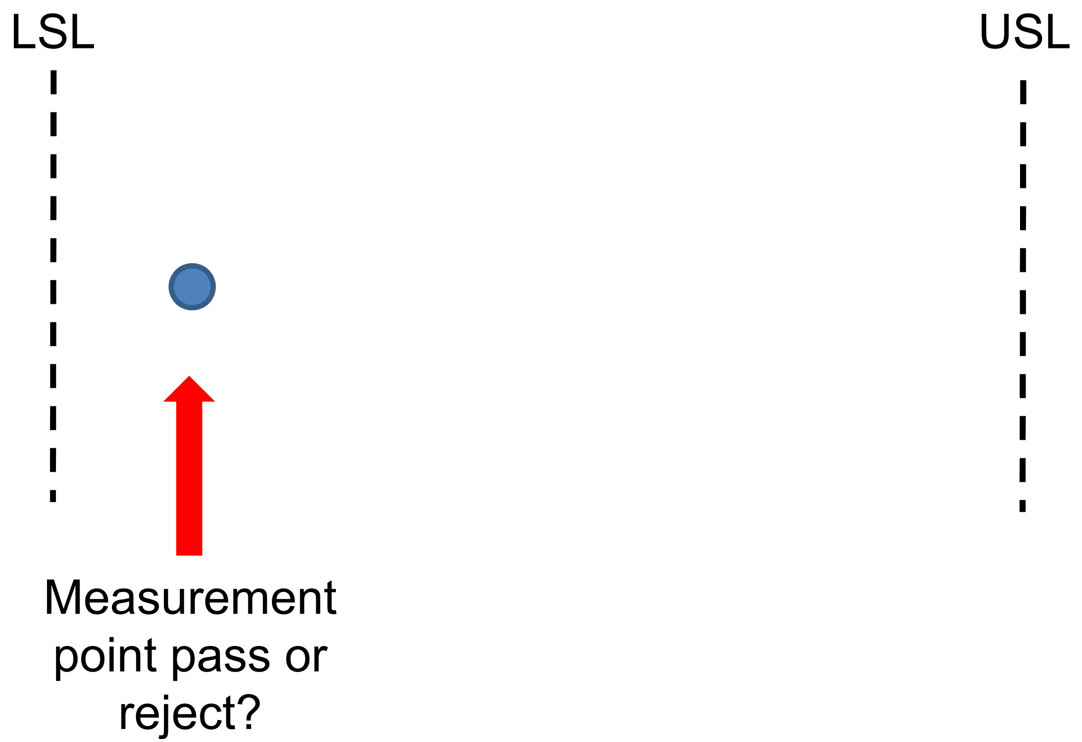
Measurement System Analysis (MSA)

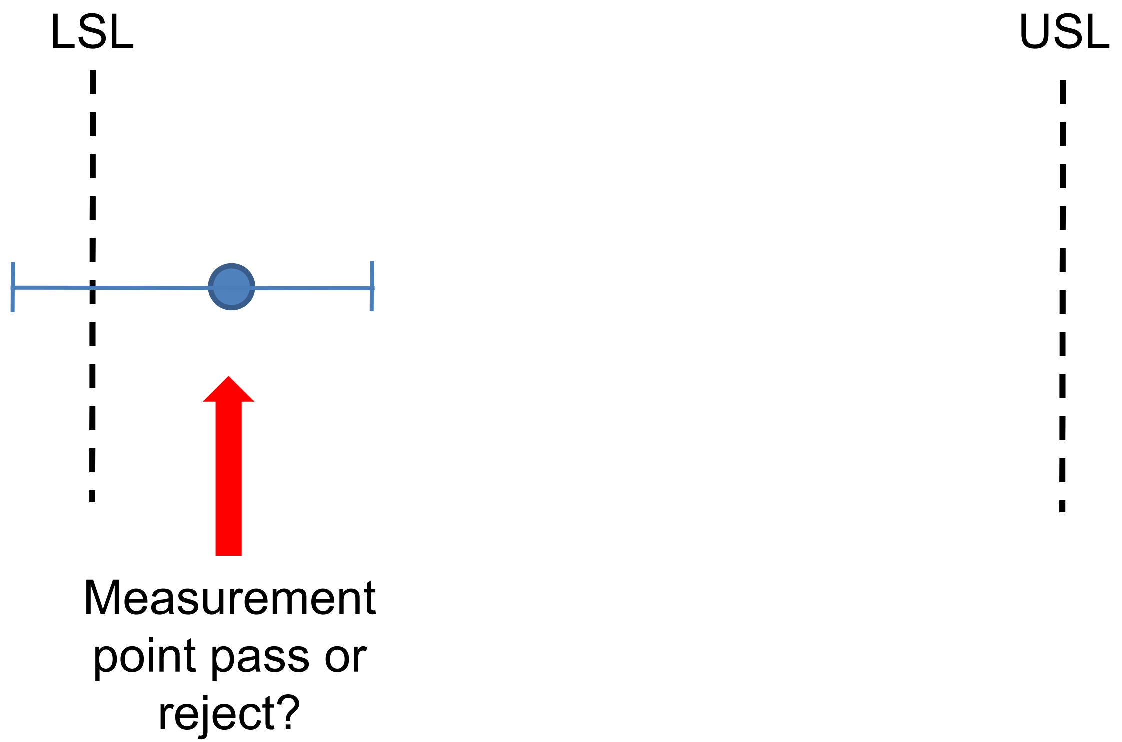
Validating your measurement systems

Measurement Uncertainty



- Imagine you measure a component and find it to be at the point shown within the specification limits
- Would you pass or reject the component?

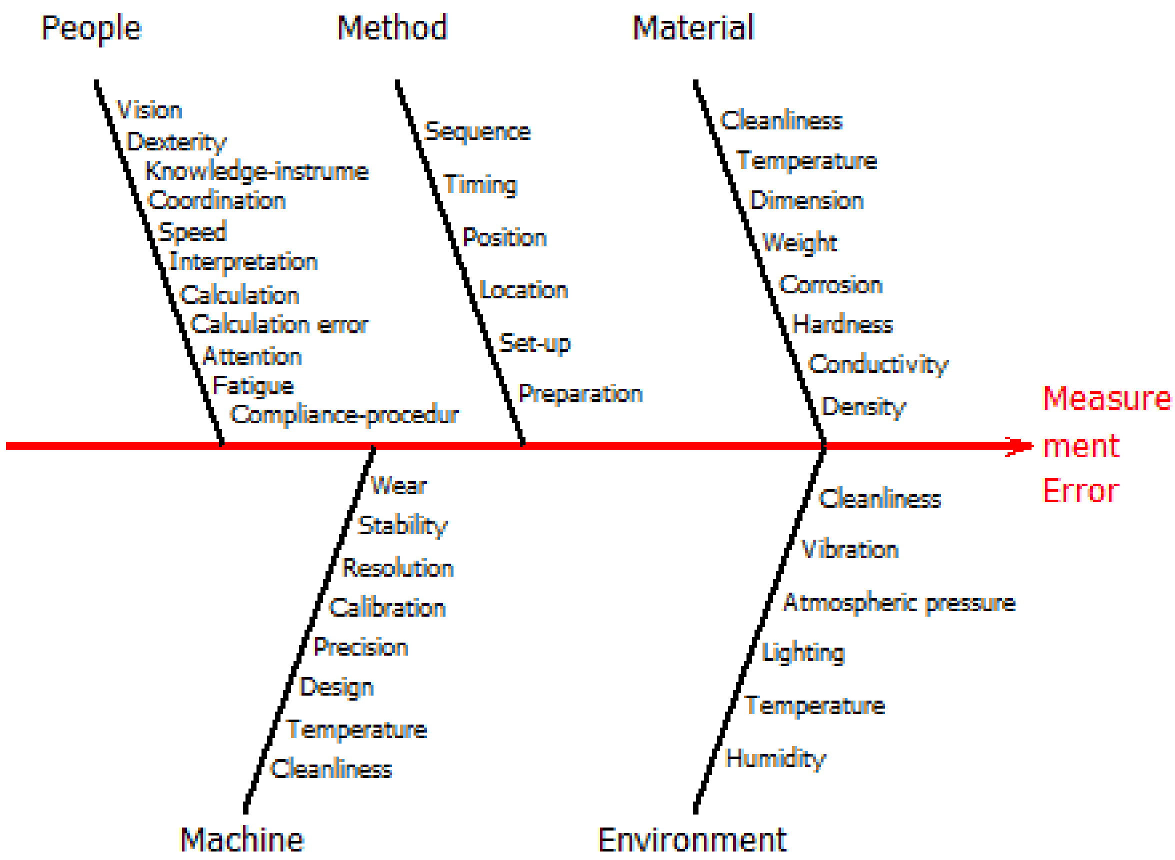
Measurement Uncertainty



- You now discover that is has a <u>measurement error</u> associated with it as shown by the error bar above
- Would you pass or reject the component?

Main sources of variation

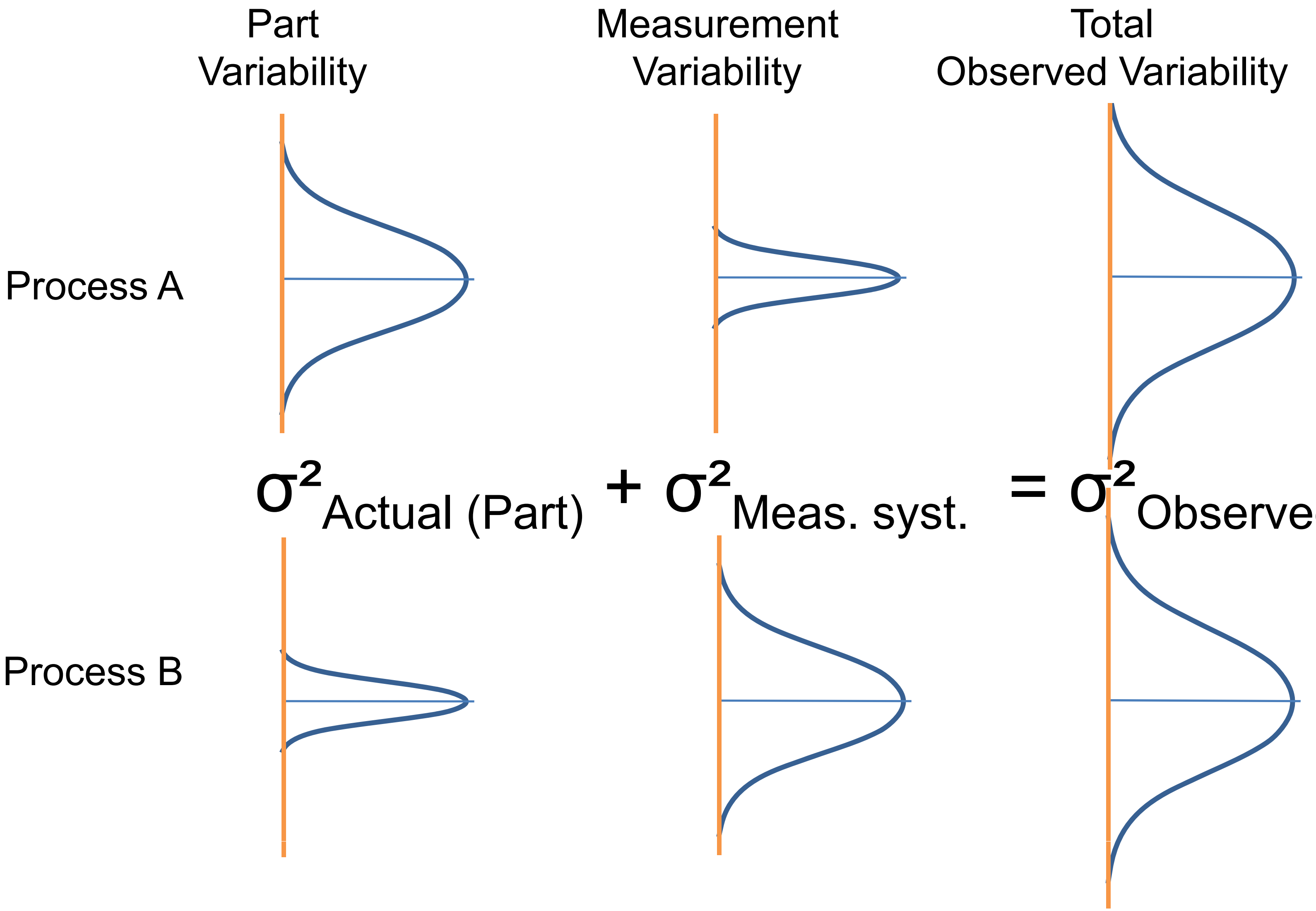
- Materials
- Methods
- Machines
- People
- Environment



Measurement System Analysis - MSA

- A scientific and objective method of analysing the validity of a measurement system.
- A tool which quantifies
  - Equipment variation
  - Appraiser (operator) variation
  - The total variation of a measurement system
- Examples of measurement systems
  - Micrometer
  - Shadowgraph
  - Go/no-go gage
  - Data collection form
  - Survey
  - On-time delivery report

Variation

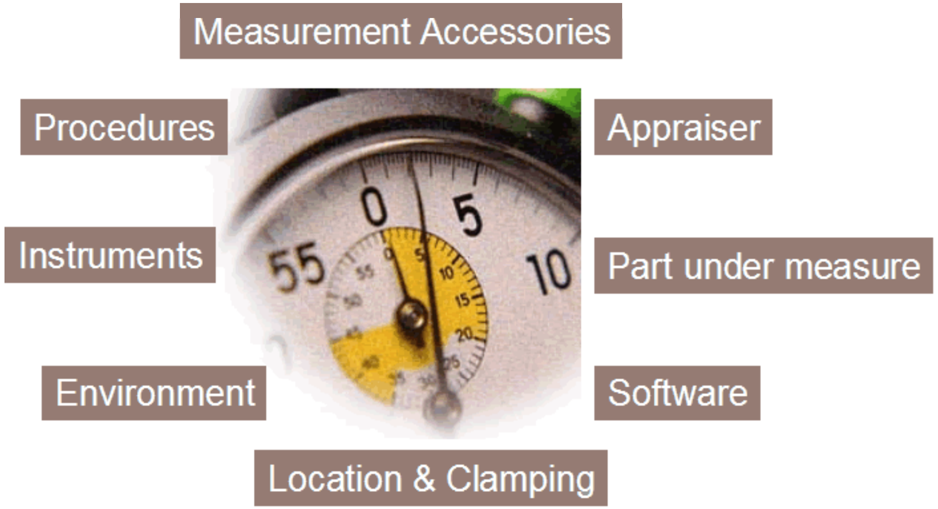


$$\sigma^2_{\text{Actual (Part)}} + \sigma^2_{\text{Meas. syst.}} = \sigma^2_{\text{Observed Total}}$$

Which process is best? Which is easier to improve?

Components of Measurement Error

1. Resolution/Discrimination
2. Accuracy (bias)
3. Linearity
4. Stability (consistency)
5. Precision – Repeatability & Reproducibility

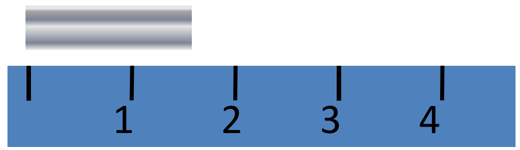


1. Resolution

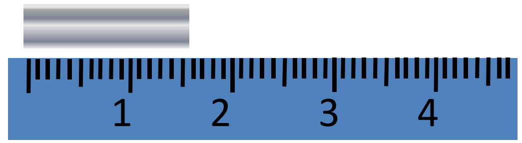
- Definition: The capability to detect the smallest acceptable change
- Cause: Inadequate measurement units
- Guideline “10 bucket rule”
  - Increments in the measurement system should be one tenth of the product specification or process variation
- Actions:
  - Change measurement device
  - Record sample averages
  - Live with it but understand its limitations

Resolution 1/10th

What is the length of this component to the nearest 10th?



Poor resolution



Better resolution

What percent of requests are issued within 4 hours of receipt??

Customer Name ____________
Date Received ____________
Date Issued ____________

Poor resolution

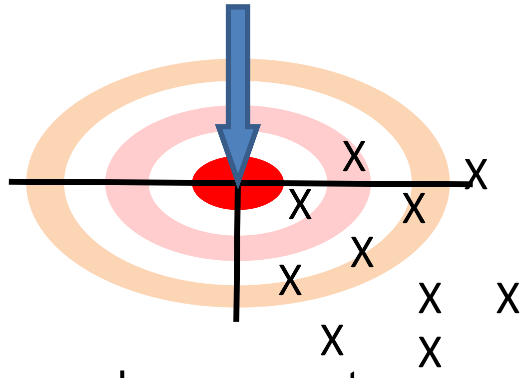
Customer Name ____________
Date Received ____________
Time Received ____________
Date Issued ____________
Time Issued ____________

Better resolution

2. Accuracy /Bias

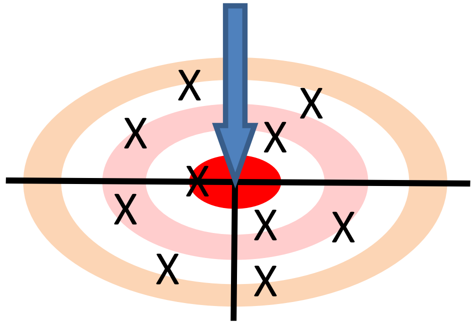
- Accuracy/Bias: Difference between the observed average value and the master reference
- Master value is an accepted, traceable reference standard
- Actions:
  - Calibrate regularly
  - Use operations instructions
  - Review specifications for resolution
  - Validate data systems input accuracy
  - Create operational definitions

Master value
Reference standard



Less accurate

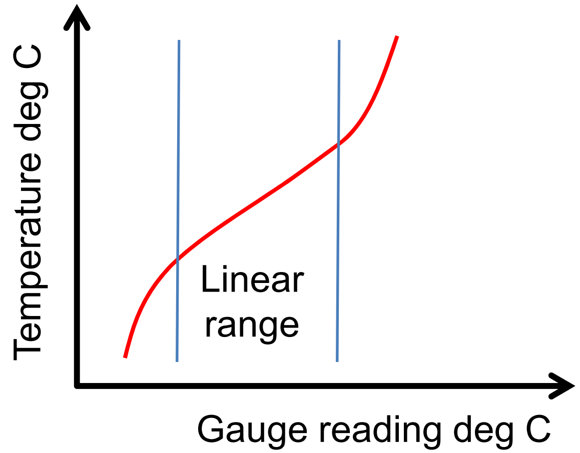
Master value
Reference standard



More accurate

3. Linearity

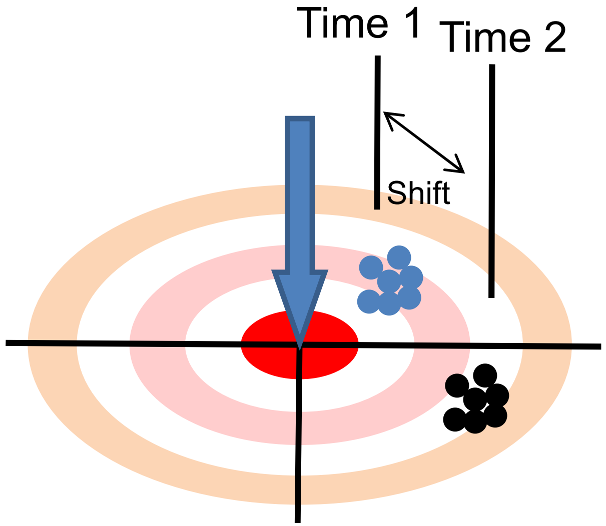
- Measurement is “true” and/or consistent across the range of the “gauge”
- Actions
  - Check gauge specification
  - Rebuild/replace gauge
  - Use within restricted range
  - Use correction factor

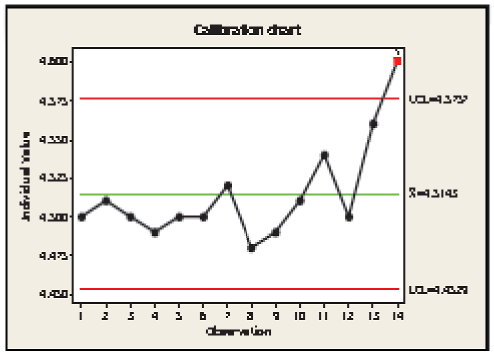


Form Linearity	
Super Outstanding	10
Outstanding	9
Incredible	8
Excellent	7
Great	6
Very Good	5
Good	4
OK	3
Fair	2
Poor	1

4. Stability

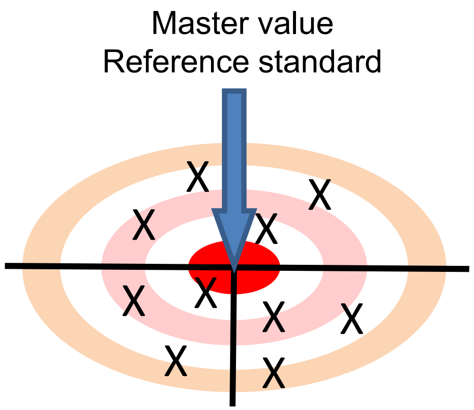
- Measurements remain constant and predictable over time i.e. accuracy remains constant
- No drifting, sudden shifts or cycles
- Actions
  - maintain and service equipment
  - use control charts
  - use SOP
  - ensure adequate training
  - regular audits



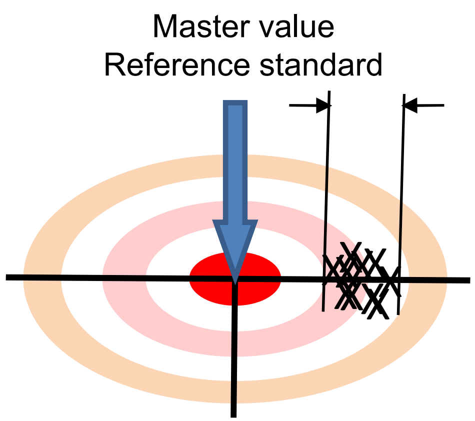


5. Precision – Repeatability & Reproducibility

- Repeatability - variation that occurs when repeated measurements are made of the same item under identical conditions
- Actions
  - repair, replace, adjust
  - SOP
- Reproducibility – variation that results when different conditions are used to make the same measurements
- Actions
  - training
  - SOP



Poor precision



Good precision

R&R or Gauge R&R study

Gauge R&R Studies

- Method of assessing Repeatability & Reproducibility of a measurement system
- A number of appraisers (usually two or three) measure a number of parts (or process output) (usually 5 to 20) a number of times (usually two or three)
- The results are compared within each appraiser (Repeatability) and between appraisers (Reproducibility)
- Randomisation is critical for repeat measurements to avoid learning or copying.

Gage R&R Study – Continuous Data

Gage Repeatability and Reproducibility Spreadsheet (Using Average and Range Method)

Part Number & Name : Gasket
Characteristics : Thickness
Specification Limits : 0.6 - 1.0 mm

Gage Name : Thickness Gage
Gage No. : X-2934
Gage Type : 0.0 - 10.1 mm

Date : 11/03/99
Performed By :

Part Number	Appraiser 1 ( ) Measurements 1	2	3	$\bar{X}$	R	Appraiser 2 ( ) Measurements 1	2	3	$\bar{X}$	R	Appraiser 3 ( ) Measurements 1	2	3	$\bar{X}$	R	Part Average
1	0.5	0.5		0.500	0.000	0.5	0.55		0.525	0.050	0.5	0.55		0.525	0.050	0.517
2	1	1		1.000	0.000	1.05	0.95		1.000	0.100	1.05	1		1.025	0.050	1.008
3	0.85	0.8		0.825	0.050	0.8	0.75		0.775	0.050	0.8	0.8		0.800	0.000	0.800
4	0.85	0.95		0.900	0.100	0.8	0.75		0.775	0.050	0.8	0.8		0.800	0.000	0.825
5	0.55	0.45		0.500	0.100	0.4	0.4		0.400	0.000	0.45	0.5		0.475	0.050	0.458
6	1	1		1.000	0.000	1	1.05		1.025	0.050	1	1.05		1.025	0.050	1.017
7	0.95	0.95		0.950	0.000	0.95	0.9		0.925	0.050	0.95	0.95		0.950	0.000	0.942
8	0.85	0.8		0.825	0.050	0.75	0.7		0.725	0.050	0.7	0.75		0.725	0.050	0.758
9	1	1		1.000	0.000	1	1.05		1.025	0.050	1.05	1.05		1.050	0.000	1.025
10	0.6	0.7		0.650	0.100	0.55	0.5		0.525	0.050	0.85	0.8		0.825	0.050	0.667

Average X_1 = 0.8150 X_2 = 0.7700 X_3 = 0.8200 $\bar{\bar{X}}$ = 0.8017

Range R_1 = 0.0400 R_2 = 0.0500 R_3 = 0.0300

$\bar{R}$ = (R1 + R2 + R3) / No. of Appraisers = 0.0400 R_p = 0.5667

X_{diff} = (Max. of X_1,X_2,X_3 - Min. of X_1,X_2,X_3) = 0.0500

UCL_R = $\bar{R}$ * D_4 (D_4 = 3.27 OR 2.58 for 2 and 3 measurements) = 0.1308

LCL_R = $\bar{R}$ * D_3 (D_3 = 0 for up to 7 trials) = 0.000

If R & R as % of Tolerance is required, enter Tolerance Range --> 0.4000

Repeatability - Equipment Variation (*EV*) = ($\bar{R}$ * K_1) = 0.1824
(K_1 = 4.56 OR 3.05 for 2 and 3 Measurements respectively)

Reproducibility - Appraiser Variation (*AV*) = [formula, partly illegible]
AV = 0.1287
(K_2 = 3.65 OR 2.70 for 2 or 3 Appraisers)
n = Number of Parts, r = Number of Measurements

Total Process Variation, TPV is determined from Sample Values

$TV = \sqrt{(R\&R^2 + PV^2)}$

TPV = 0.9443

Parts	K_3
5	2.08
6	1.93
7	1.82
8	1.74
9	1.67
10	1.62

Repeatability & Reproducibility, $R\&R = \sqrt{(EV^2 + AV^2)}$
R & R = 0.2232

Part Variation (*PV*) = R_p * K_3 = 0.9180
(Value of K_3 taken from the given table)

%Gage R & R :

	% of Tolerance	% of Total Process Variation (TPV)
EV =	45.60	19.31
AV =	32.17	13.62
PV =	229.50	97.17
R & R =	55.81	23.63

Note 1 : Data can be entered only in the columns marked 1, 2, 3 and Cell for Tolerance Range and top header section. (All those cells which are shaded light blue)

Note 2 : Study require any combination of 2 or 3 Appraisers, 2 or 3 Measurements and any parts from 5 to 10 .

Note 3 : (%R & R Interpretation - Lower of %Tolerance and % Total Process Variation- TPV)
Under 10% error - Measurement system is acceptable;
Between 10 - 30 % error - Marginal (May be acceptable based upon importance of application, cost of gage, cost of repairs, etc.;
More than 30% error - Needs improvement. Make every effort to identify the problems and have them corrected

Results of this Gage R & R: MEASUREMENT SYSTEM IS MARGINAL

gs-R&r-use.xls

Three appraisers, two measurements each

% of Tolerance

% of Total Variation

EV=Equip't Variation
AV=Appraiser Variation
PV=Part Variation
R&R = $\sqrt{(EV^2+AV^2)}$

Gage R&R Study – Attribute Data

ATTRIBUTE GAGE R&R STUDY

Study Attribute :
Characteristics :
Specification Limits :

Gauge name :
Gauge number :
Gauge type :

Date :
Prepared by :

Trial Number	Control	Appraiser 1 ( ) Measurement 1	2	3	Between	vs Control	Appraiser 2 ( ) Measurement 1	2	3	Between	vs Control	Appraiser 3 ( ) Measurement 1	2	3	Between	vs Control	Overall Between	Overall vs Control
1	Blue	Blue	Blue		100%	100%	Blue	Blue		100%	100%						100%	100%
2	Red	Red	Red		100%	100%	Red	Red		100%	100%						100%	100%
3	Red	Blue	Red		0%	50%	Red	Red		100%	100%						50%	75%
4	Blue	Blue	Blue		100%	100%	Blue	Blue		100%	100%						100%	100%
5	Green	Green	Green		100%	100%	Green	Green		100%	100%						100%	100%
6	Black	Black	Black		100%	100%	Black	Blue		0%	50%						50%	75%
7	Blue	Blue	Blue		100%	100%	Blue	Blue		100%	100%						100%	100%
8	Red	Red	Red		100%	100%	Red	Red		100%	100%						100%	100%
9	Blue	Blue	Blue		100%	100%	Blue	Blue		100%	100%						100%	100%
10	Red	Red	Red		100%	100%	Red	Red		100%	100%						100%	100%
11																		
12																		
13																		
14																		
15																		
16																		
17																		
18																		
19																		
20																		
		90%	100%		90%	95%	100%	90%		90%	95%						90%	95%

Note 1: Enter data in the cells shaded light blue
Enter up to 20 Control, master or reference Attribute data in the Control column
Data can be Y or N, 0 or 1, Names, Colours, Dates, Categories, Rankings, Defects, Defectives

Note 2: Study requires an combination of 2 or 3 appraisers, 2 or 3 measurements

Note 3: Between Appraisers
<80% needs improvement
>80% to <95% marginally acceptable
>95% acceptable for most purposes
>99% for high risk situations

All Appraisers vs Control
<80% needs improvement
>80% to <90% marginally acceptable
>90% acceptable for most purposes
>99% for high risk situations

Appraiser Variation :	90%
Appraiser vs Control :	95%
Total (√(BAxAvsC)) :	92%

Results of this R&R study : Measurement System is Marginal

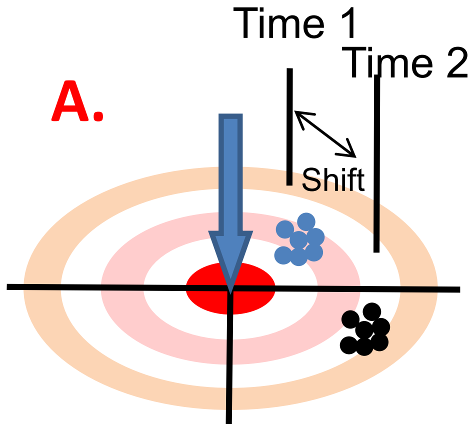
Two appraisers, two measurements each

Appraiser Variation

Appraiser vs Control

AV=Appraiser Variation
AC=Appraiser vs Control
R&R = √(AV*AC)

Measurement Error Matching Exercise



1. Resolution/Discrimination
2. Accuracy (bias)
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