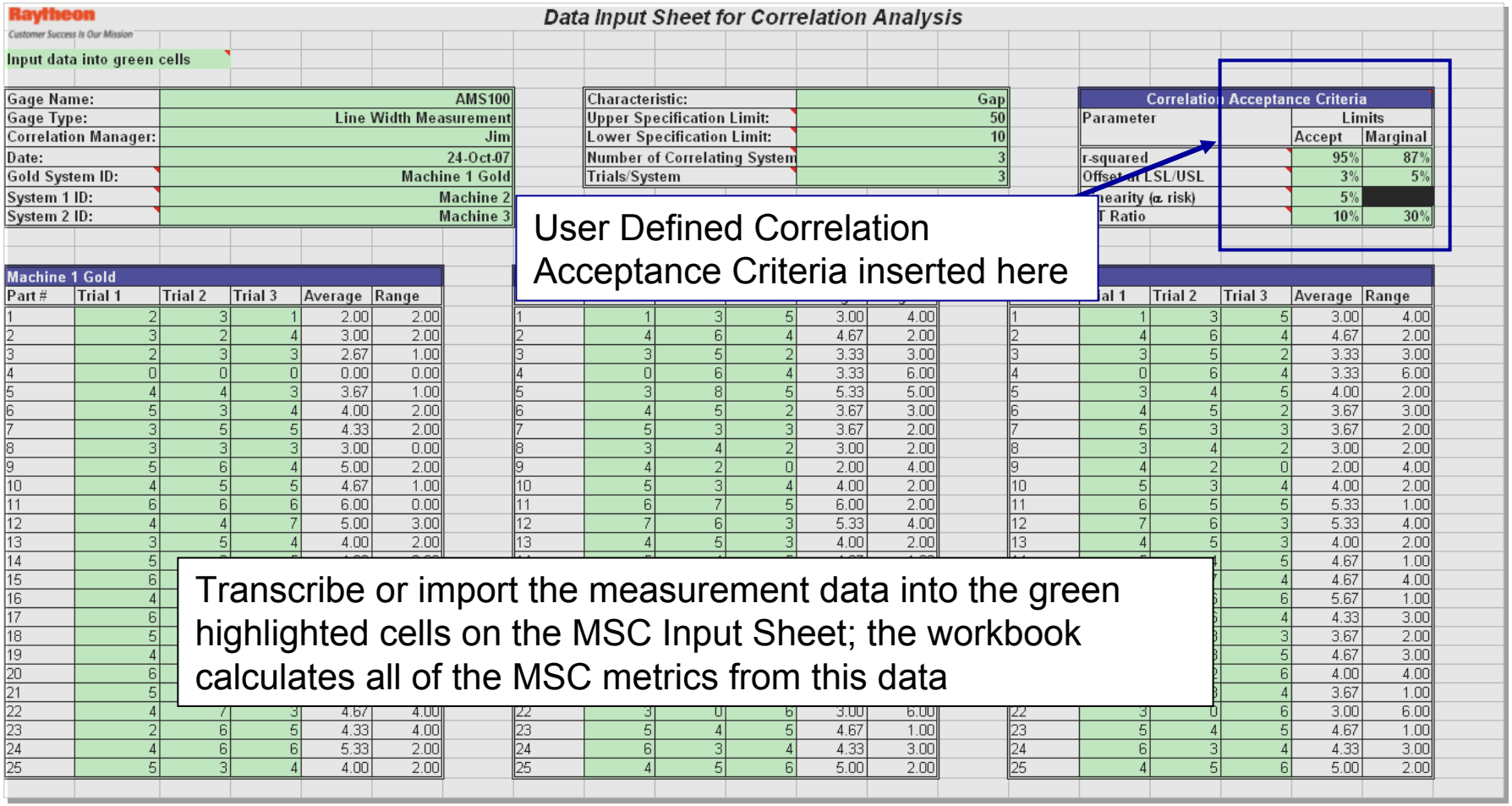

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Data Input Sheet for Correlation Analysis

Input data into green cells

Gage Name:	AMS100
Gage Type:	Line Width Measurement
Correlation Manager:	Jim
Date:	24-Oct-07
Gold System ID:	Machine 1 Gold
System 1 ID:	Machine 2
System 2 ID:	Machine 3

Characteristic:	Gap
Upper Specification Limit:	50
Lower Specification Limit:	10
Number of Correlating System	3
Trials/System	3

Correlation Acceptance Criteria		
Parameter	Limits	
	Accept	Marginal
r-squared	95%	87%
Offset in LSL/USL	3%	5%
Linearity (α risk)	5%	
GT Ratio	10%	30%

User Defined Correlation Acceptance Criteria inserted here

Machine 1 Gold

Part #	Trial 1	Trial 2	Trial 3	Average	Range
1	2	3	1	2.00	2.00
2	3	2	4	3.00	2.00
3	2	3	3	2.67	1.00
4	0	0	0	0.00	0.00
5	4	4	3	3.67	1.00
6	5	3	4	4.00	2.00
7	3	5	5	4.33	2.00
8	3	3	3	3.00	0.00
9	5	6	4	5.00	2.00
10	4	5	5	4.67	1.00
11	6	6	6	6.00	0.00
12	4	4	7	5.00	3.00
13	3	5	4	4.00	2.00
14	5				
15	6				
16	4				
17	6				
18	5				
19	4				
20	6				
21	5				
22	4	7	3	4.67	4.00
23	2	6	5	4.33	4.00
24	4	6	6	5.33	2.00
25	5	3	4	4.00	2.00

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	0	6	4	3.33	6.00
5	3	8	5	5.33	5.00
6	4	5	2	3.67	3.00
7	5	3	3	3.67	2.00
8	3	4	2	3.00	2.00
9	4	2	0	2.00	4.00
10	5	3	4	4.00	2.00
11	6	7	5	6.00	2.00
12	7	6	3	5.33	4.00
13	4	5	3	4.00	2.00
22	3	0	6	3.00	6.00
23	5	4	5	4.67	1.00
24	6	3	4	4.33	3.00
25	4	5	6	5.00	2.00

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	0	6	4	3.33	6.00
5	3	4	5	4.00	2.00
6	4	5	2	3.67	3.00
7	5	3	3	3.67	2.00
8	3	4	2	3.00	2.00
9	4	2	0	2.00	4.00
10	5	3	4	4.00	2.00
11	6	5	5	5.33	1.00
12	7	6	3	5.33	4.00
13	4	5	3	4.00	2.00
			5	4.67	1.00
			4	4.67	4.00
			6	5.67	1.00
			4	4.33	3.00
			3	3.67	2.00
			5	4.67	3.00
			6	4.00	4.00
			4	3.67	1.00
22	3	0	6	3.00	6.00
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 cells on the MSC Input Sheet; the workbook calculates all of the MSC metrics from this data

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Interpreting the Results

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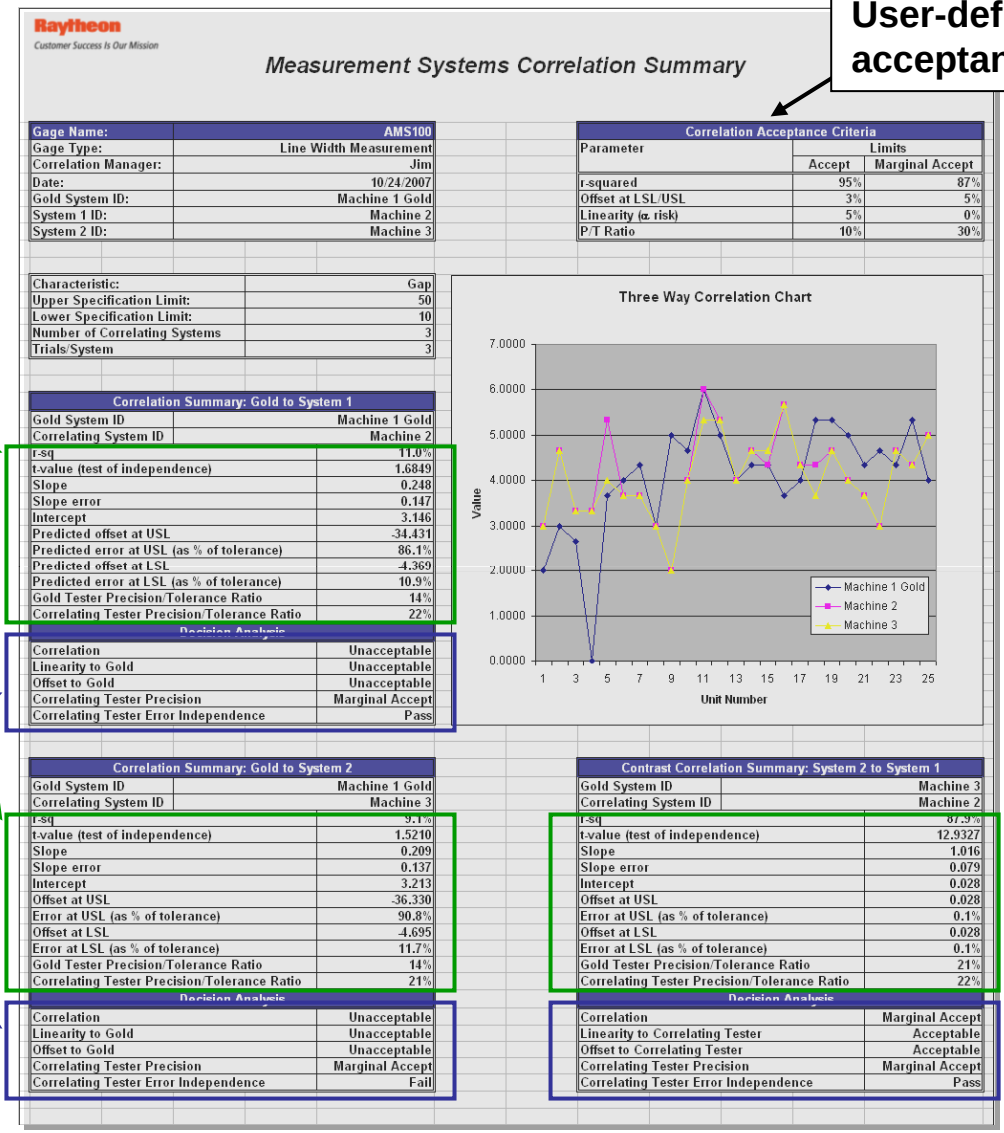
User-defined acceptance criteria

Correlation and precision performance metrics for the correlating gage

Acceptability results; decisions based on user-defined acceptance criteria



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Measurement Systems Correlation Summary

Gage Name:	AMS100
Gage Type:	Line Width Measurement
Correlation Manager:	Jim
Date:	10/24/2007
Gold System ID:	Machine 1 Gold
System 1 ID:	Machine 2
System 2 ID:	Machine 3

Correlation Acceptance Criteria		
Parameter	Limits	
	Accept	Marginal Accept
r-squared	95%	87%
Offset at LSL/USL	3%	5%
Linearity (α risk)	5%	0%
P/T Ratio	10%	30%

Characteristic:	Gap
Upper Specification Limit:	50
Lower Specification Limit:	10
Number of Correlating Systems	3
Trials/System	3

Three Way Correlation Chart

Correlation Summary: Gold to System 1	
Gold System ID	Machine 1 Gold
Correlating System ID	Machine 2
r-sq	11.0%
t-value (test of independence)	1.6849
Slope	0.248
Slope error	0.147
Intercept	3.146
Predicted offset at USL	-34.431
Predicted error at USL (as % of tolerance)	86.1%
Predicted offset at LSL	-4.369
Predicted error at LSL (as % of tolerance)	10.9%
Gold Tester Precision/Tolerance Ratio	14%
Correlating Tester Precision/Tolerance Ratio	22%
Decision Analysis	
Correlation	Unacceptable
Linearity to Gold	Unacceptable
Offset to Gold	Unacceptable
Correlating Tester Precision	Marginal Accept
Correlating Tester Error Independence	Pass

Correlation Summary: Gold to System 2	
Gold System ID	Machine 1 Gold
Correlating System ID	Machine 3
r-sq	9.1%
t-value (test of independence)	1.5210
Slope	0.209
Slope error	0.137
Intercept	3.213
Offset at USL	-36.330
Error at USL (as % of tolerance)	90.8%
Offset at LSL	-4.695
Error at LSL (as % of tolerance)	11.7%
Gold Tester Precision/Tolerance Ratio	14%
Correlating Tester Precision/Tolerance Ratio	21%
Decision Analysis	
Correlation	Unacceptable
Linearity to Gold	Unacceptable
Offset to Gold	Unacceptable
Correlating Tester Precision	Marginal Accept
Correlating Tester Error Independence	Fail

Contrast Correlation Summary: System 2 to System 1	
Gold System ID	Machine 3
Correlating System ID	Machine 2
r-sq	87.9%
t-value (test of independence)	12.9327
Slope	1.016
Slope error	0.079
Intercept	0.028
Offset at USL	0.028
Error at USL (as % of tolerance)	0.1%
Offset at LSL	0.028
Error at LSL (as % of tolerance)	0.1%
Gold Tester Precision/Tolerance Ratio	21%
Correlating Tester Precision/Tolerance Ratio	22%
Decision Analysis	
Correlation	Marginal Accept
Linearity to Correlating Tester	Acceptable
Offset to Correlating Tester	Acceptable
Correlating Tester Precision	Marginal Accept
Correlating Tester Error Independence	Pass

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Call to Action

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- MSC assures that the production or source measurement equipment can repeat values obtained on the “originating” Gold Measurement system, providing confidence that production units meet the customer specification
- Raytheon template is easy to use and requires no calculation or data manipulation from the user
- Utilizing MSC processes on production measurement equipment is a Raytheon requirement for specific product characteristics

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References and Resources

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Textbooks:

- Statistics for Management: Levin, Richard

Questions? Ask the expert!

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End