Gauge R & R

Evaluating the Precision of your Measurement System

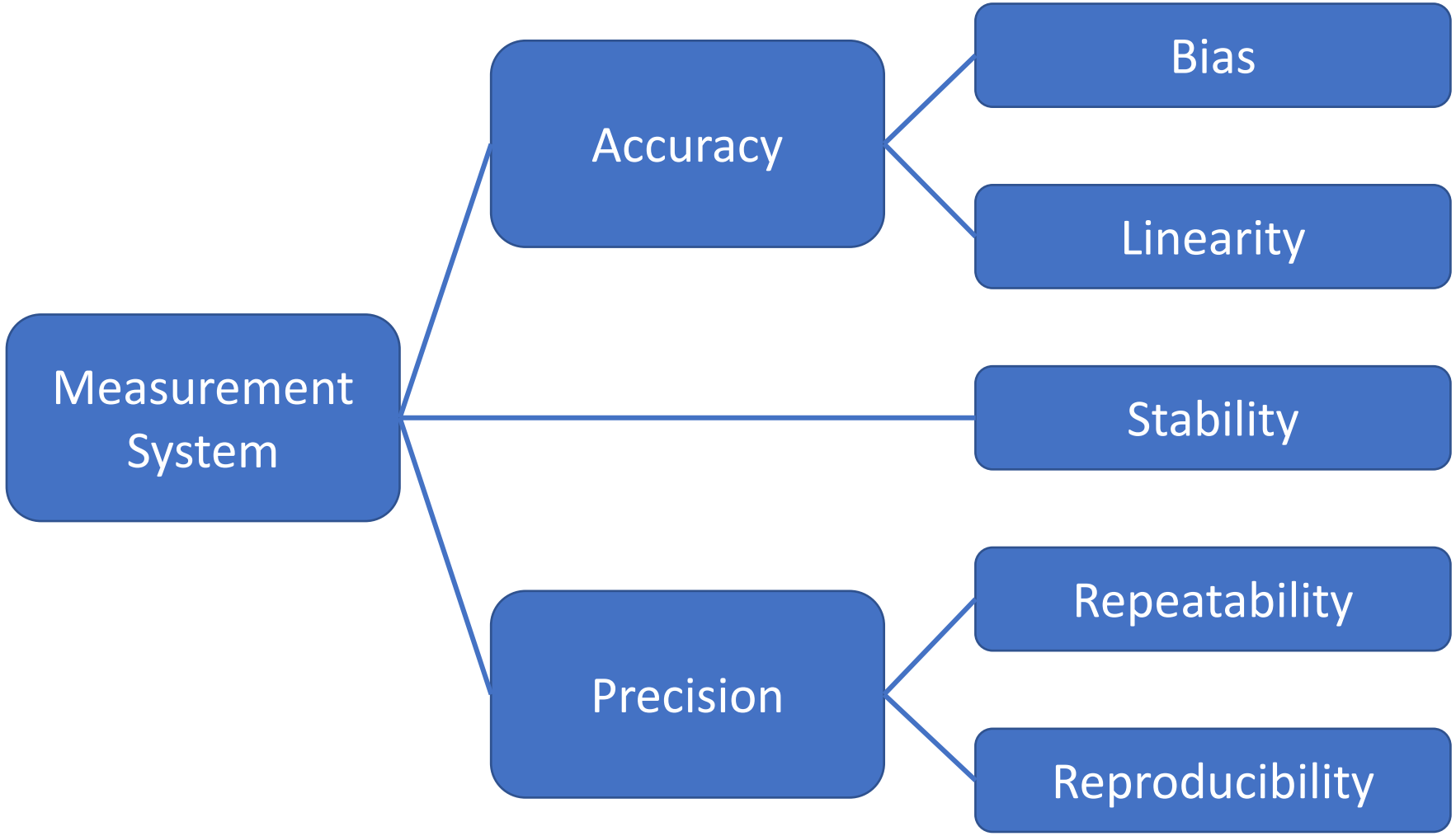
Precision Scientific Software Inc.

Contents

Measurement System Analysis (MSA)

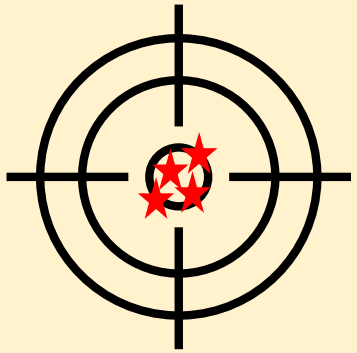
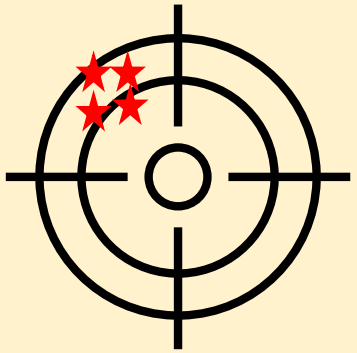
- Variation is inherent in all measurements
  - Product and Process: input materials, production process
  - Measurement System: test methods, equipment, appraisers
- Measurement system analysis is used to analyze the contribution of the measurement system to the total variation seen in the final product
- Goal of measurement system analysis
  - Minimize the amount of variation due to the measurement system
- Variation in the measurement system should be small compared to the variation in the product
  - Ideally no more than 10% of the variation in the product and process

Components of Measurement System Variation



Components of MS Variation – Accuracy vs Precision

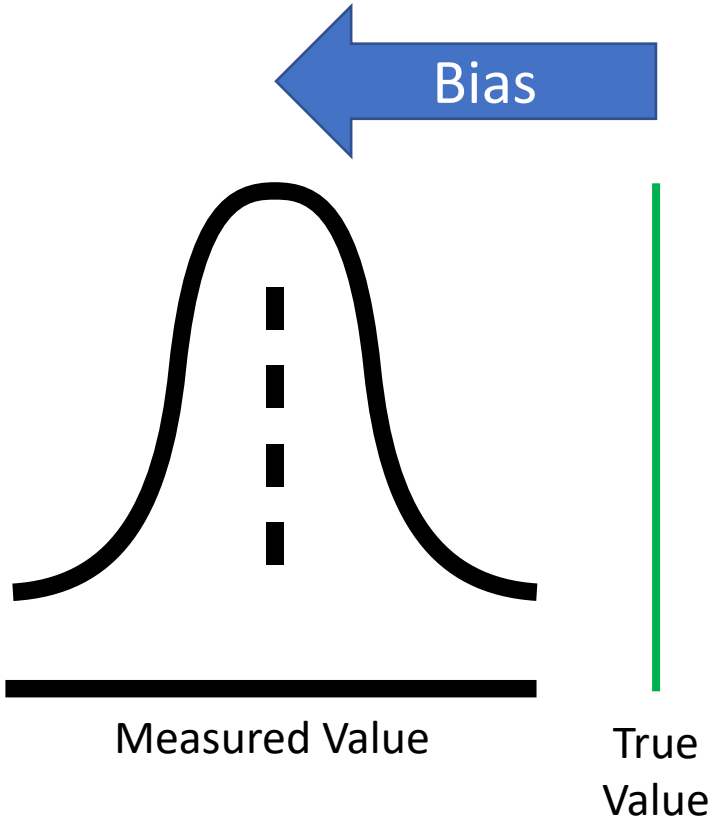
- Accuracy – degree of closeness of a measurement to the true value
- Precision – degree of closeness of repeated measurements to each other

Accurate and Precise	Accurate but Not Precise	Precise but Not Accurate	Not Accurate and Not Precise
			

- Error in Accuracy results in an error of location
- Error in Precision results in an error of spread

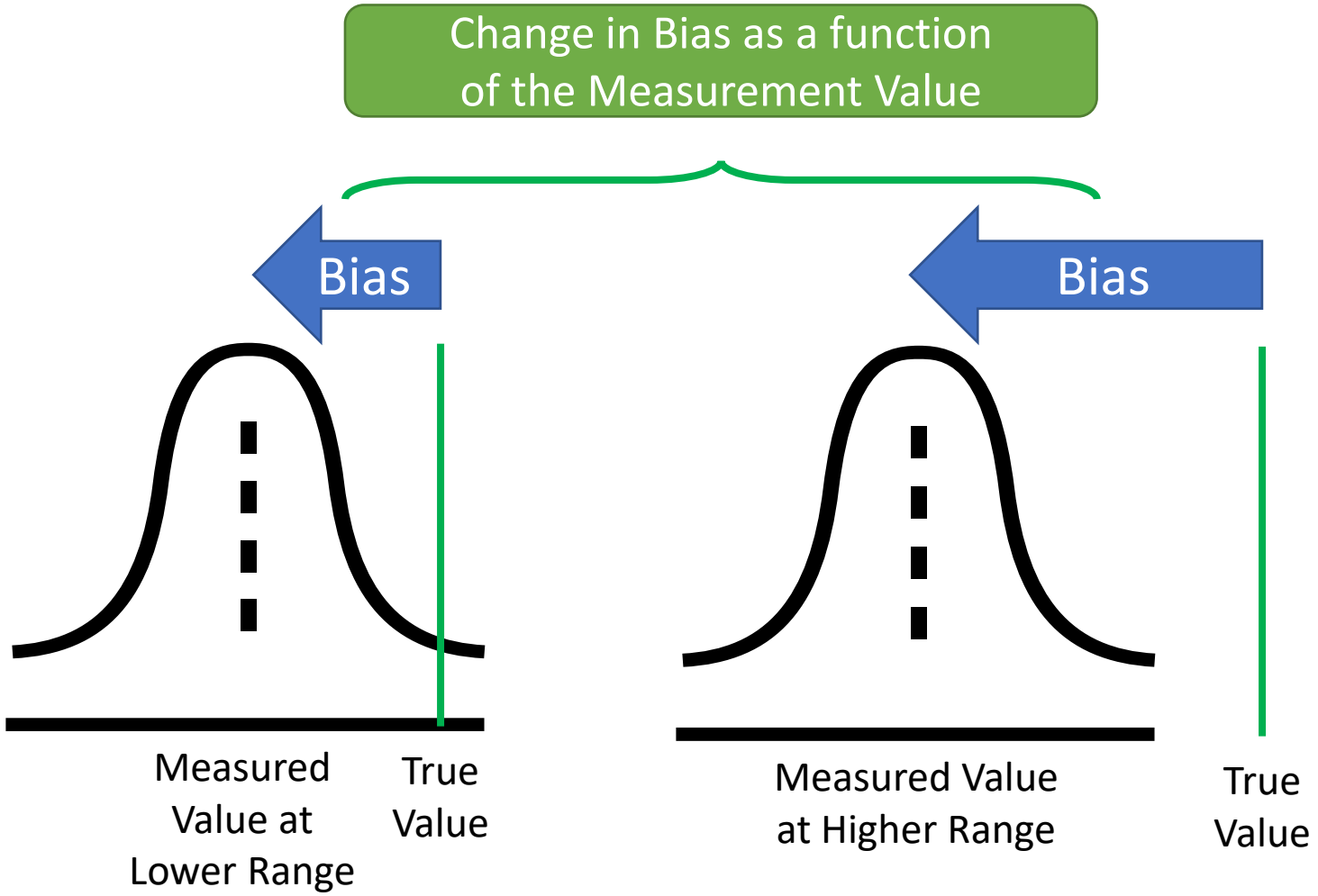
Components of MS Variation – Bias

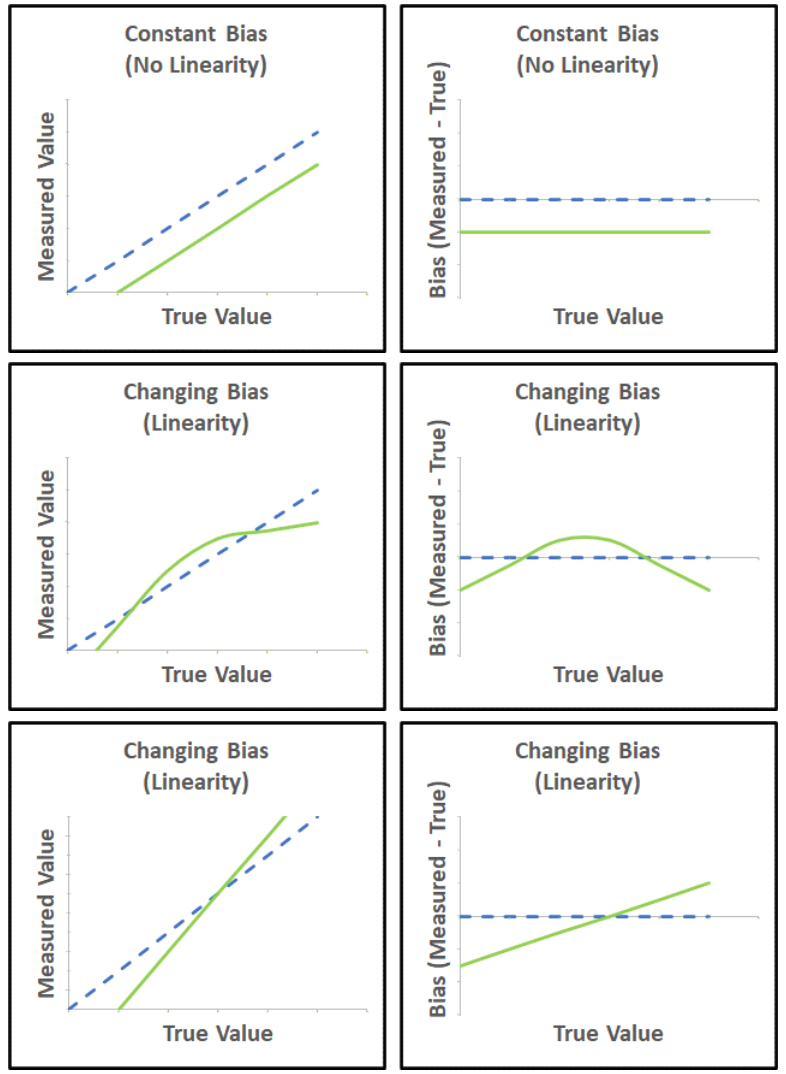
- Bias is the difference between the measured value and the true value
  - The true value can be determined by averaging repeated measurements using a "higher order" measurement device



Components of MS Variation – Linearity

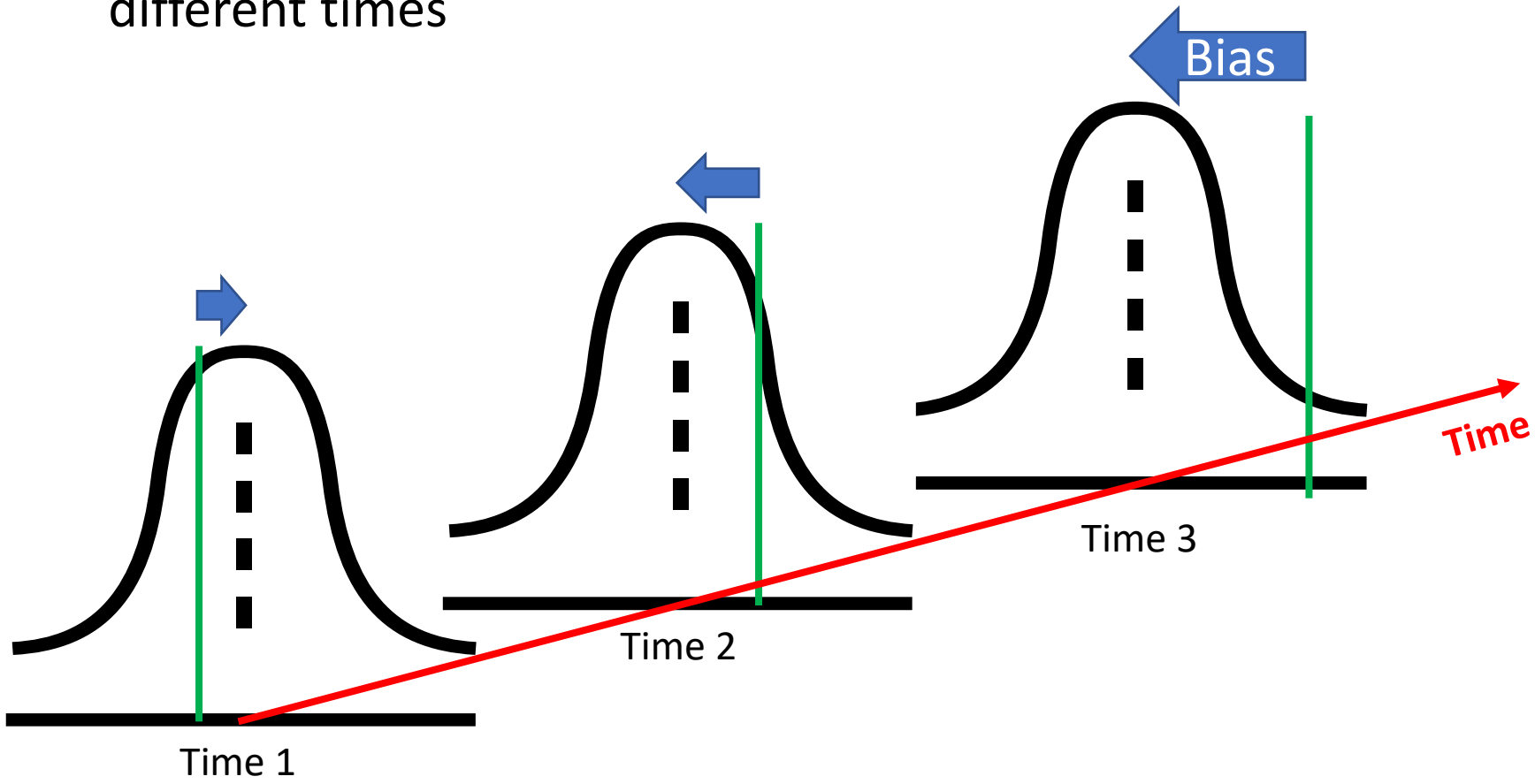
- Linearity is the change in bias over the operating range of the instrument
  - Measured by same appraiser using the same gauge

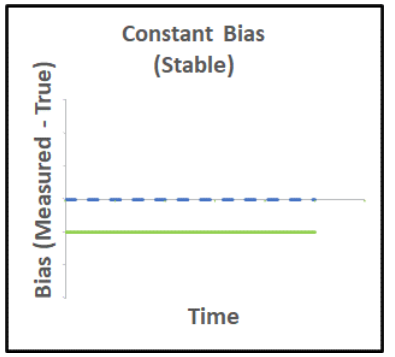


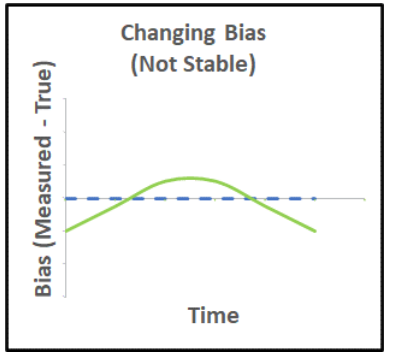


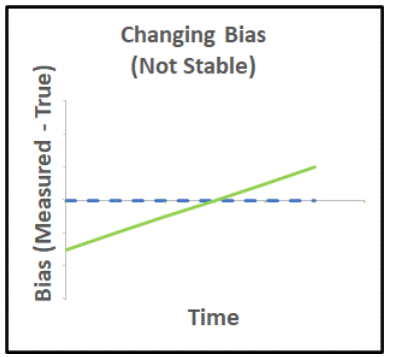
Components of MS Variation – Stability

- Stability is the change in bias when measurements are made over an extended period of time (days / weeks / months)
  - Same part measured by same appraiser using the same gauge at different times





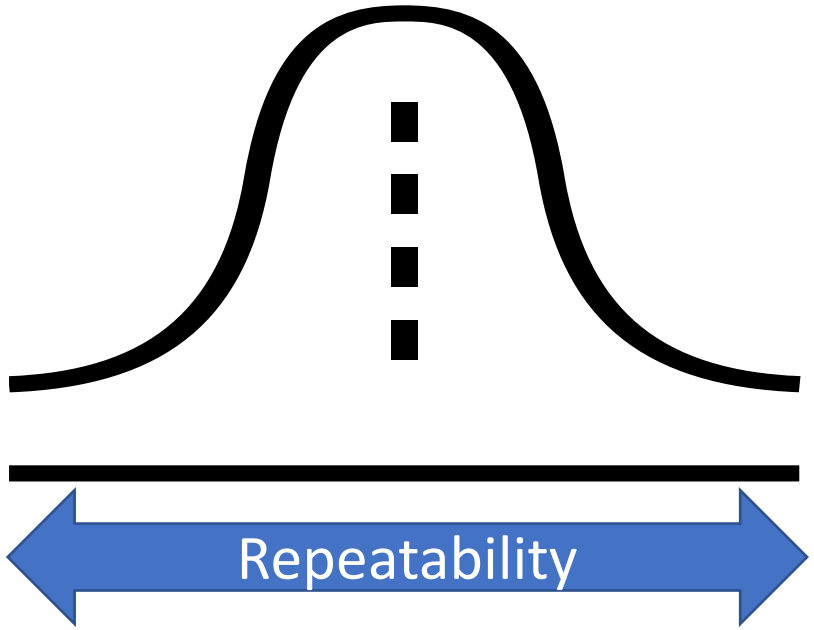




Components of MS Variation – Repeatability

- Repeatability is amount of variation between repeated measurements
  - Same part measured by same appraiser using the same gauge at the same time

- Referred to as Equipment Variation (EV)
  - Also referred to as “within appraiser variation”

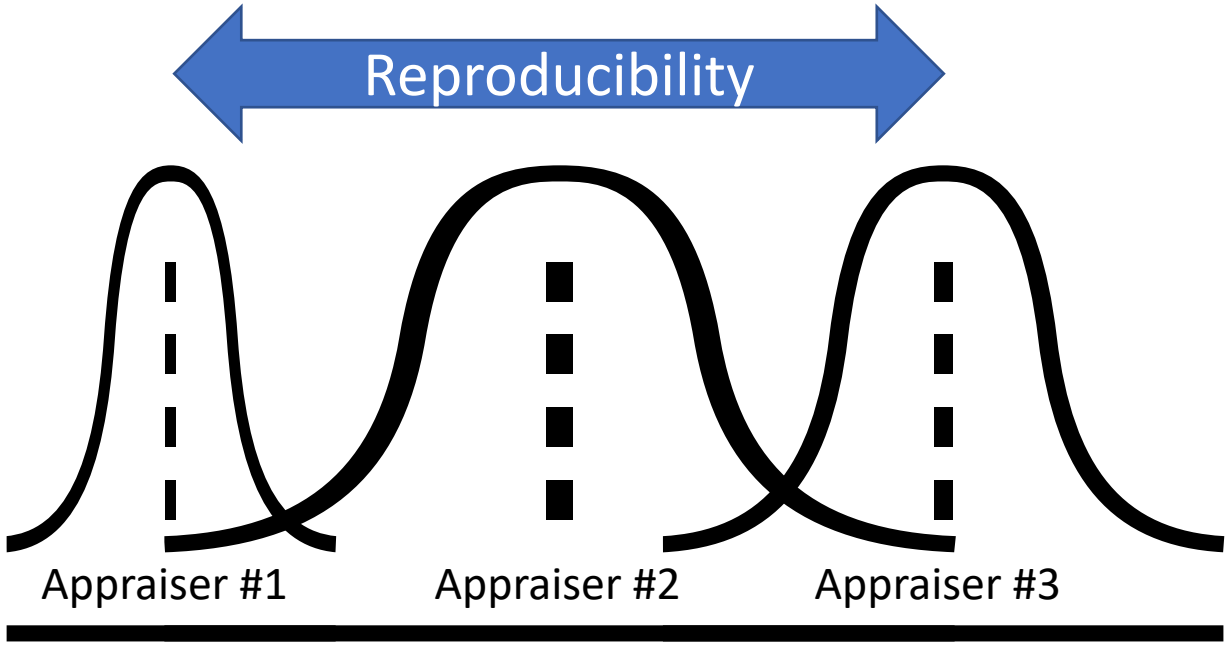


Narrower range indicates improved repeatability

Components of MS Variation – Reproducibility

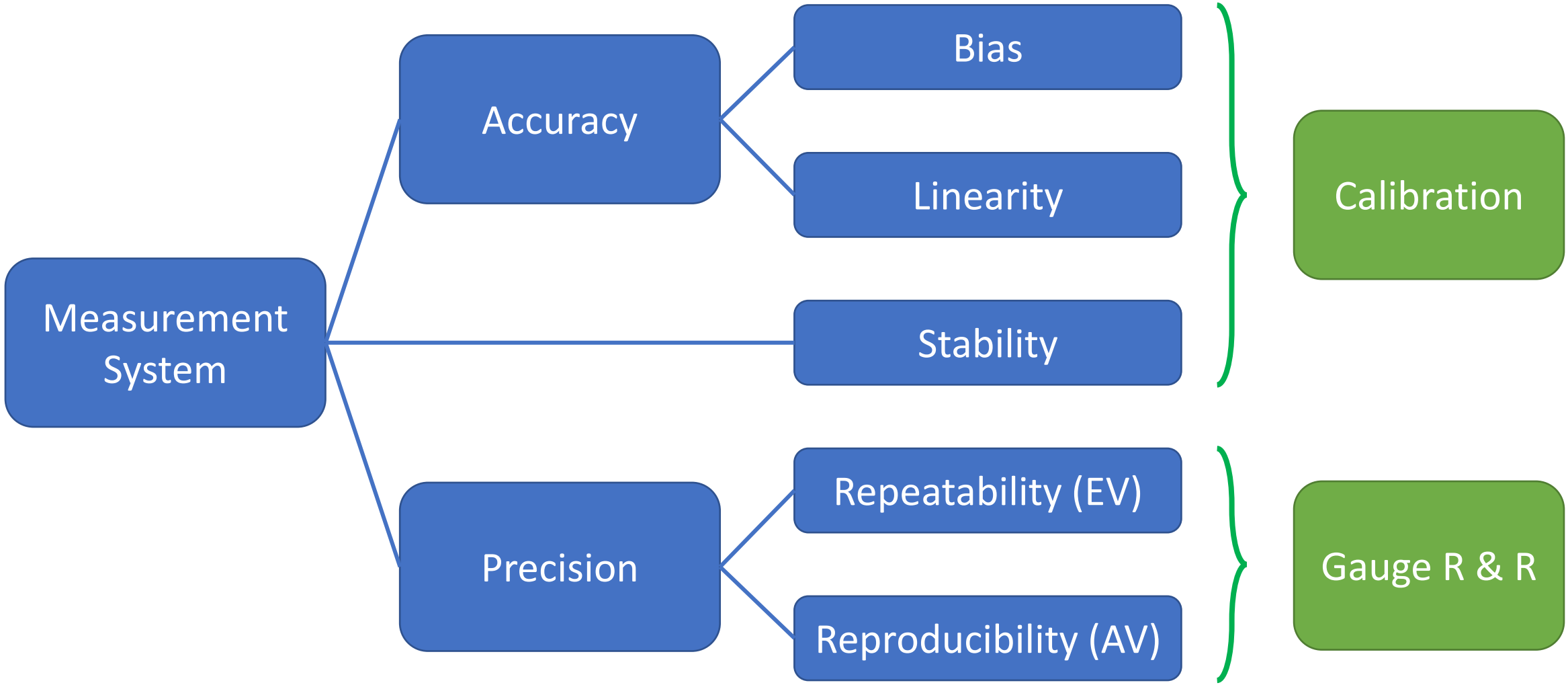
- Reproducibility is amount of variation between different appraisers
  - Same part measured by different appraisers using the same gauge

- Referred to as Appraiser Variation (AV)
  - Also referred to as “between appraiser variation”



Narrower range indicates improved reproducibility

Components of Measurement System Variation



Gauge R & R Concepts

- Measurement variation is comprised of
  - True product variation (PV)
  - Repeatability: variation due to measurement equipment (EV)
  - Reproducibility: variation due to different appraisers (AV)

- Relationship of the variances
  - $\sigma_m^2 = \sigma_P^2 + \sigma_E^2 + \sigma_A^2$

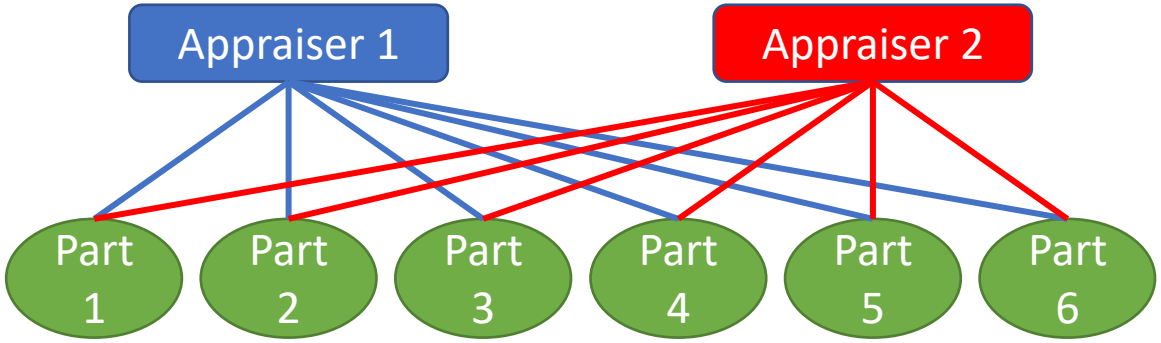
- Gauge R & R isolates the σ_E^2 and σ_A^2 terms to quantify the amount of measurement variation that is attributable to the measurement system

Gauge R & R Experimental Design

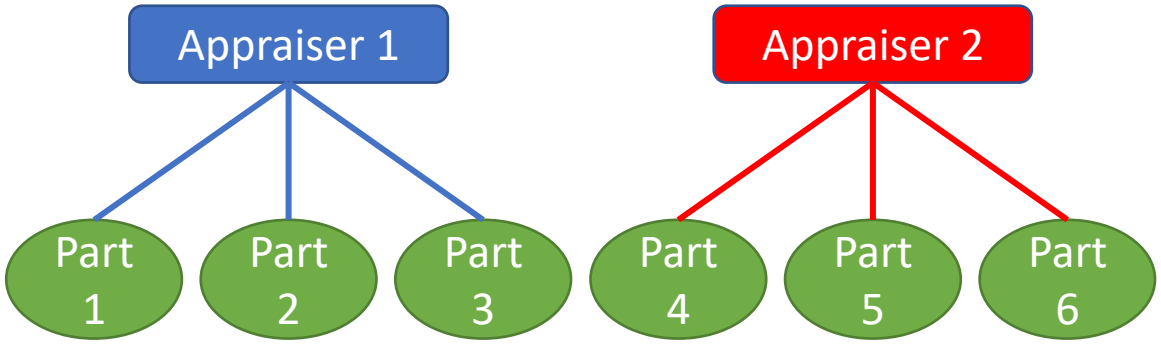
- Number of observations
  - Appraisers — minimum 2 — preferably 3 or 4
  - Parts — 10 — cover entire range of the product's tolerance
  - Trials — minimum 2 — preferably 3 repeats per part per appraiser
  - Observations — 3 x 10 x 3 = 90 — (3 Appraisers x 10 Parts x 3 Trials)
- Parts should be presented to the appraisers in random order and masked to avoid introducing bias into the measurements
- All appraisers should use the same testing method and the same gauge
- This configuration analyzes the R & R of different appraisers
  - To analyze the R & R of different gauges, conduct the analysis with 1 appraiser using 3 gauges (randomizing the order of both the parts and the gauges)

Gauge R & R Experimental Design

- Crossed Study
  - Each part measured by all appraisers
  - Used for non-destructive testing
  - 2-factors: appraiser and part



- Nested Study
  - Each part measured by one appraiser
  - Used for destructive testing
  - 2-factors: appraiser and part
  - Care must be taken to ensure that the parts measured by each appraiser are as identical as possible
    - Parts 1 & 4 should be equivalent, parts 2 & 5 should be equivalent, etc

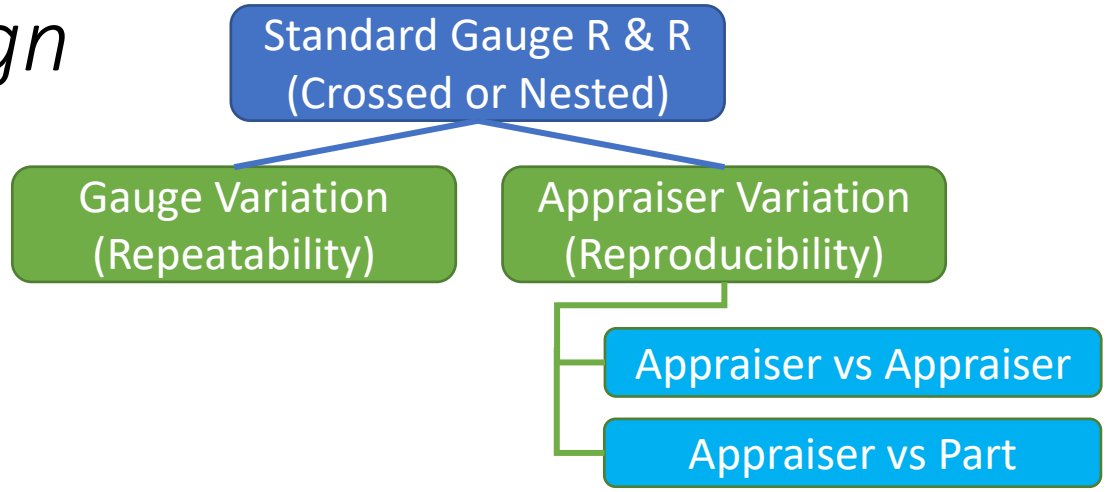


Gauge R & R Experimental Design

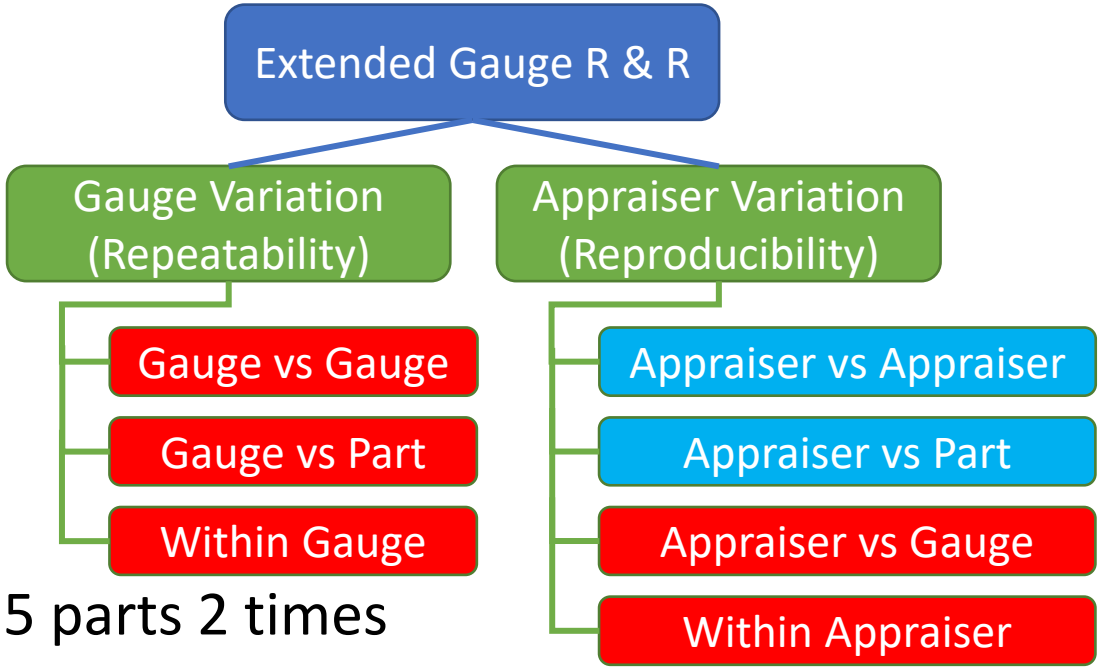
- Destructive testing
  - There are situations where an individual part cannot be tested more than one
    - Example: testing a part either destroys or permanently changes the part
  - Collect parts from Lots which cover the entire range of the production process
  - Take individual parts from each of the Lots
    - The individual parts from each Lot should be as identical as possible
  - For instance, taking 9 individual parts from each of 10 Lots allows 3 appraisers to each test 3 parts from each of the 10 Lots
  - This design mimics a Gauge R & R Study done with non-destructive testing
  - However, there will unavoidably be a component of process variation built into the part-to-part variation (PV)
    - If the Lots are as dissimilar from each other as possible, and the parts within each Lot are as similar as possible then the degree of process variation will be minimized relative to the part-to-part variation

Gauge R & R Experimental Design

- Expanded Study
  - Analyze up to 8 factors
    - Appraiser, Part,
    - Gauge, Lab, Location
  - Analyze interactions between all factors
  - Can handle missing data

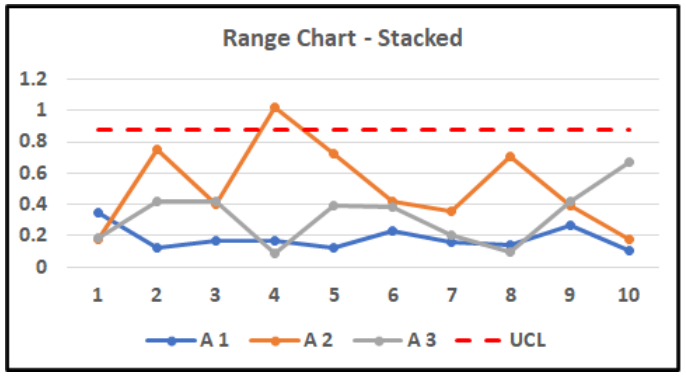


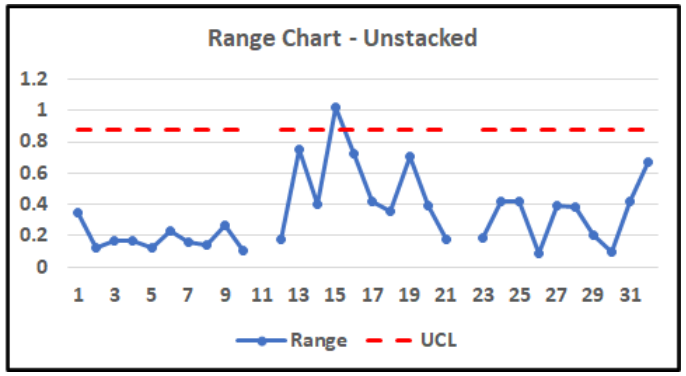
- Data collection plan is often adjusted to avoid the large number of tests that would be required by repeating the standard plan for each new factor
  - Example:
    - 3 appraisers use 3 gauges to measure 5 parts 2 times
      - 3 x 3 x 5 x 2 = 90 total observations



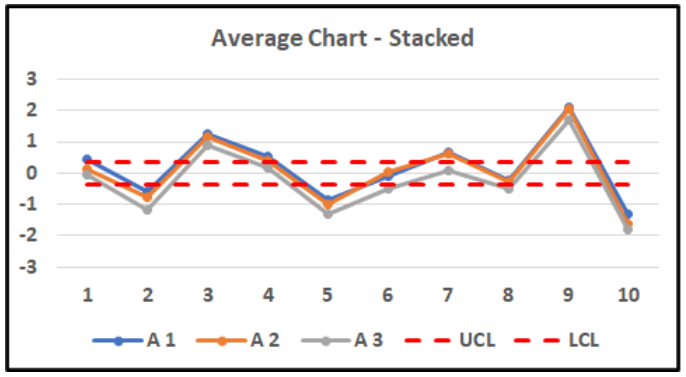
Gauge R & R Findings

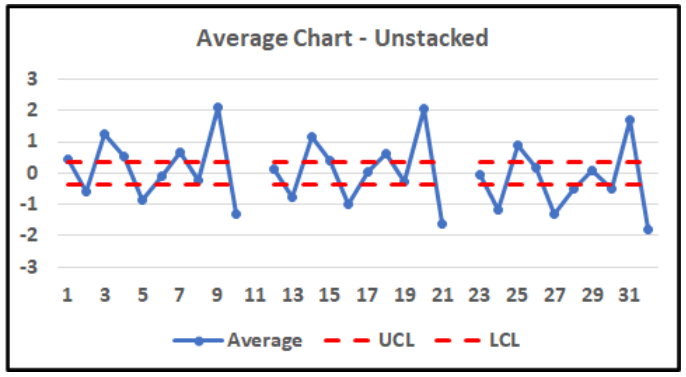
- Calculation methods





  - Range method
    - Quick approximation of measurement variability
    - Does not compute repeatability and reproducibility separately





  - Average and range method
    - Quantifies variability
    - Calculates repeatability, reproducibility, and part variation
    - Can only be used with Crossed Study

Gauge R & R Findings

- Calculation methods
  - Analysis of Variance (ANOVA) method
    - Most widely used and accurate method
    - Calculates repeatability, reproducibility, and interactions between all factors
    - Can be used with Nested, Crossed, and Extended Study types
- Targets indicating that the GRR Study was well designed and that the measurement system is suitable for the process being measured

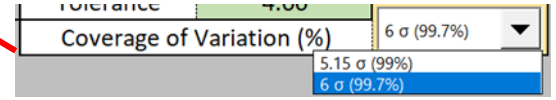
% Contribution to Variance	% of Study Variation – or – % of Process Tolerance	Comment
< 1%	< 10%	Measurement System is considered acceptable
>= 1% & < 9%	>= 10% & < 30%	Measurement System may be acceptable depending on application and cost factors, but try to improve it
>= 9%	>= 30%	Measurement System is considered unacceptable

  - Number of Distinct Categories (NDC)
    - >= 5

Using the Gauge R & R Template – Data Region

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	About	Gauge Repeatability & Reproducibility Study					Date	2021-03-22	Analyst	Lily Kim		Study No.	2021 Pipe 001	
2														
3		Appraiser	Name		Location		Gauge ID		Gauge Type		Part Type	metal pipe		
4		A	Lynda Mann		Quality Assurance		Caliper		CAL-QA-001		Characteristic	outside diameter		
5		B	Isabelle Valdez		Quality Assurance		Trial Count	3	K1 (EV)	0.5908	Units	mm		
6		C	Yousef Khan		Production		Appraiser Count	3	K2 (AV)	0.5231	Spec Range	98.00	102.00	
7		D					Part Count	10	K3 (PV)	0.3146	Tolerance	4.00		
8		E					Observations	90			Coverage of Variation (%)	6 σ (99.7%)		
9														
10														
11							Part							
12		Part ID	Dowel - 01	Dowel - 02	Dowel - 03	Dowel - 04	Dowel - 05	Dowel - 06	Dowel - 07	Dowel - 08	Dowel - 09	Dowel - 10		
13		Part Number	1	2	3	4	5	6	7	8	9	10	Statistics	
14	Appraiser A	1	98.78	98.36	98.22	100.56	99.56	98.11	98.24	101.47	98.44	100.10	Ave	99.18
15	Sum	2	97.87	98.36	98.45	100.21	99.47	98.23	98.24	101.89	97.80	99.88	Ave	99.04
16	2971.45	3	97.87	98.21	98.33	100.13	99.69	98.12	98.27	101.31	97.72	99.56	Ave	98.92
17	Sum^2 / Count	Average	98.17	98.31	98.33	100.30	99.57	98.15	98.25	101.56	97.99	99.85	XbarA	99.05
18	294317.17	Range	0.910	0.150	0.230	0.430	0.220	0.120	0.030	0.580	0.720	0.540	RbarA	0.393
19	Appraiser B	1	98.56	98.13	98.41	100.12	99.47	98.11	98.22	101.36	98.44	100.65	Ave	99.15
20	Sum	2	98.22	98.36	98.36	100.36	99.89	98.23	98.23	101.47	97.80	99.89	Ave	99.08
21	2973.38	3	98.14	98.34	98.33	100.56	99.78	98.12	98.24	101.87	97.72	100.00	Ave	99.11
22	Sum^2 / Count	Average	98.31	98.28	98.37	100.35	99.71	98.15	98.23	101.57	97.99	100.18	XbarB	99.11
23	294699.62	Range	0.420	0.230	0.080	0.440	0.420	0.120	0.020	0.510	0.720	0.760	RbarB	0.372
24	Appraiser C	1	98.56	98.56	98.12	100.25	99.47	98.11	98.27	101.21	98.44	100.12	Ave	99.11
25	Sum	2	98.22	98.12	98.45	100.36	99.89	98.23	98.26	101.36	97.80	99.25	Ave	98.99
26	2971.11	3	98.15	98.32	98.33	100.22	99.75	98.12	98.22	101.54	97.72	99.69	Ave	99.01
27	Sum^2 / Count	Average	98.31	98.33	98.30	100.28	99.70	98.15	98.25	101.37	97.99	99.69	XbarC	99.04
28	294249.82	Range	0.410	0.440	0.330	0.140	0.420	0.120	0.050	0.330	0.720	0.870	RbarC	0.383
29	Appraiser D	1											Ave	n/a
30	Sum	2											Ave	n/a
31	0.00	3											Ave	n/a
32	Sum^2 / Count	Average	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	XbarD	n/a
33	0.00	Range	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	RbarD	n/a
34	Appraiser E	1											Ave	n/a
35	Sum	2											Ave	n/a
36	0.00	3											Ave	n/a
37	Sum^2 / Count	Average	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	XbarF	n/a
38	0.00	Range	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	RbarF	n/a
39	All Appraisers	Average	98.26	98.31	98.33	100.31	99.66	98.15	98.24	101.50	97.99	99.90	Xbarbar	99.07
40		Range	0.500	0.290	0.250	0.300	0.200	0.000	0.030	0.250	0.000	0.330	Rbar Appr	0.215
41	Count	n	9	9	9	9	9	9	9	9	9	9	Total	90
42	Sum	X	884.37	884.76	885.00	902.77	896.97	883.38	884.19	913.48	881.88	899.14	Total	8915.94
43	Sum^2 / Count	X^2 / n	86901.14	86977.81	87025.00	90554.85	89395.02	86706.69	86865.77	92716.19	86412.48	89828.08	Total	883383.04
44		Sum[Sum^2/#Trials]	86901.18	86977.81	87025.01	90554.86	89395.06	86706.69	86865.77	92716.26	86412.48	89828.46	Total	883383.59
45		Sum(X^2)	86901.93	86977.96	87025.09	90555.07	89395.27	86706.72	86865.78	92716.64	86413.42	89829.33	Total	883387.19
46													Rpart	3.511
47	Average of Ranges	[RbarA + RbarB + RbarC + RbarD + RbarE] / [Count of Appraisers]											Rbarbar	0.383
48	Range of Averages	MAX(XbarA + XbarB + XbarC + XbarD + XbarE) - MIN(XbarA + XbarB + XbarC + XbarD + XbarE)											Xbar diff	0.08
49	Upper Control Limit of Range	Rbarbar * D4								D4	2.5740		Range UCL	0.985
50	+/- Control Limits of Average	Rbarbar * A2								A2	1.0230		Ave CL (+/-)	0.39

Enter Study Information, including High and Low Tolerance Specs and Coverage of Variation (5.15 or 6 σ), in this top region

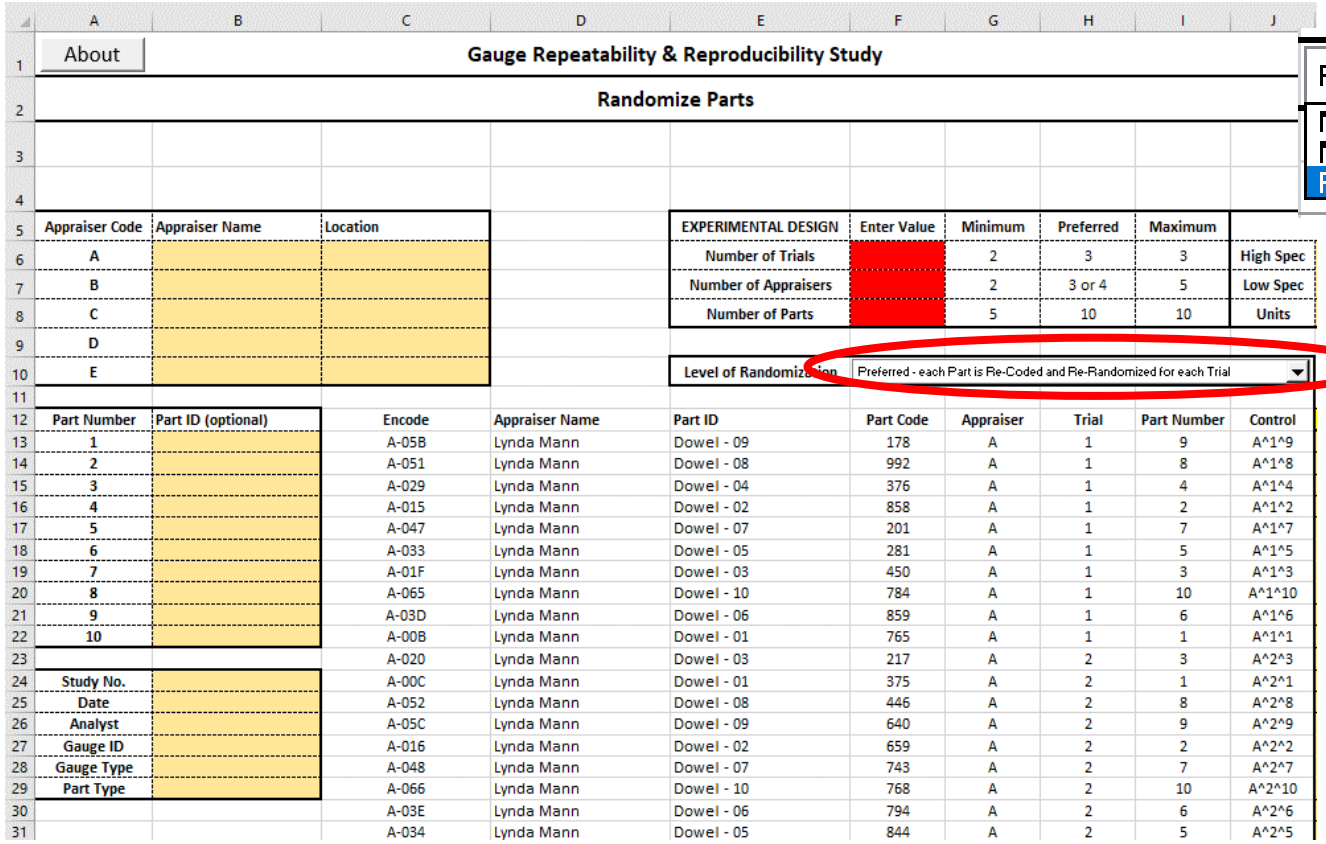


Enter the Test Results in this region. This example shows 3 Appraisers each testing 10 Parts with 3 repetitions per Part. Up to 5 Appraisers can be included in the GRR Study.

Cells are colour-coded based on their contents:
- Yellow cells: data entry
- Green cells: calculated results
- Grey cells: sub-calculations required for statistical results

Using the Gauge R & R Template – Randomization

- The Randomize worksheet conveniently:
  - Randomize the order of presentation of the Parts to the Appraisers
  - Generate random code numbers to mask the identity of the Parts
  - Enable recording the test results without having to “de-randomized” the data



About

Gauge Repeatability & Reproducibility Study

Randomize Parts

Appraiser Code	Appraiser Name	Location
A		
B		
C		
D		
E		

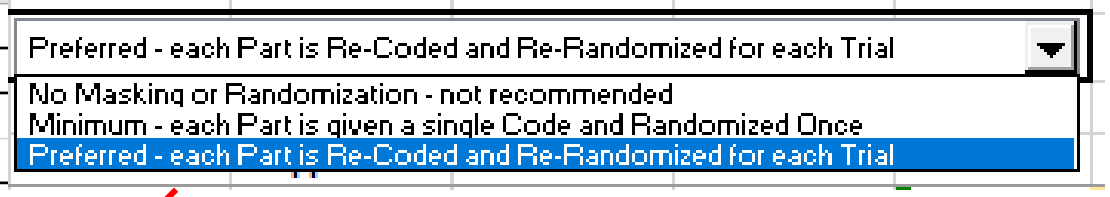
EXPERIMENTAL DESIGN	Enter Value	Minimum	Preferred	Maximum	
Number of Trials		2	3	3	High Spec
Number of Appraisers		2	3 or 4	5	Low Spec
Number of Parts		5	10	10	Units

Level of Randomization: Preferred - each Part is Re-Coded and Re-Randomized for each Trial

Part Number	Part ID (optional)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Study No.	
Date	
Analyst	
Gauge ID	
Gauge Type	
Part Type	

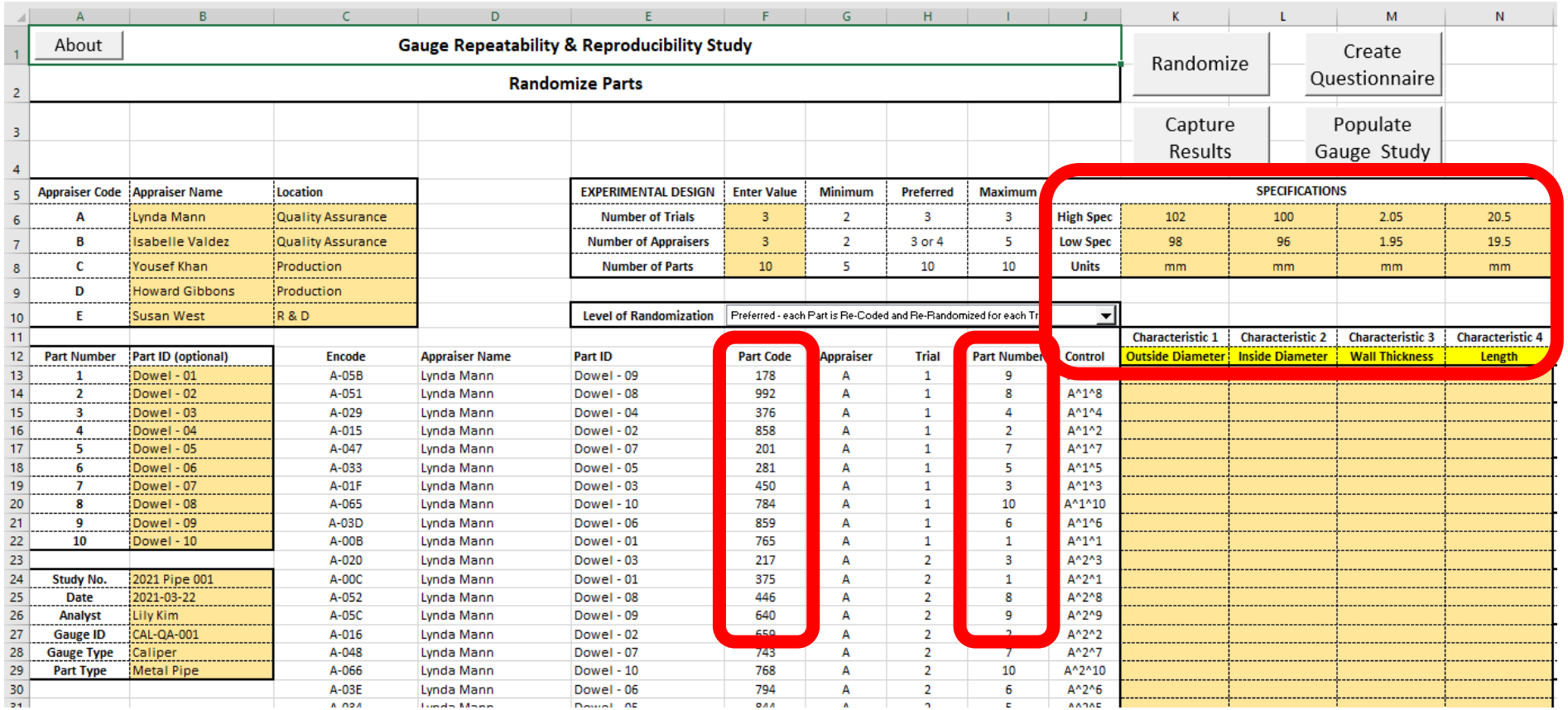
Encode	Appraiser Name	Part ID	Part Code	Appraiser	Trial	Part Number	Control
A-05B	Lynda Mann	Dowel - 09	178	A	1	9	A^1^9
A-051	Lynda Mann	Dowel - 08	992	A	1	8	A^1^8
A-029	Lynda Mann	Dowel - 04	376	A	1	4	A^1^4
A-015	Lynda Mann	Dowel - 02	858	A	1	2	A^1^2
A-047	Lynda Mann	Dowel - 07	201	A	1	7	A^1^7
A-033	Lynda Mann	Dowel - 05	281	A	1	5	A^1^5
A-01F	Lynda Mann	Dowel - 03	450	A	1	3	A^1^3
A-065	Lynda Mann	Dowel - 10	784	A	1	10	A^1^10
A-03D	Lynda Mann	Dowel - 06	859	A	1	6	A^1^6
A-00B	Lynda Mann	Dowel - 01	765	A	1	1	A^1^1
A-020	Lynda Mann	Dowel - 03	217	A	2	3	A^2^3
A-00C	Lynda Mann	Dowel - 01	375	A	2	1	A^2^1
A-052	Lynda Mann	Dowel - 08	446	A	2	8	A^2^8
A-05C	Lynda Mann	Dowel - 09	640	A	2	9	A^2^9
A-016	Lynda Mann	Dowel - 02	659	A	2	2	A^2^2
A-048	Lynda Mann	Dowel - 07	743	A	2	7	A^2^7
A-066	Lynda Mann	Dowel - 10	768	A	2	10	A^2^10
A-03E	Lynda Mann	Dowel - 06	794	A	2	6	A^2^6
A-034	Lynda Mann	Dowel - 05	844	A	2	5	A^2^5



- Specify the Experimental Design
  - Number of Trials, Number of Appraisers, and Number of Parts
  - Study Number, Gauge ID and Type
- Enter the desired Level of Randomization
  - None / Minimum / Preferred
- Enter the Appraiser Names and Part IDs
- Randomize button randomly orders the Parts and generates their random masking codes

Using the Gauge R & R Template – Randomization

- The randomization table has 1 row for each test that will be performed
  - Rows are grouped by Appraiser and then by Trial (repetition)
  - The Part masking code and order are randomized
  - Up to 4 Characteristics and their specifications can be entered in the template



About

Gauge Repeatability & Reproducibility Study

Randomize Parts

Randomize | Create Questionnaire | Capture Results | Populate Gauge Study

Appraiser Code	Appraiser Name	Location
A	Lynda Mann	Quality Assurance
B	Isabelle Valdez	Quality Assurance
C	Yousef Khan	Production
D	Howard Gibbons	Production
E	Susan West	R & D

Study No.	2021 Pipe 001
Date	2021-03-22
Analyst	Lily Kim
Gauge ID	CAL-QA-001
Gauge Type	Caliper
Part Type	Metal Pipe

EXPERIMENTAL DESIGN	Enter Value	Minimum	Preferred	Maximum
Number of Trials	3	2	3	3
Number of Appraisers	3	2	3 or 4	5
Number of Parts	10	5	10	10

Level of Randomization: Preferred - each Part is Re-Coded and Re-Randomized for each Tr

SPECIFICATIONS				
High Spec	102	100	2.05	20.5
Low Spec	98	96	1.95	19.5
Units	mm	mm	mm	mm

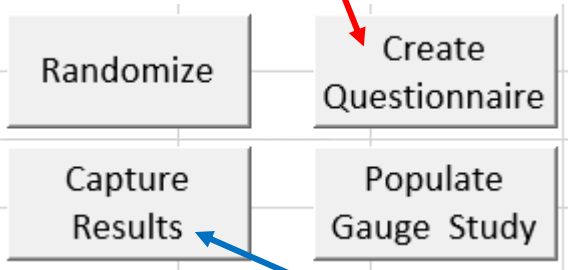
Part Number	Part ID (optional)	Encode	Appraiser Name	Part ID	Part Code	Appraiser	Trial	Part Number	Control	Characteristic 1	Characteristic 2	Characteristic 3	Characteristic 4
										Outside Diameter	Inside Diameter	Wall Thickness	Length
1	Dowel - 01	A-05B	Lynda Mann	Dowel - 09	178	A	1	9					
2	Dowel - 02	A-051	Lynda Mann	Dowel - 08	992	A	1	8	A^1^8				
3	Dowel - 03	A-029	Lynda Mann	Dowel - 04	376	A	1	4	A^1^4				
4	Dowel - 04	A-015	Lynda Mann	Dowel - 02	858	A	1	2	A^1^2				
5	Dowel - 05	A-047	Lynda Mann	Dowel - 07	201	A	1	7	A^1^7				
6	Dowel - 06	A-033	Lynda Mann	Dowel - 05	281	A	1	5	A^1^5				
7	Dowel - 07	A-01F	Lynda Mann	Dowel - 03	450	A	1	3	A^1^3				
8	Dowel - 08	A-065	Lynda Mann	Dowel - 10	784	A	1	10	A^1^10				
9	Dowel - 09	A-03D	Lynda Mann	Dowel - 06	859	A	1	6	A^1^6				
10	Dowel - 10	A-00B	Lynda Mann	Dowel - 01	765	A	1	1	A^1^1				
		A-020	Lynda Mann	Dowel - 03	217	A	2	3	A^2^3				
		A-00C	Lynda Mann	Dowel - 01	375	A	2	1	A^2^1				
		A-052	Lynda Mann	Dowel - 08	446	A	2	8	A^2^8				
		A-05C	Lynda Mann	Dowel - 09	640	A	2	9	A^2^9				
		A-016	Lynda Mann	Dowel - 02	659	A	2	2	A^2^2				
		A-048	Lynda Mann	Dowel - 07	743	A	2	7	A^2^7				
		A-066	Lynda Mann	Dowel - 10	768	A	2	10	A^2^10				
		A-03E	Lynda Mann	Dowel - 06	794	A	2	6	A^2^6				

Using the Gauge R & R Template – Generate Questionnaire

- There are 3 ways to enter the data into the system
  1. A Questionnaire worksheet is automatically generated
     - This worksheet can be printed out and each page can be given to an Appraiser
     - Questionnaire includes the random sample codes and space to enter results

	A	B	C	D	E	F
1	Gauge R&R Study		Lynda Mann			Trial 1
2						
3	Study Date	Study Number	Gauge ID	Gauge Type	Part Type	
4	2021-03-22	2021 Pipe 001	CAL-QA-001	Caliper	Metal Pipe	
5						
6	Sample	Outside Diameter	Inside Diameter	Wall Thickness	Length	Code
7		mm	mm	mm	mm	
8	178	98.44	96.05	2.528	27.16	A-05B
9	992	101.47	99.07	2.44	27.34	A-051
10	376	100.56	98.45	2.092	27.18	A-029
11	858	98.36	95.48	2.71	27.86	A-015
12	201	98.24	95.79	2.574	27.49	A-047
13	281	99.56	96.78	2.798	27.35	A-033
14	450	98.22	95.94	2.184	27.24	A-01F
15	784	100.1	97.49	2.576	27.04	A-065
16	859	98.11	95.43	2.524	27.9	A-03D
17	765	98.78	96.06	2.91	27.9	A-00B

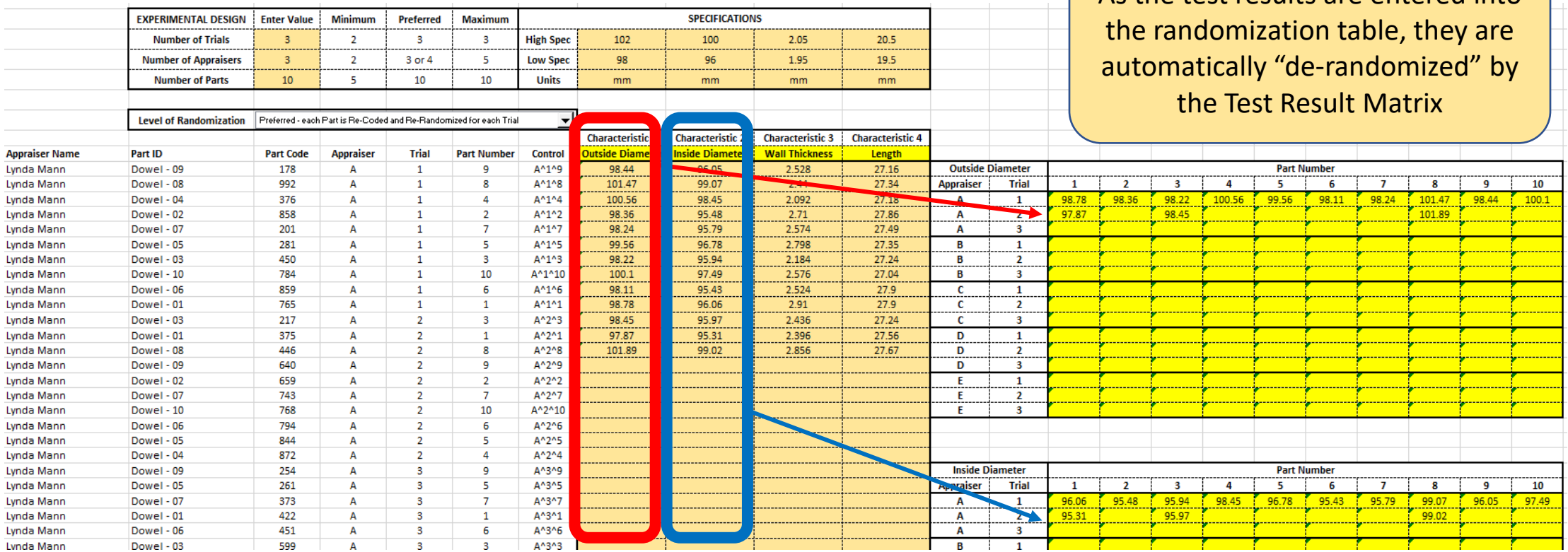
The results can either be written onto a paper Questionnaire or can be entered directly into the Study workbook



Use the Capture Results command button on the Randomize worksheet to transfer the results from the Questionnaire into the data region of Randomize

Using the Gauge R & R Template – Enter Data in Randomize

2. If preferred, the results can be entered directly into the data region of the Randomize worksheet
   - This is especially useful if the Appraisers wrote their results onto paper Questionnaire sheets



EXPERIMENTAL DESIGN	Enter Value	Minimum	Preferred	Maximum	SPECIFICATIONS				
Number of Trials	3	2	3	3	High Spec	102	100	2.05	20.5
Number of Appraisers	3	2	3 or 4	5	Low Spec	98	96	1.95	19.5
Number of Parts	10	5	10	10	Units	mm	mm	mm	mm

Level of Randomization: Preferred - each Part is Re-Coded and Re-Randomized for each Trial

Appraiser Name	Part ID	Part Code	Appraiser	Trial	Part Number	Control	Characteristic	Characteristic	Characteristic 3	Characteristic 4
							Outside Diame	Inside Diamete	Wall Thickness	Length
Lynda Mann	Dowel - 09	178	A	1	9	A^1^9	98.44	[illegible]	2.528	27.16
Lynda Mann	Dowel - 08	992	A	1	8	A^1^8	101.47	99.07	[illegible]	27.34
Lynda Mann	Dowel - 04	376	A	1	4	A^1^4	100.56	98.45	2.092	27.18
Lynda Mann	Dowel - 02	858	A	1	2	A^1^2	98.36	95.48	2.71	27.86
Lynda Mann	Dowel - 07	201	A	1	7	A^1^7	98.24	95.79	2.574	27.49
Lynda Mann	Dowel - 05	281	A	1	5	A^1^5	99.56	96.78	2.798	27.35
Lynda Mann	Dowel - 03	450	A	1	3	A^1^3	98.22	95.94	2.184	27.24
Lynda Mann	Dowel - 10	784	A	1	10	A^1^10	100.1	97.49	2.576	27.04
Lynda Mann	Dowel - 06	859	A	1	6	A^1^6	98.11	95.43	2.524	27.9
Lynda Mann	Dowel - 01	765	A	1	1	A^1^1	98.78	96.06	2.91	27.9
Lynda Mann	Dowel - 03	217	A	2	3	A^2^3	98.45	95.97	2.436	27.24
Lynda Mann	Dowel - 01	375	A	2	1	A^2^1	97.87	95.31	2.396	27.56
Lynda Mann	Dowel - 08	446	A	2	8	A^2^8	101.89	99.02	2.856	27.67
Lynda Mann	Dowel - 09	640	A	2	9	A^2^9				
Lynda Mann	Dowel - 02	659	A	2	2	A^2^2				
Lynda Mann	Dowel - 07	743	A	2	7	A^2^7				
Lynda Mann	Dowel - 10	768	A	2	10	A^2^10				
Lynda Mann	Dowel - 06	794	A	2	6	A^2^6				
Lynda Mann	Dowel - 05	844	A	2	5	A^2^5				
Lynda Mann	Dowel - 04	872	A	2	4	A^2^4				
Lynda Mann	Dowel - 09	254	A	3	9	A^3^9				
Lynda Mann	Dowel - 05	261	A	3	5	A^3^5				
Lynda Mann	Dowel - 07	373	A	3	7	A^3^7				
Lynda Mann	Dowel - 01	422	A	3	1	A^3^1				
Lynda Mann	Dowel - 06	451	A	3	6	A^3^6				
Lynda Mann	Dowel - 03	599	A	3	3	A^3^3				

Outside Diameter		Part Number									
Appraiser	Trial	1	2	3	4	5	6	7	8	9	10
A	1	98.78	98.36	98.22	100.56	99.56	98.11	98.24	101.47	98.44	100.1
A	2	97.87		98.45					101.89		
A	3										
B	1										
B	2										
B	3										
C	1										
C	2										
C	3										
D	1										
D	2										
D	3										
E	1										
E	2										
E	3										

Inside Diameter		Part Number									
Appraiser	Trial	1	2	3	4	5	6	7	8	9	10
A	1	96.06	95.48	95.94	98.45	96.78	95.43	95.79	99.07	96.05	97.49
A	2	95.31		95.97					99.02		
A	3										
B	1										

As the test results are entered into the randomization table, they are automatically “de-randomized” by the Test Result Matrix

Using the Gauge R & R Template – Populate Gauge Study

- Once all the test results have been entered, use the Populate Gauge Study command button to transfer them from the Test Result Matrix into the Gauge R & R worksheets

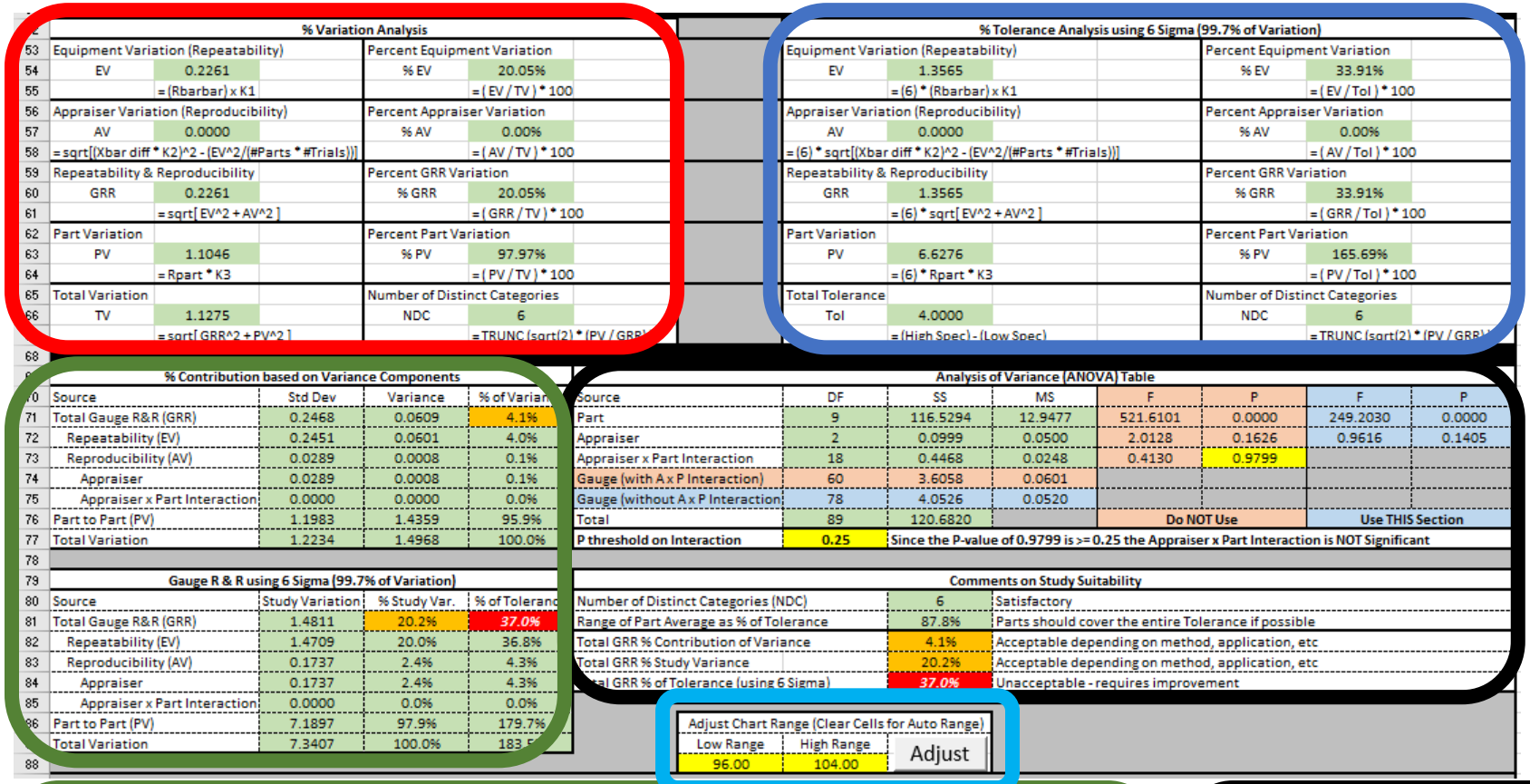
Outside Diameter		Part Number									
Appraiser	Trial	1	2	3	4	5	6	7	8	9	10
A	1	98.78	98.36	98.22	100.56	99.56	98.11	98.24	101.47	98.44	100.1
A	2	97.87	98.36	98.45	100.21	99.47	98.23	98.24	101.89	97.8	99.88
A	3	97.87	98.21	98.33	100.13	99.69	98.12	98.27	101.31	97.72	99.56
B	1	98.56	98.13	98.41	100.12	99.47	98.11	98.22	101.36	98.44	100.65
B	2	98.22	98.36	98.36	100.36	99.89	98.23	98.23	101.47	97.8	99.89
B	3	98.14	98.34	98.33	100.56	99.78	98.12	98.24	101.87	97.72	100
C	1	98.56	98.56	98.12	100.25	99.47	98.11	98.27	101.21	98.44	100.12
C	2	98.22	98.12	98.45	100.36	99.89	98.23	98.26	101.36	97.8	99.25
C	3	98.15	98.32	98.33	100.22	99.75	98.12	98.22	101.54	97.72	99.69
D	1										
D	2										
D	3										
E	1										
E	2										
E	3										

		Part									
	Part ID	Dowel - 01	Dowel - 02	Dowel - 03	Dowel - 04	Dowel - 05	Dowel - 06	Dowel - 07	Dowel - 08	Dowel - 09	Dowel - 10
Appraiser A	1	98.78	98.36	98.22	100.56	99.56	98.11	98.24	101.47	98.44	100.10
Sum	2	97.87	98.36	98.45	100.21	99.47	98.23	98.24	101.89	97.80	99.88
2971.45	3	97.87	98.21	98.33	100.13	99.69	98.12	98.27	101.31	97.72	99.56
Sum^2 / Count	Average	98.17	98.31	98.33	100.30	99.57	98.15	98.25	101.56	97.99	99.85
Appraiser B	1	98.56	98.13	98.41	100.12	99.47	98.11	98.22	101.36	98.44	100.65
Sum	2	98.22	98.36	98.36	100.36	99.89	98.23	98.23	101.47	97.80	99.89
2973.38	3	98.14	98.34	98.33	100.56	99.78	98.12	98.24	101.87	97.72	100.00
Sum^2 / Count	Average	98.31	98.28	98.37	100.35	99.71	98.15	98.23	101.57	97.99	100.18
Appraiser C	1	98.56	98.56	98.12	100.25	99.47	98.11	98.27	101.21	98.44	100.12
Sum	2	98.22	98.12	98.45	100.36	99.89	98.23	98.26	101.36	97.80	99.25
2971.11	3	98.15	98.32	98.33	100.22	99.75	98.12	98.22	101.54	97.72	99.69
Sum^2 / Count	Average	98.31	98.33	98.30	100.28	99.70	98.15	98.25	101.37	97.99	99.69
Appraiser D	1										

OR:

3. The results can also be entered directly into the Gauge R&R worksheets manually

Using the Gauge R & R Template – Report



% Variation Analysis			
Equipment Variation (Repeatability)		Percent Equipment Variation	
EV	0.2261	% EV	20.05%
	= (Rbarbar) x K1		= (EV / TV) * 100
Appraiser Variation (Reproducibility)		Percent Appraiser Variation	
AV	0.0000	% AV	0.00%
= sqrt[(Xbar diff * K2)^2 - (EV^2/(#Parts * #Trials))]			= (AV / TV) * 100
Repeatability & Reproducibility		Percent GRR Variation	
GRR	0.2261	% GRR	20.05%
	= sqrt[EV^2 + AV^2]		= (GRR / TV) * 100
Part Variation		Percent Part Variation	
PV	1.1046	% PV	97.97%
	= Rpart * K3		= (PV / TV) * 100
Total Variation		Number of Distinct Categories	
TV	1.1275	NDC	6
	= sqrt[GRR^2 + PV^2]		= TRUNC (sqrt(2) * (PV / GRR)

% Tolerance Analysis using 6 Sigma (99.7% of Variation)			
Equipment Variation (Repeatability)		Percent Equipment Variation	
EV	1.3565	% EV	33.91%
	= (6) * (Rbarbar) x K1		= (EV / Tol) * 100
Appraiser Variation (Reproducibility)		Percent Appraiser Variation	
AV	0.0000	% AV	0.00%
= (6) * sqrt[(Xbar diff * K2)^2 - (EV^2/(#Parts * #Trials))]			= (AV / Tol) * 100
Repeatability & Reproducibility		Percent GRR Variation	
GRR	1.3565	% GRR	33.91%
	= (6) * sqrt[EV^2 + AV^2]		= (GRR / Tol) * 100
Part Variation		Percent Part Variation	
PV	6.6276	% PV	165.69%
	= (6) * Rpart * K3		= (PV / Tol) * 100
Total Tolerance		Number of Distinct Categories	
Tol	4.0000	NDC	6
	= (High Spec) - (Low Spec)		= TRUNC (sqrt(2) * (PV / GRR)

% Contribution based on Variance Components			
Source	Std Dev	Variance	% of Varian
Total Gauge R&R (GRR)	0.2468	0.0609	4.1%
Repeatability (EV)	0.2451	0.0601	4.0%
Reproducibility (AV)	0.0289	0.0008	0.1%
Appraiser	0.0289	0.0008	0.1%
Appraiser x Part Interaction	0.0000	0.0000	0.0%
Part to Part (PV)	1.1983	1.4359	95.9%
Total Variation	1.2234	1.4968	100.0%

Gauge R & R using 6 Sigma (99.7% of Variation)			
Source	Study Variation	% Study Var.	% of Tolerand
Total Gauge R&R (GRR)	1.4811	20.2%	37.0%
Repeatability (EV)	1.4709	20.0%	36.8%
Reproducibility (AV)	0.1737	2.4%	4.3%
Appraiser	0.1737	2.4%	4.3%
Appraiser x Part Interaction	0.0000	0.0%	0.0%
Part to Part (PV)	7.1897	97.9%	179.7%
Total Variation	7.3407	100.0%	183.5

Analysis of Variance (ANOVA) Table							
Source	DF	SS	MS	F	P	F	P
Part	9	116.5294	12.9477	521.6101	0.0000	249.2030	0.0000
Appraiser	2	0.0999	0.0500	2.0128	0.1626	0.9616	0.1405
Appraiser x Part Interaction	18	0.4468	0.0248	0.4130	0.9799		
Gauge (with A x P Interaction)	60	3.6058	0.0601				
Gauge (without A x P Interaction	78	4.0526	0.0520				
Total	89	120.6820		Do NOT Use		Use THIS Section	
P threshold on Interaction	0.25	Since the P-value of 0.9799 is >= 0.25 the Appraiser x Part Interaction is NOT Significant					

Comments on Study Suitability		
Number of Distinct Categories (NDC)	6	Satisfactory
Range of Part Average as % of Tolerance	87.8%	Parts should cover the entire Tolerance if possible
Total GRR % Contribution of Variance	4.1%	Acceptable depending on method, application, etc
Total GRR % Study Variance	20.2%	Acceptable depending on method, application, etc
Total GRR % of Tolerance (using 6 Sigma)	37.0%	Unacceptable - requires improvement

Adjust Chart Range (Clear Cells for Auto Range)		
Low Range	High Range	Adjust
96.00	104.00	

% Variation Analysis

Calculates the Study's Actual and Percent EV (Repeatability), AV (Reproducibility), GRR, PV (Part Variation), and TV (Total Variation)

Also calculates the NDC

% Tolerance Analysis

Using either 5.15 σ or 6 σ (99% or 99.7% of the Variation)

Use 6 σ for critical applications such as Automotive. The less rigorous 5.15 σ can be used if desired for other applications.

Adjust Chart Range

Use to set the Chart Ranges if the Excel defaults are not suitable

% Contribution of Variance Components and Gauge R & R Components

This shows the contribution of each of the components to the Total Variation. Most importantly, it shows the GRR as a percent of the Variance, of the Study Variance, and of the Tolerance (note the cells highlighted in orange and red).

ANOVA Table and Comments on Study Suitability

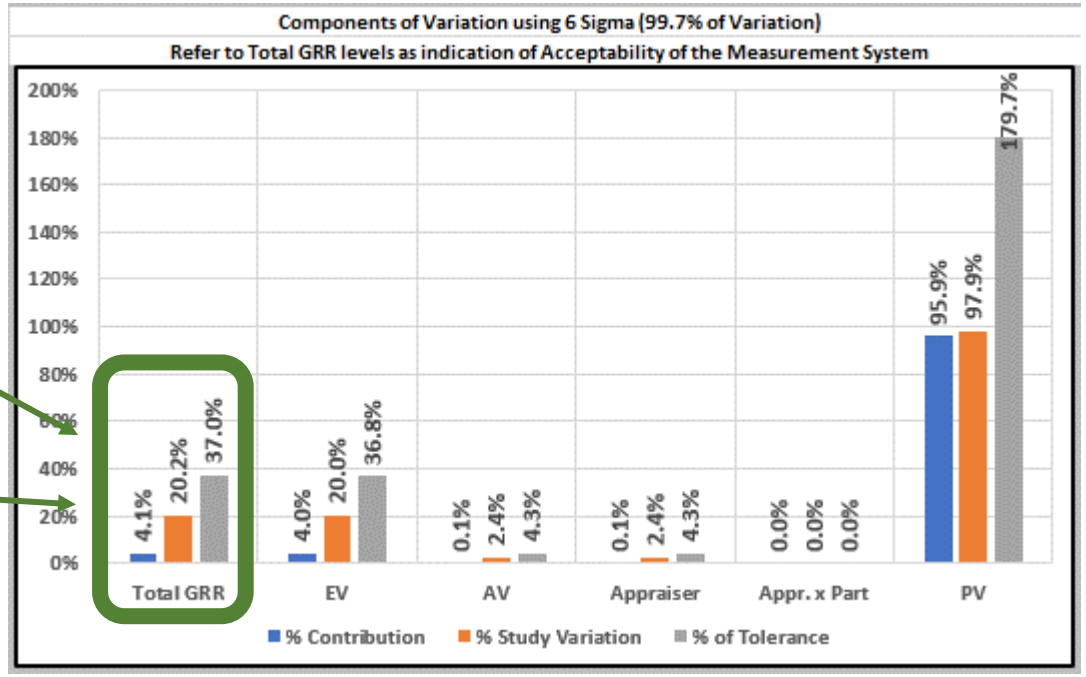
The ANOVA Table shows the F and P-values for the Part, Appraiser, and Appraiser x Part Interaction. A P-value less than 0.05 shows a statistically significant relationship.

The Study Suitability shows the commentary on the NDC and the GRR.

Using the Gauge R & R Template – Charts

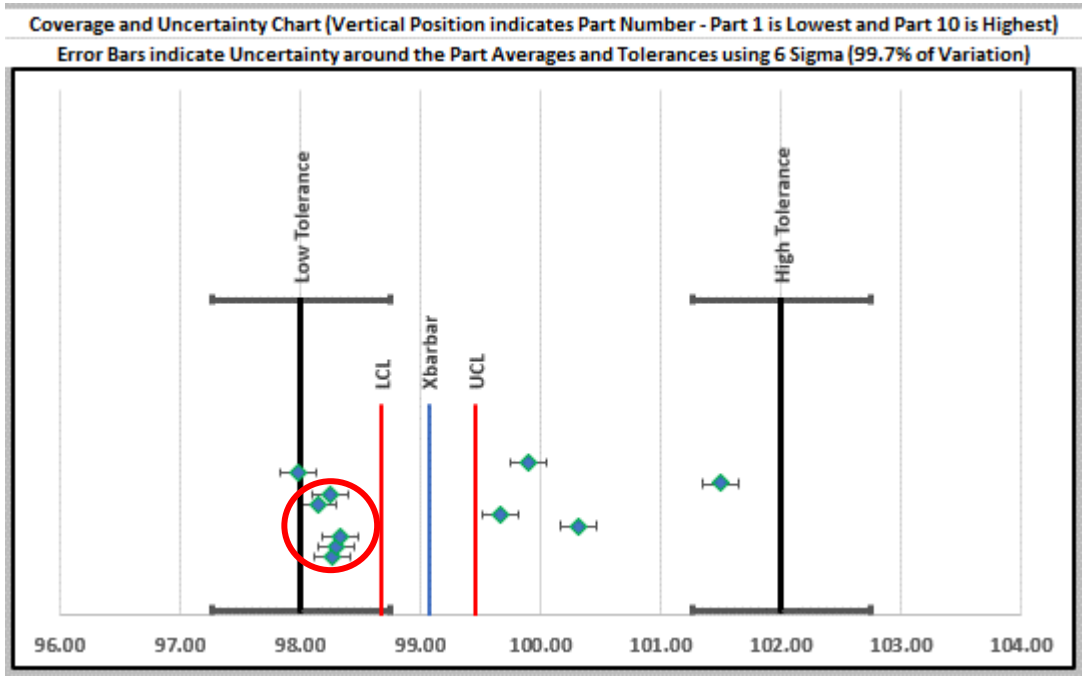
- Components of Variation Chart
  - This chart graphs the breakdown of the components of the Gauge R & R Study the % Contribution, % Study Variation, and % of Tolerance
  - The most critical factors are the Total GRR component which is the sum of the Repeatability and Reproducibility

69	% Contribution based on Variance Components			
70	Source	Std Dev	Variance	% of Variance
71	Total Gauge R&R (GRR)	0.2468	0.0609	4.1%
72	Repeatability (EV)	0.2451	0.0601	
73	Reproducibility (AV)	0.0289	0.0008	0.1%
74	Appraiser	0.0289	0.0008	0.1%
75	Appraiser x Part Interaction	0.0000	0.0000	0.0%
76	Part to Part (PV)	1.1983	1.4359	95.9%
77	Total Variation	1.2234	1.4968	100.0%
78				
79	Gauge R & R using 6 Sigma (99.7% of Variation)			
80	Source	Study Variation	% Study Var.	% of Tolerance
81	Total Gauge R&R (GRR)	1.4811	20.2%	37.0%
82	Repeatability (EV)	1.4709		
83	Reproducibility (AV)	0.1737	2.4%	4.3%
84	Appraiser	0.1737	2.4%	4.3%
85	Appraiser x Part Interaction	0.0000	0.0%	0.0%
86	Part to Part (PV)	7.1897	97.9%	179.7%
87	Total Variation	7.3407	100.0%	183.5%



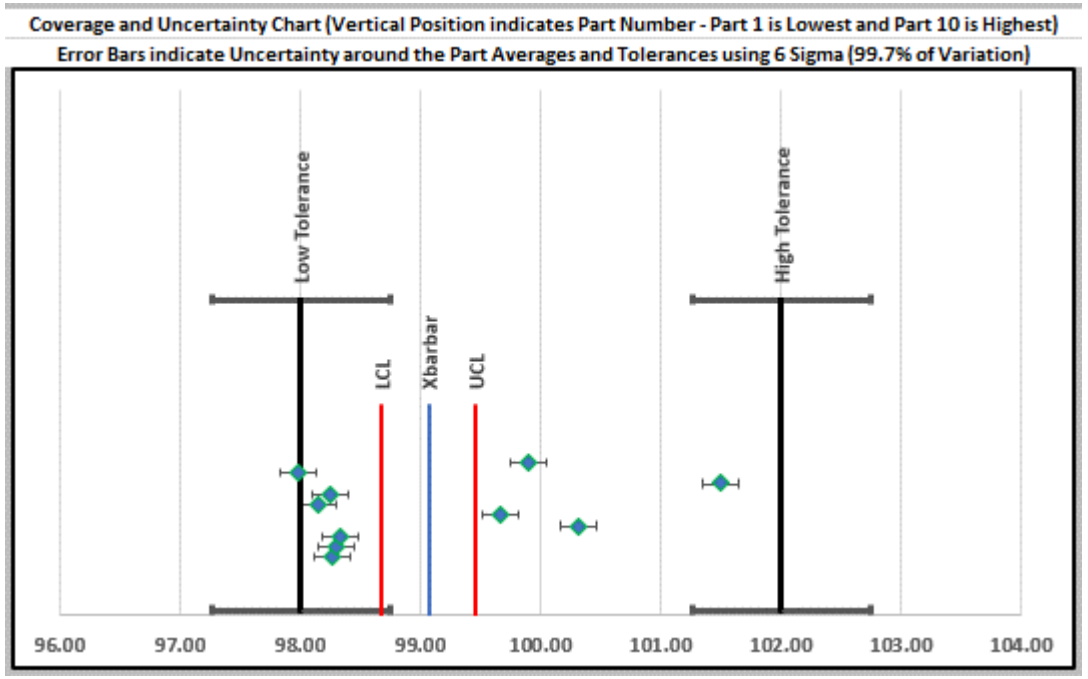
Using the Gauge R & R Template – Charts

- Coverage and Uncertainty Chart – Parts Measurements
  - The measurement is shown on the horizontal scale at the bottom
  - The green points are the average measurements for each Part
  - The vertical height of each point indicates the Part number
    - Part 1 is the lowest point and Part 10 is the highest
  - The error bars indicate the 95% confidence limits around the averages
- Number of Distinct Categories (NDC)
  - Each distinct category comprises those Parts that cannot be statistically distinguished from each other
  - This plot shows 6 groups of Parts whose error bars overlap each others' averages
  - Parts 1, 2, 3, 6, and 7 cannot be distinguished so they comprise 1 DC



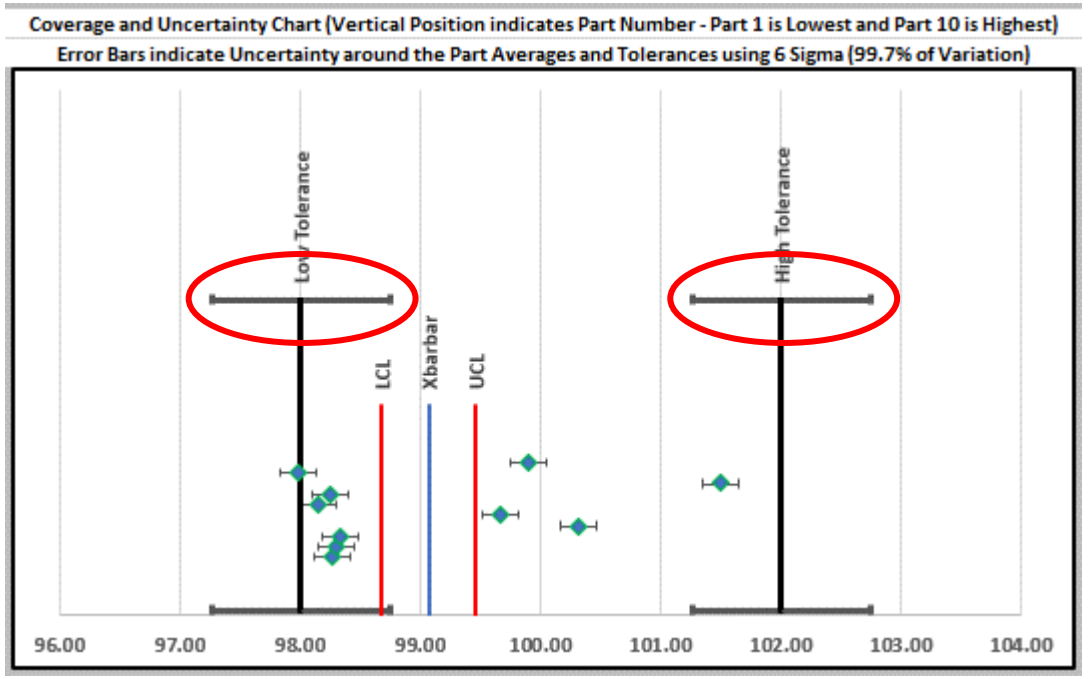
Using the Gauge R & R Template – Charts

- Coverage and Uncertainty Chart – Average and Confidence Limits
  - $\bar{\bar{X}}$ (Xbarbar) is the overall average
  - LCL and UCL are the control limits around the overall average
    - Note that the Part measurements are outside the control limits
    - This is good: the control limits are based on the GRR calculations
    - By being outside the control limits, the measurements indicate that most of the variation is due to Part-to-Part (process) rather than Gauge (measurement) variation



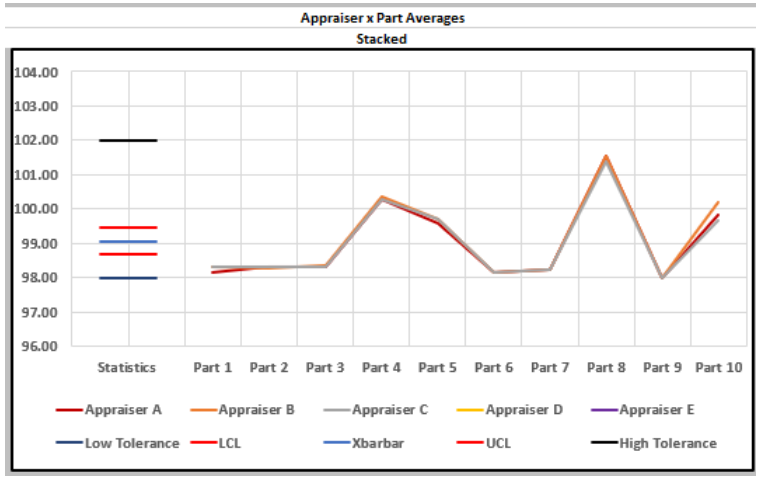
Using the Gauge R & R Template – Charts

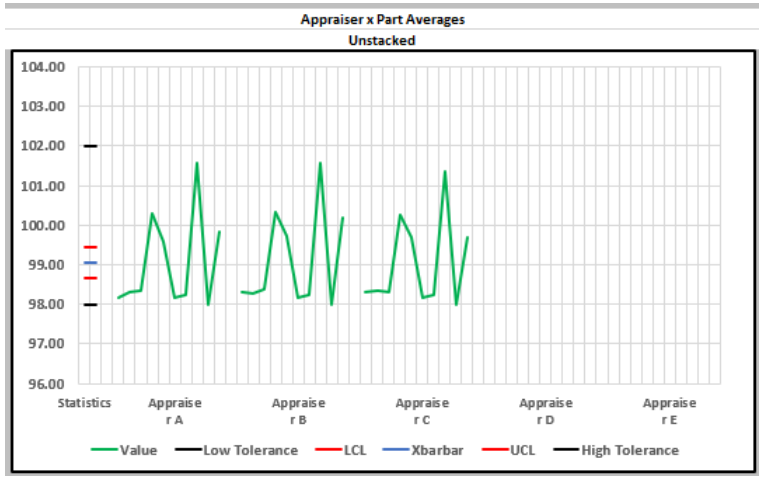
- Coverage and Uncertainty Chart – Tolerances
  - The Low and High Tolerances (98 mm to 102 mm) are shown
  - Error bars on the Tolerance show the width of the GRR relative to the Tolerance
  - Any measurement within these error bars may be in or out of the Tolerance
    - Example: the Tolerance has a width of 4 mm and the GRR is 37% of that width
      - 37% of 4 mm is 1.48 mm ($\pm$ 0.74 mm)
    - At the low end the uncertainty goes from 97.26 mm to 98.74 mm
      - 101.26 to 102.74 mm at the high end
      - You cannot be certain whether any measurement in this range indicates that the Part is in or out of spec
  - If the GRR encompasses too much of the Tolerance then the process cannot be monitored for on-spec performance

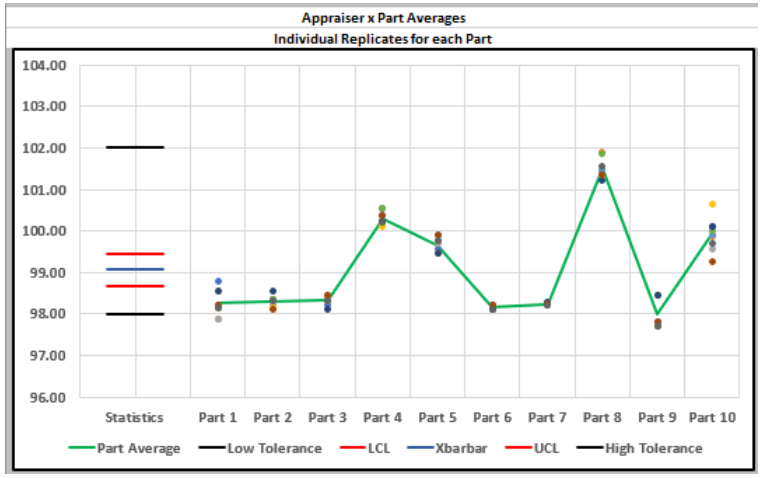


Using the Gauge R & R Template – Charts

- Appraiser x Part Average Charts
  - These charts show 3 views of the same information
    - Average measurements for all parts as measured by each appraiser
    1. All appraisers overlapped to show any differences between appraisers
    2. All appraisers individually to more clearly compare their patterns
    3. Average and individual measurements for each part
  - Short bars at the right show the Tolerances, Control Limits, and Overall Average

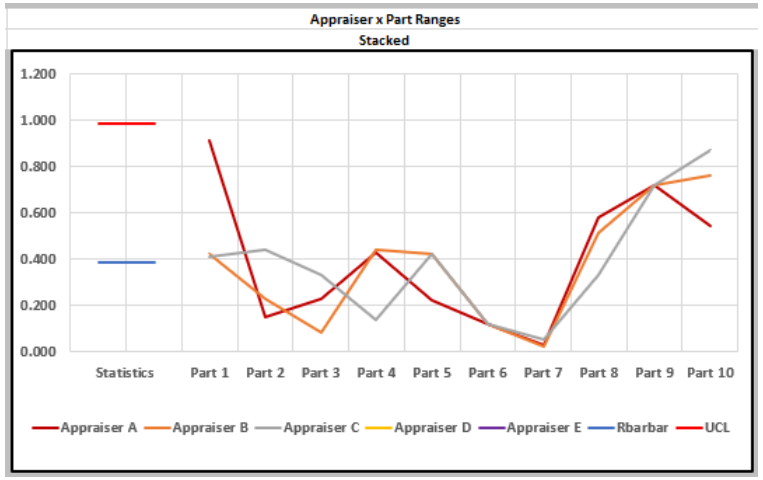


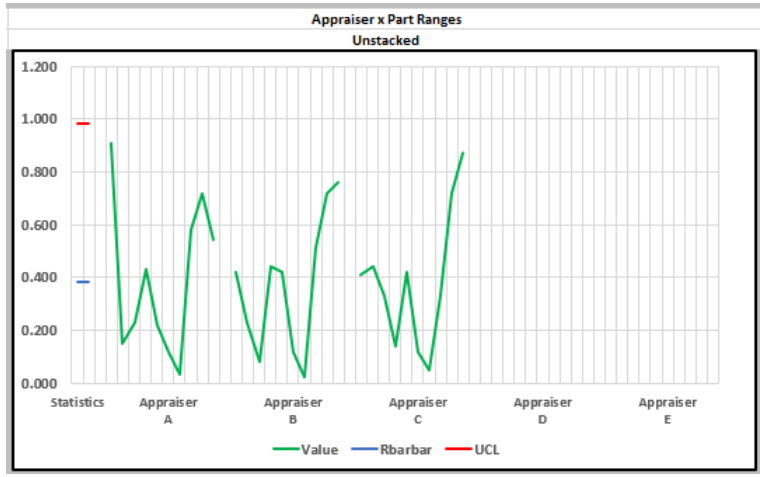


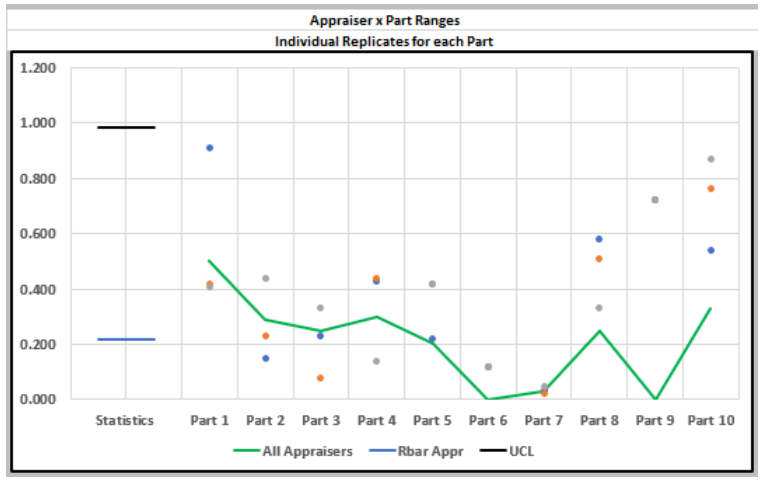


Using the Gauge R & R Template – Charts

- Appraiser x Part Range Charts
  - These charts show 3 views of the same information
    - Range measurements for all parts as measured by each appraiser
    1. All appraisers overlapped to show any differences between appraisers
    2. All appraisers individually to more clearly compare their patterns
    3. Range and individual measurements for each part
  - Short bars at the right show the Upper Control Limit and Overall Average
    - The Range does not have Tolerances and the Lower Control Limit on Range is 0







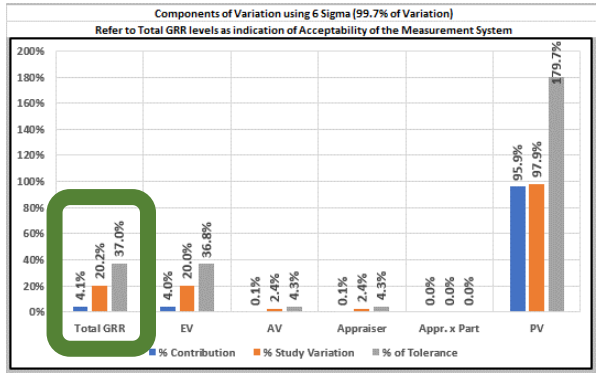
Recap of Gauge R & R – Summary of Key Points

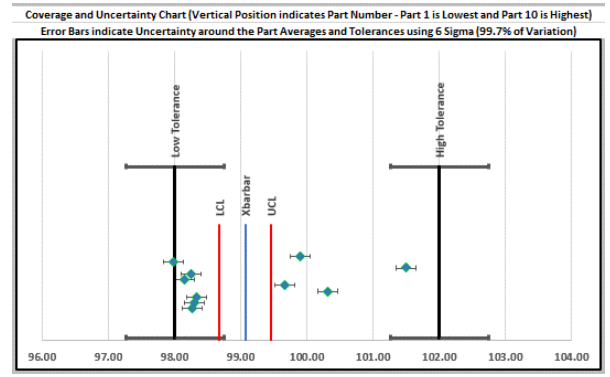
- Gauge R & R is an analysis of the repeatability and reproducibility of the Measurement System – it is not an analysis of the product

- Experimental Design
  - Set the appropriate level of Coverage of Variation
    - 6 σ for critical applications (eg automotive) or 5.15 σ for less rigor
  - Use at least 2 (preferably 3 or 4) appraisers to measure up to 10 parts
    - At least 2 (preferably 3) repetitions per part
    - Randomize and mask the parts to avoid subjective bias
  - The parts should cover the entire range of the product's tolerance
    - The Number of Distinct Categories (NDC) should be at least 5

Recap of Gauge R & R – Summary of Key Points

- Determine the acceptability of the measurement system
  - Does the GRR meet the recommended standards of acceptability?
    - % Contribution to Variance: < 1% (< 9% depending on application)
    - % Study Variation & % of Tolerance: < 10% (< 30% depending on application)
  - If the GRR is > 30% of the width of the Tolerance then there is too much uncertainty in the identification of in-spec or out-of-spec parts
- Review all report statistics and charts
  - The most informative charts are:
    - Components of Variation
    - Coverage and Uncertainty





- If GRR is not acceptable, possible remedies are appraiser training, equipment calibration / maintenance, or upgrading the test equipment