ETI GROUP

Six Sigma/Lean Six Sigma
Lean Enterprise
Business Management Systems
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Integrated Performance Measurement
Supplier Management

Measurement Systems Analysis (MSA)

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Measurement System Analysis

Using Excel

by

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1 Introduction

- Gages
- Measurement system
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- The need for measurement system analysis (MSA)
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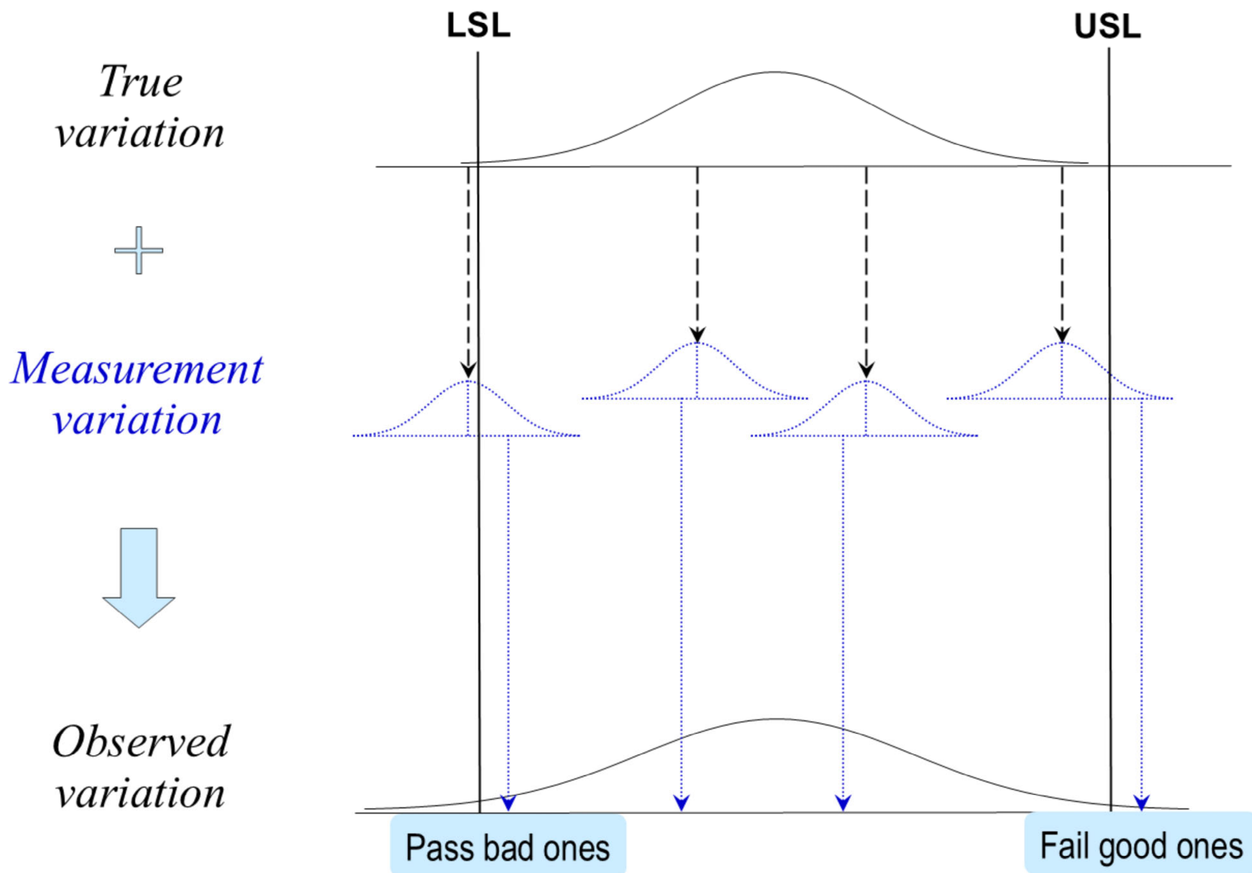
Gages

- A *gage* is a measurement device
- Gages can produce *continuous* or *attribute* data
- The people who use the gages are usually called *appraisers*, *inspectors*, or *operators*
- For visual inspections, the appraisers are themselves the gages, but they are not called that
- For automated measurement systems, the appraisers may not play a significant role in producing the results

Measurement system

- A set of gages used to measure defined characteristics of a defined class of objects or events
- The gages produce the same type of data
- For continuous data, the gages provide the same data resolution (x.x, x.xx, x.xxx, xx.x, . . .)
- The appraisers are part of the system
- The methods and documentation are part of the system
- If there are standards, they are part of the system

Impact of measurement system variation



Impact of measurement variation

		Action taken	
		Pass	**Fail**
True outcome	**Good**		"False alarm"
	Bad	"Escape"	

Which type of error is more costly? For which is the cost easier to quantify?

Measurement system capability

Action taken

True outcome	Pass	Fail
Good		Prob(*False alarm*) "Supplier risk"
Bad	Prob(*Escape*) "Customer risk"	

We want both risks to be small, but how small is small enough?
There are no universal standards.

The need for MSA

- One large high-tech firm estimated $33M annual cost due to measurement variation

- MSA quantifies and classifies measurement variation

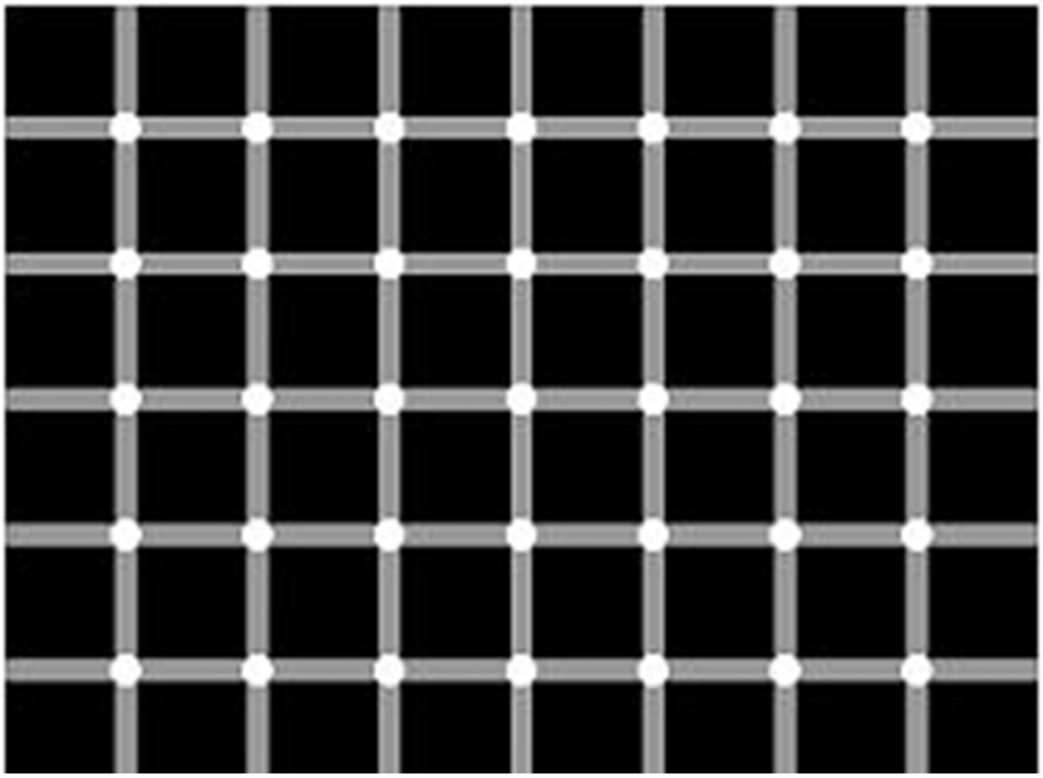
- MSA $\rightarrow$ corrective action $\rightarrow$ reduced measurement variation $\rightarrow$ reduced cost

Common corrective actions

- Training appraisers
- Improving procedures
- Improving gages
- Acquiring better gages

Basic assumption for MSA

Can you count the black dots?



Notes

This optical illusion illustrates a key requirement for measurement system analysis: we must have “unchanging objects” to which the measurement system can be applied.

For situations where this is not possible, various *ad hoc* workarounds have been devised. These workarounds are highly dependent on the particular technologies employed in a given measurement system. For this reason, they are not included in this course.

2 Measurement Variation

- The Normal distribution
- Population model for measurement variation
- How components of variation add up
- Calculating total variation
- Calculating measurement system variation*
- Degrees of freedom

*A very simple example.

Notes

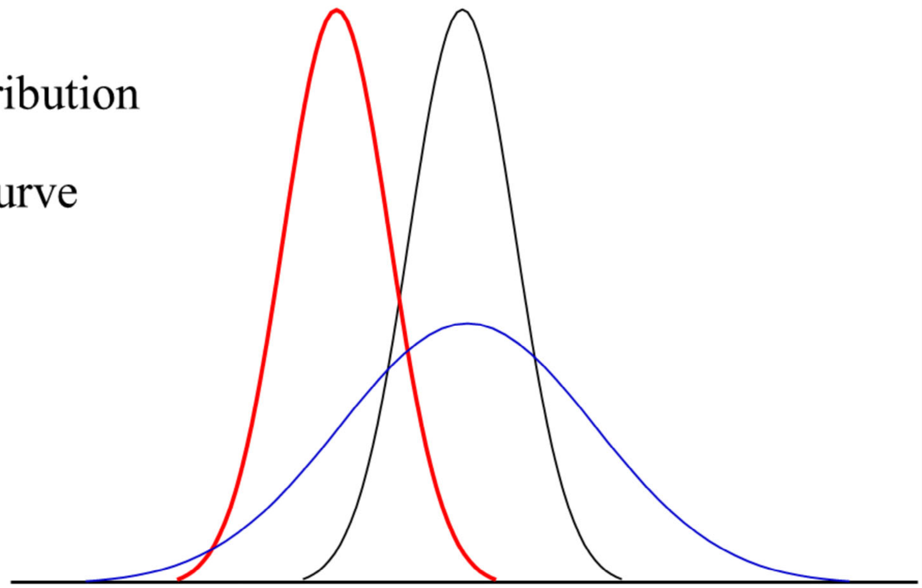
There is no data without measurement, and there is no measurement without measurement variation. The total variation we observe always consists of two components: one from the items being measured, the other from the measurement system itself. In this section we show how the measurement component of total variation can be determined.

The basic assumption required here is that items can be measured more than once without altering or destroying them.

The Normal distribution

Also known as

- Gaussian distribution
- Bell-shaped curve

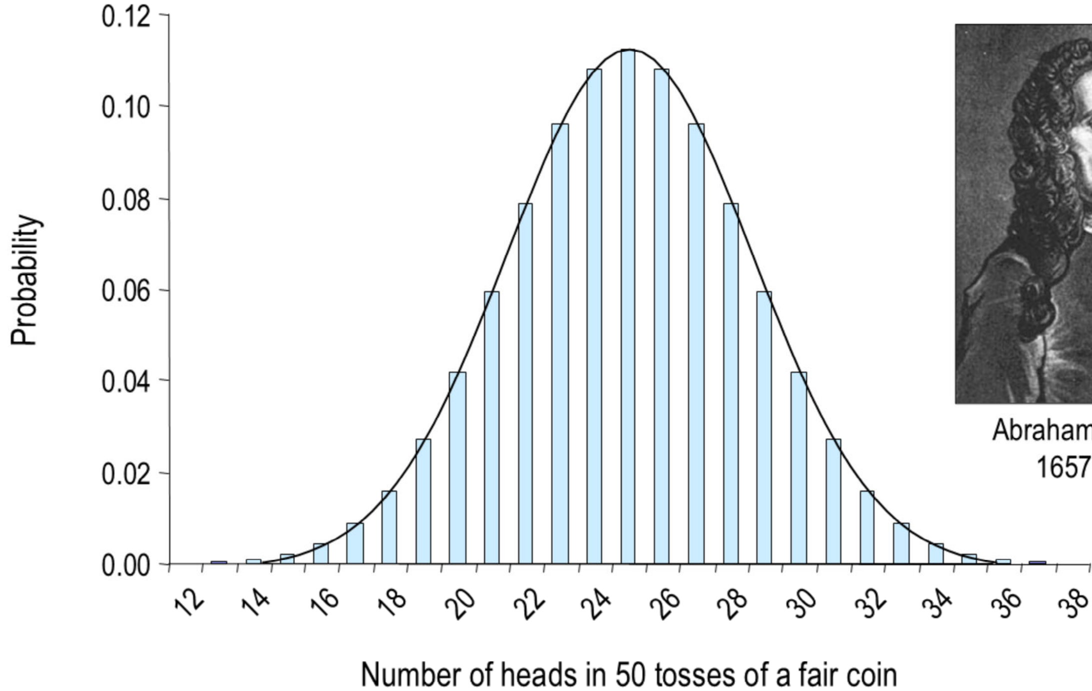


Everyone believes in the Normal curve. Experimenters think it has been proven mathematically, mathematicians think it has been proven empirically.

— G. Lippman

Where does the Normal distribution come from?

As the number of tosses of a fair coin increases,
the probability distribution of the number of heads
approaches a bell-shaped curve.

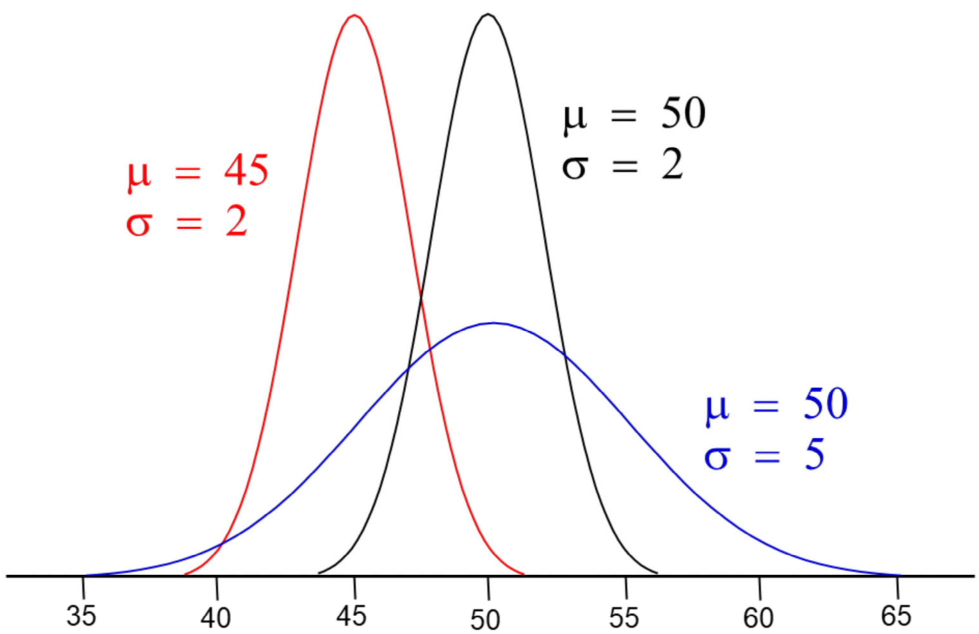


Abraham de Moivre
1657 - 1754

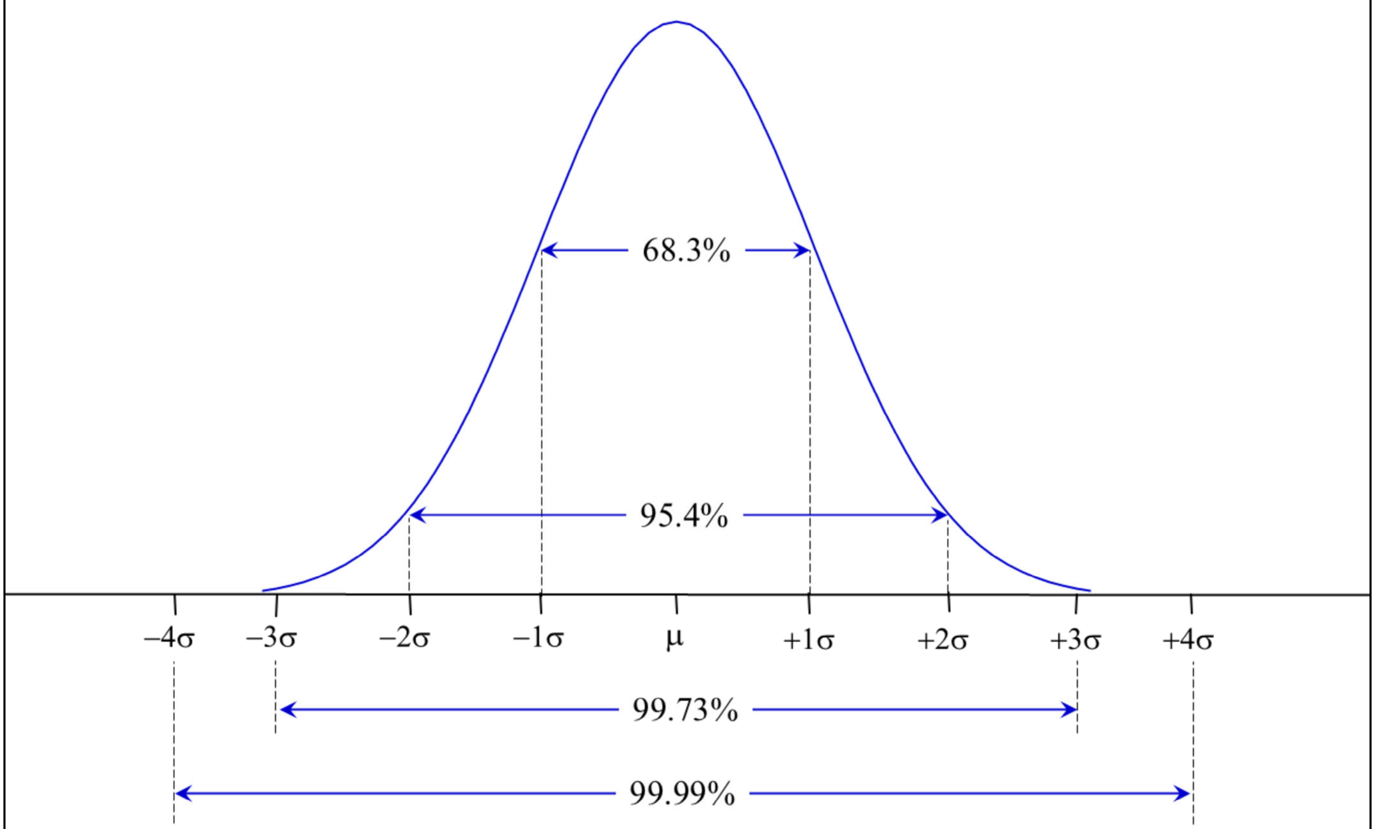
The bell-shaped curve is determined by μ and σ

μ = Greek letter *mu* → Population mean

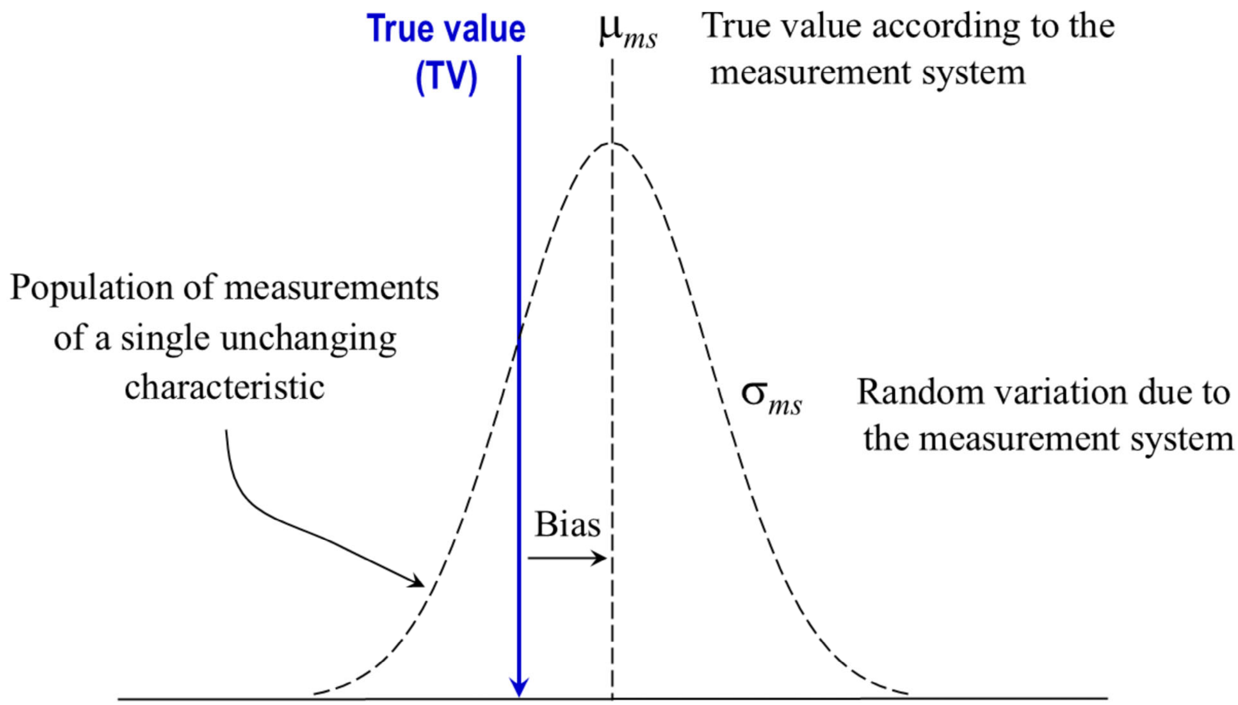
σ = Greek letter *sigma* → Population standard deviation



Area under curve = % of population



Population model for measurement variation

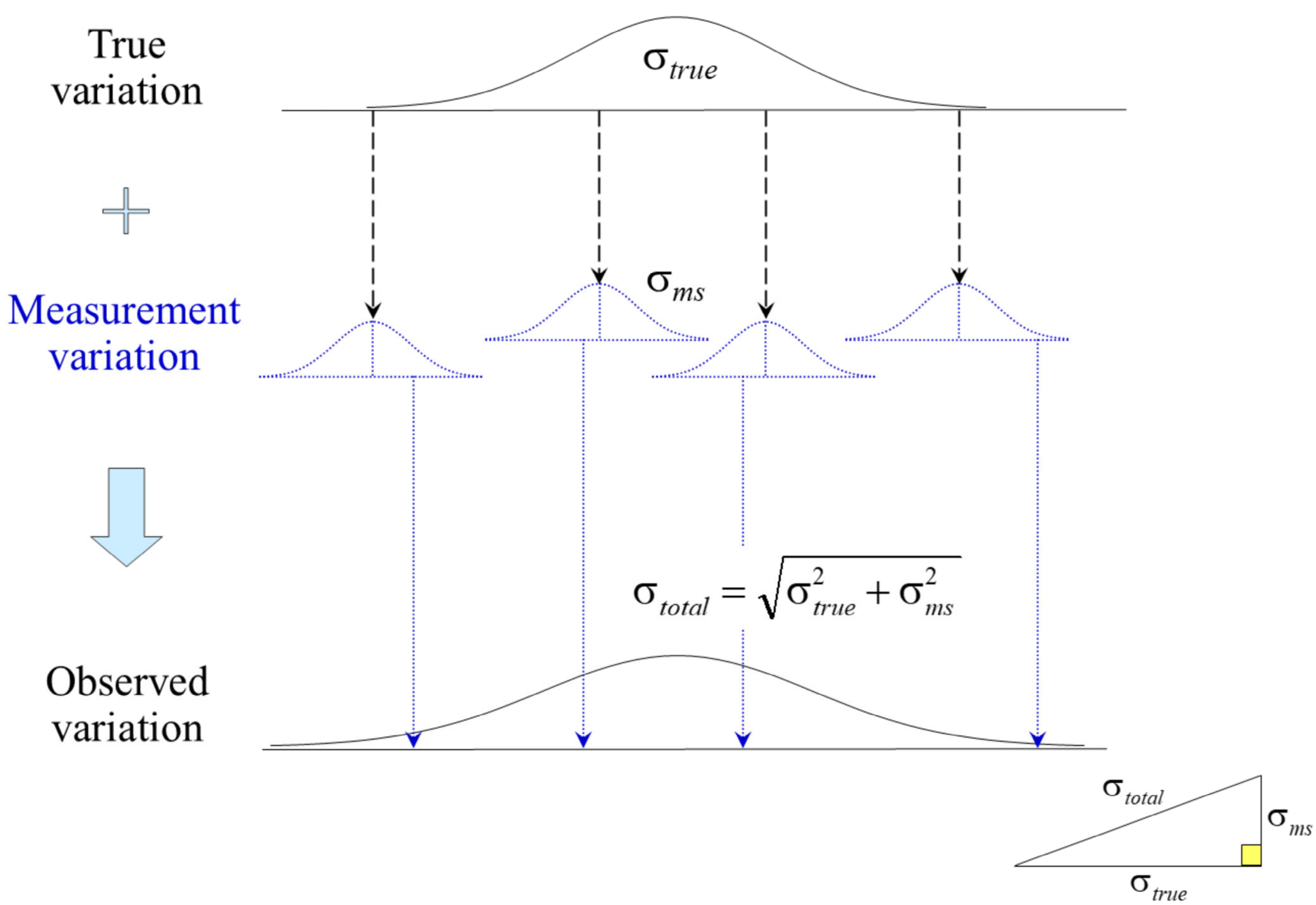


Measurement error = Systematic error (bias) + Random error

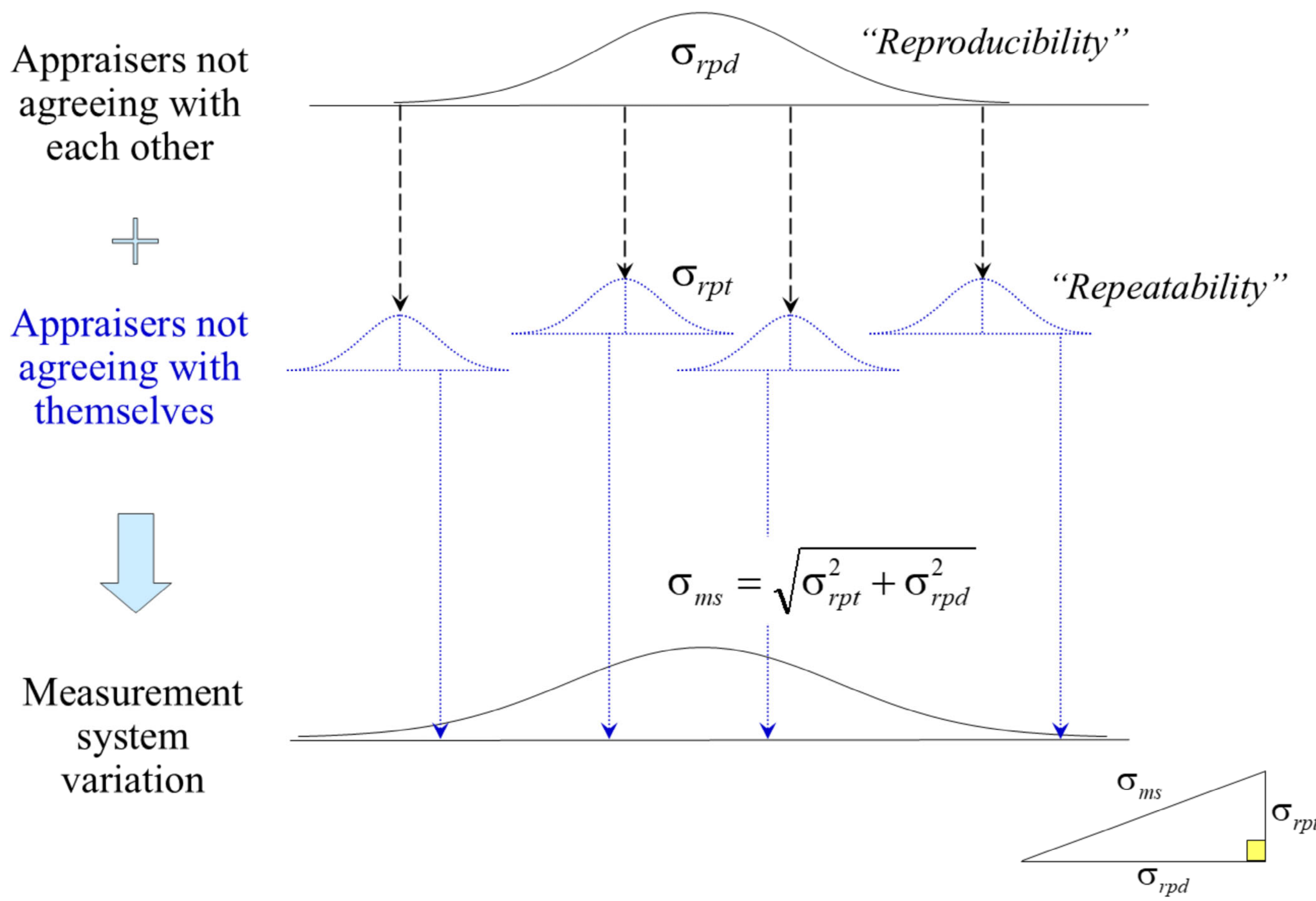
Population model for measurement variation

- The objective of calibration is to eliminate bias
- Calibration requires a standard (measurable item whose true value is known, or calibrated second gage of high accuracy)
- The objective of continuous MSA is to determine σ_{ms}
- Continuous MSA does not require a standard
- If the gage is biased, but the bias is constant during the MSA, the resulting σ_{ms} is not biased
- If the gage drifts during the MSA, the resulting σ_{ms} will biased upwards

How components of variation add up



Components of measurement system variation



Calculating total variation

	Data		Average		Variance		
	9.61		9.691		-0.081		
	9.71		9.691		0.019		
	9.54		9.691		-0.151		
	9.67		9.691		-0.021		
	9.75		9.691		0.059		
	9.49		9.691		-0.201		
	9.55		9.691		-0.141		
	9.42	=	9.691	+	-0.271	Sum =	0.00000000
	9.58		9.691		-0.111		
	9.61		9.691		-0.081		
	9.87		9.691		0.179		
	9.93		9.691		0.239		
	9.81		9.691		0.119		
	9.89		9.691		0.199		
	9.94		9.691		0.249		
Degrees of freedom (DF)	15	=	1	+	14		
Sum of squares (SS)	1409.220	=	1408.829	+	0.391		
Mean square (MS)	*(SS / DF)*				0.028		
Square root of MS					**0.167**		

↑ Sample standard deviation (STDEV)

Notes

Open the Excel file *total and meas syst variation*. Go to the sheet *total variation*. This sheet lays out the standard calculation of sample standard deviation.

The *Data* column contains 15 independent measurements (no constraints among them). This column has 15 *degrees of freedom* (DF).

The *Average* column contains only 1 value derived from the data. This column has 1 DF.

The *Variance* column contains only 14 independent values derived from the data. It is constrained to sum to 0, so any 14 values determine the remaining value. (What is the formula for the remaining value?) This column has 14 DF.

Calculating measurement system variation (simple example)

	A	B	D	E	F	G	H	J	K
1					**Part**		**Measurement**		
2		**Part**	**Data**		**averages**		**variation**		
3		1	9.61		9.656		-0.046		
4		1	9.71		9.656		0.054		
5		1	9.54		9.656		-0.116	Sum =	0.00000000
6		1	9.67		9.656		0.014		
7		1	9.75		9.656		0.094		
8		2	9.49		9.530		-0.040		
9		2	9.55		9.530		0.020		
10		2	9.42	=	9.530	+	-0.110	Sum =	0.00000000
11		2	9.58		9.530		0.050		
12		2	9.61		9.530		0.080		
13		3	9.87		9.888		-0.018		
14		3	9.93		9.888		0.042		
15		3	9.81		9.888		-0.078	Sum =	0.00000000
16		3	9.89		9.888		0.002		
17		3	9.94		9.888		0.052		
18	Degrees of freedom (DF)		15	=	3	+	12		
19	Sum of squares (SS)		1409.220	=	1409.159	+	0.061		
20	Mean square (MS)		*(SS / DF)*				0.005		
21	Square root of MS						**0.072**		
22							↑		
23							σ of measurement variation		
24									

Notes

Go to the sheet *meas syst variation*. This sheet lays out a very simple example of calculating σ_{ms}.

As before, the *Data* column has 15 DF.

The *Part averages* column contains 3 independent values derived from the data. This column has 3 DF.

The *Measurement variation* column contains only 12 independent values derived from the data. The values for each part are constrained to sum to 0, so any 4 of them determine the remaining value. There are 3 parts in this case, so this column has 12 DF.

So, σ_{ms} is calculated from only 12 independent values derived from the data. We express this by saying that σ_{ms} has 12 DF.

The larger the DF, the more accurate the σ_{ms} value.

Degrees of freedom

- Let: N = sample size of an MSA (total number of measurements)
  I = number of items in the MSA (parts, transactions, whatever)
  A = number of appraisers
  S = number of *sessions* (measurements per item per appraiser)

- In general: DF for σ_{ms} . . . . N–I
  DF for σ_{rpt} (repeatability) . . . . . IA(S–1)
  DF for σ_{rpd} (reproducibility) . . . . I(A–1)

- Note that: IA(S–1) + I(A–1) = N–I (because N = IAS)

Degrees of freedom

- In the simple example: N = 15, I = 3, A = 1, S = 5

- DF for σ_{ms} . . . . N–I = **15–3** = **12**
  DF for σ_{rpt} (repeatability) . . . . . IA(S–1) = **3(1)(4)** = **12**
  DF for σ_{rpd} (reproducibility) . . . I(A–1) = **3(0)** = **0**

- These relationships are useful for planning MSAs

Exercise 1

For each scenario below, give the total number of measurements and the degrees of freedom for σ_{ms}. (There is only one appraiser in each case.)

	N	DF
(a) 1 item is measured 15 times		
(b) Each of 15 items is measured 1 time		
(c) Each of 3 items is measured 5 times		
(d) Each of 3 items is measured 10 times		
(e) Each of 15 items is measured 2 times		
(f) Each of 4 items is measured 10 times		
(g) Each of 20 items is measured 2 times		
(h) Each of 8 items is measured 8 times		
(i) Each of 36 items is measured 2 times		

Exercise 1 (cont'd)

(j) What is the problem with scenario (b)?

(k) Which of scenarios (d) and (e) provides the more accurate value for σ_{ms}?

(l) Which of scenarios (f) and (g) provides the more accurate value for σ_{ms}?

(m) Which of scenarios (h) and (i) provides the more accurate value for σ_{ms}?

3 MSA for Continuous Data

- Measurement capability metrics
- Designing and conducting a continuous MSA
- Analyzing a continuous MSA

Notes

MSA for continuous data is also called “Gage R&R.”

Metrology topics like developing standards and calibration procedures are very important. The operational details vary significantly from one measurement system to another. These topics are not included in this course.

Measurement capability metrics

% Tolerance	$100 \times \frac{6\sigma_{ms}}{USL - LSL}$	• Most common metric • Must have both LSL and USL (usually product specs)
% Tolerance LSL only	$100 \times \frac{3\sigma_{ms}}{\mu - LSL}$	• Use when there is only LSL • Process mean (μ) should be based on historical data, not the MSA data
% Tolerance USL only	$100 \times \frac{3\sigma_{ms}}{USL - \mu}$	• Use when there is only USL • Process mean (μ) should be based on historical data, not MSA data
% Process	$100 \times \frac{\sigma_{ms}}{\sigma_{total}}$	• Doesn't require spec limits • Process standard deviation (σ_{total}) should be based on historical data, not MSA data
Measurement error	$3\sigma_{ms}$	• Has units of the measured characteristic • Intrinsic capability, not relative to product requirements

Acceptability criteria (for the unitless metrics)

10% or less	Excellent
10-20%	Good
20-30%	Acceptable
Greater than 30%	Unacceptable

Designing a continuous MSA

1. Choose at least 5 items (parts, samples, documents…) spanning the range of application of the measurement system. (Spanning the range is more important than the actual number of items.)

2. If the measurement system has only a few appraisers, include them all in the study. If there are many appraisers, include as large a representative sample as possible.

3. Let I = the number of items, A = the number of appraisers, and S = the number of *sessions* (measurements per item per appraiser).

   - The quantity I × A × (S – 1) is the number of independent opportunities for appraisers to agree *with themselves* (DF for repeatability). It should be at least 30.
   - The quantity I × (A – 1) is the number of independent opportunities for appraisers to agree *with each other* (reproducibility). It also should be at least 30.

   It is best to satisfy these requirements by increasing A, with I = 5 and S = 2. If this is not possible, increase I.

Designing a continuous MSA

4. If the measurements are taken by devices, and operators have no influence on the results, the devices are the appraisers.

5. If devices are used to aid human inspection, combinations of devices and human inspectors should be treated as the appraisers. The ideal is to use all possible combinations of human inspectors and devices. If this is not possible, a DOE matrix with an acceptable number of combinations should be created.

Examples of step 3

Open *sample size calculator for MSA*

Number of items	10	
Number of appraisers	3	
Number of sessions	3	
# Opportunities for appraiser cross-agreement	20	These should be at least 30 for continuous, at least 60 for attribute.
# Opportunities for appraiser self-agreement	60	
Total sample size	90	

- The standard automotive gage study (10-3-3)
- Not enough opportunities for appraiser cross agreement
- Unnecessarily many opportunities for appraiser self agreement

Examples of step 3

A better plan

Number of items	15	
Number of appraisers	3	
Number of sessions	2	
# Opportunities for appraiser cross-agreement	30	These should be at least 30 for continuous, at least 60 for attribute.
# Opportunities for appraiser self-agreement	45	
Total sample size	90	

- Better balance of opportunities for cross and self agreement
- Same total sample size

Examples of step 3

Best plan, assuming there are actually 7 appraisers

Number of items	5	
Number of appraisers	7	
Number of sessions	2	
# Opportunities for appraiser cross-agreement	30	These should be at least 30 for continuous, at least 60 for attribute.
# Opportunities for appraiser self-agreement	35	
Total sample size	70	

- Adequate opportunities for cross and self agreement
- Smaller total sample size

Conducting a continuous MSA

1. Perform this sequence for each session: *first appraiser measures all items once*, *second appraiser measures all items once, . . . , last appraiser measures all items once*.

2. The order in which the items are measured should be reversed each time the appraiser changes.

3. If possible, arrange for measurements to be “blind.” (This means appraisers can’t see the measured values.)

Analyzing a continuous MSA

Open *velocity gage*

- This is the data format required for continuous MSA in Excel
- The standard analysis requires that every appraiser measures every part the same number of times
- I = 8, A = 3, S = 2
- Was this a well designed MSA?

	A	B	C	D	E
1	**Session**	**Part**	**Oper A**	**Oper B**	**Oper C**
2	1	1	9.61	9.54	9.67
3	1	2	9.49	9.44	9.58
4	1	3	9.87	9.77	9.89
5	1	4	9.78	9.66	9.74
6	1	5	9.89	9.91	9.89
7	1	6	10.15	10.12	10.16
8	1	7	9.96	9.87	9.97
9	1	8	9.80	9.72	9.72
10	2	1	9.71	9.61	9.75
11	2	2	9.55	9.42	9.61
12	2	3	9.93	9.81	9.94
13	2	4	9.75	9.63	9.72
14	2	5	10.03	9.84	9.93
15	2	6	10.31	10.08	10.18
16	2	7	10.05	9.96	9.97
17	2	8	9.87	9.74	9.78
18					

- The overall standard deviation is 0.2017 [=STDEV(C2:E17)]
- How much of this should we attribute to the measurement system?

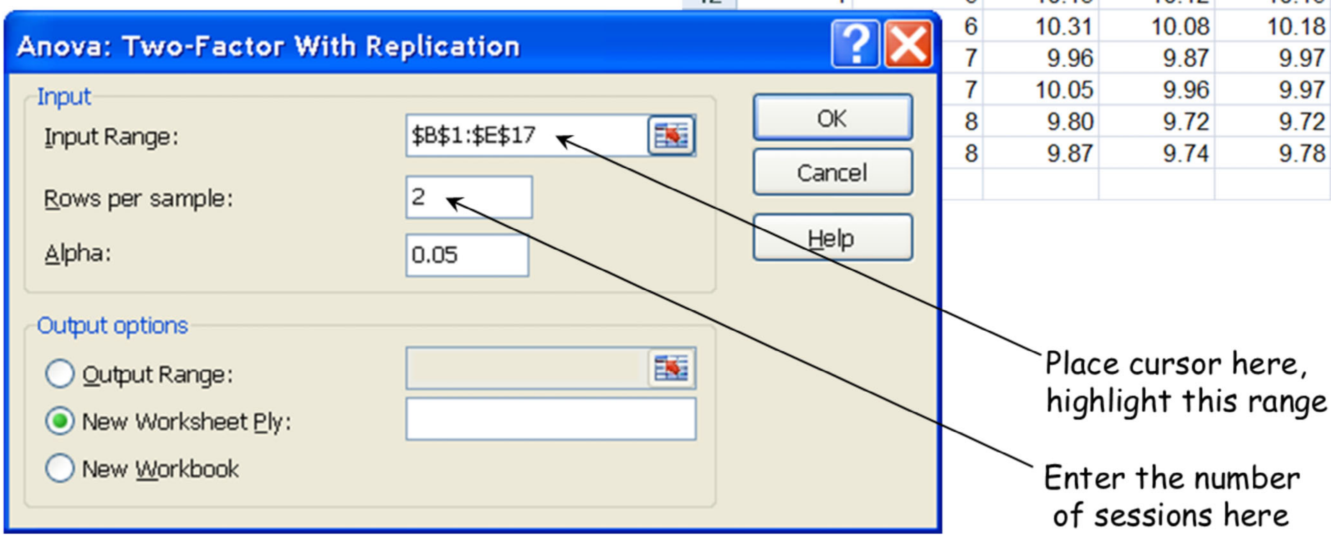
Example

1. Sort the data as shown to the right (the Excel procedure needs this).

2. Data (or Tools) → Data Analysis → Anova: Two-Factor With Replication → OK.

3. Set up as shown below, click OK.

	A	B	C	D	E
1	Session	Part	Oper A	Oper B	Oper C
2	1	1	9.61	9.54	9.67
3	2	1	9.71	9.61	9.75
4	1	2	9.49	9.44	9.58
5	2	2	9.55	9.42	9.61
6	1	3	9.87	9.77	9.89
7	2	3	9.93	9.81	9.94
8	1	4	9.78	9.66	9.74
9	2	4	9.75	9.63	9.72
10	1	5	9.89	9.91	9.89
11	2	5	10.03	9.84	9.93
12	1	6	10.15	10.12	10.16
		6	10.31	10.08	10.18
		7	9.96	9.87	9.97
		7	10.05	9.96	9.97
		8	9.80	9.72	9.72
		8	9.87	9.74	9.78



Example

4. Scroll down to the ANOVA table as shown to the right.

	A	B	C	D	E	F	G
58							
59	ANOVA						
60	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
61	Sample	1.729748	7	0.247107	103.23	2.37E-16	2.422629
62	Columns	0.096329	2	0.048165	20.12097	7.39E-06	3.402826
63	Interaction	0.028371	14	0.002026	0.846575	0.618209	2.129797
64	Within	0.05745	24	0.002394			
65							
66	Total	1.911898	47				
67							
68							
69							

5. Open *ANOVA 2F template*.

6. Copy the shaded area.

	A	B	C	D	E
1	ANOVA				
2	*Source of Variation*	*SS*	*df*	*MS*	
3	Sample	22.4742	7	3.2106	
4	Columns	84.5409	2	42.2704	
5	Interaction	73.5770	14	5.2555	
6	Within	233.2751	24	9.7198	
7					
8	Total	413.8672	47		
9					
10		σ^2		σ	
11	Reproducibility (Appraisers)	2.3134	19.2%	1.5210	
12	Reproducibility (Interaction)	0.0000	0.0%	0.0000	
13	Repeatability	9.7198	80.8%	3.1177	
14	Measurement System	12.0332	100.0%	**3.4689**	
15					
16	N	48			
17	Items	8			
18	Appraisers	3			
19	Sessions	2			
20					

Example

7. Paste the shaded area below your ANOVA table as shown.

σ_{total} = 0.2017
σ_{ms} = 0.0726
(34%)

Reproducibility is the dominant component, but not by much.

	A	B	C	D	E	F	G
58							
59	ANOVA						
60	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
61	Sample	1.729748	7	0.247107	103.23	2.37E-16	2.422629
62	Columns	0.096329	2	0.048165	20.12097	7.39E-06	3.402826
63	Interaction	0.028371	14	0.002026	0.846575	0.618209	2.129797
64	Within	0.05745	24	0.002394			
65							
66	Total	1.911898	47				
67							
68		σ^2		σ			
69	Reproducibility (Appraisers)	0.0029	54.6%	0.0537			
70	Reproducibility (Interaction)	0.0000	0.0%	0.0000			
71	Repeatability	0.0024	45.4%	0.0489			
72	Measurement System	0.0053	100.0%	**0.0726**			
73							
74	N	48					
75	Items	8					
76	Appraisers	3					
77	Sessions	2					
78							

8. For this example, USL–LSL = 3.3. Use Excel formulas to calculate the *% Tolerance* metric.

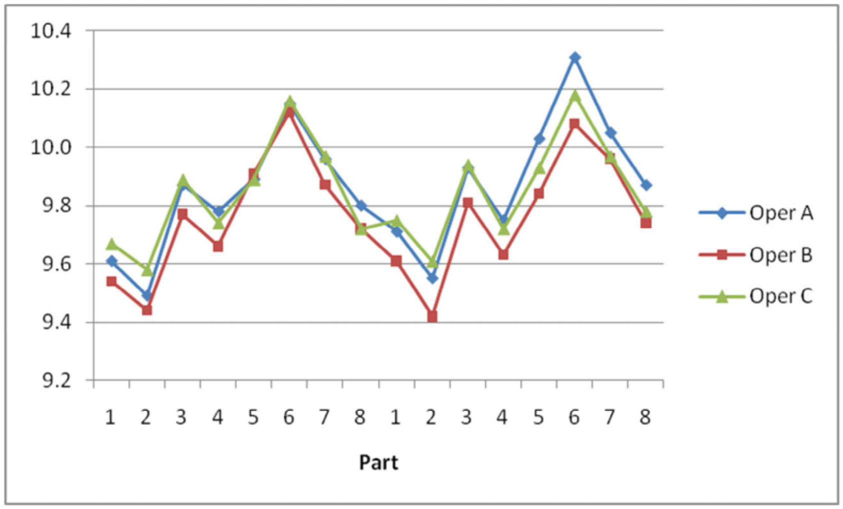
$$\%\text{Tolerance} = \frac{600\sigma_{ms}}{USL - LSL} = 13.2\%$$

Example

9. Sort your data back to the original sequence (by *Session*, then *Part*).

10. Create a line chart of the operator columns

11. This is what a good one looks like. The operator curves are close together and roughly parallel.



13. If the *interaction* component of reproducibility had been large, the operator curves would be noticeably non-parallel.

- This can be caused by inconsistent identification of parts across sessions.
- Barring that, it indicates severe disagreement among appraisers.

Notes

Exercise 2

Open *calipers*. These are dimensional inspections of PVC extrusions made with a hand-held digital caliper.

(a) For this example, USL – LSL = 0.040. Find σ_{ms} and calculate the *% Tolerance* metric. Classify the measurement system as excellent, good, acceptable, or unacceptable.

(b) Create a line chart of the operator columns. Who seems to be the greatest opportunity for improvement?

Exercise 3

Open *gloss*. These are measurements of % gloss on 7 sheets of photographic paper by 9 technicians. MSAs were conducted at 3 different temperatures.

(a) Find the measurement error ($3\sigma_{ms}$) at 20 deg. Identify the dominant component of σ_{ms}.

(b) Find the measurement error ($3\sigma_{ms}$) at 60 deg. Identify the dominant component of σ_{ms}.

(c) Find the measurement error ($3\sigma_{ms}$) at 85 deg. Identify the dominant component of σ_{ms}.

4 Workshop

Each team is to conduct an MSA involving coins of different diameters. Every team member will be an appraiser in the study. Each appraiser will measure the diameter of each coin twice (S = 2). Each team is to do the following:

a) Develop and document a procedure for measuring the diameter.

b) Determine the number of coins needed for the study.

c) Create an appropriately formatted Excel worksheet for data collection.

d) Follow the guidelines for conducting a continuous MSA.

e) Collect and enter the data. Calculate the *% Tolerance* metric. (The spec limits for all diameters are *nominal diameter* ± 0.015".)

f) Is the measurement system excellent, good, acceptable or unacceptable?

Notes

Designing an attribute MSA

1. Choose at least 10 items (parts, samples, documents…) to be inspected. There should be roughly equal numbers of items that are clearly passing, borderline passing, borderline failing and clearly failing. Choose an expert appraiser to function as the reference standard.

2. If the measurement system has only a few appraisers, include them all in the study. If there are many appraisers, include as large a representative sample as possible.

3. Let I = the number of items, A = the number of appraisers, and S = the number of measurements per item per appraiser.

   - The quantity $I \times A \times (S - 1)$ is the number of independent opportunities for appraisers to agree *with themselves*. It should be at least 60.

   - The quantity $I \times (A - 1)$ is the number of independent opportunities for appraisers to agree *with each other*. It should be at least 60.

   It is best to satisfy these requirements by increasing A with $I = 10$ and $S = 2$. If this is not possible, increase I.

Designing an attribute MSA

4. If the measurements are taken by devices, and operators have no influence on the results, the devices are the appraisers.

5. If devices are used to aid human inspection, combinations of devices and human inspectors should be treated as the appraisers. The ideal is to use all possible combinations of human inspectors and devices. If this is not possible, a DOE matrix with an acceptable number of combinations should be created.

Designing an attribute MSA

Number of items	30	
Number of appraisers	3	
Number of sessions	2	
# Opportunities for appraiser self-agreement	90	These should be at least 30 for continuous data, at least 60 for attribute data.
# Opportunities for appraiser cross-agreement	60	
Total sample size	180	

Best plan if there are only 3 appraisers

Conducting an attribute MSA

1. Perform this sequence for each session: *first appraiser measures all items once*, *second appraiser measures all items once, . . . , last appraiser measures all items once*.

2. The order in which the items are measured should be reversed each time the appraiser changes.

Example

- Open *pass-fail*
- I = 50, A = 3, S = 3
- Did they follow the best plan for 3 appraisers?
- P = pass, F = fail
- *Standard* gives the correct answer for each part inspected
- The analysis is based on % agreement with the standard

	A	B	C	D	E	F
1	Session	Part	Standard	Insp A	Insp B	Insp C
2	1	1	P	P	P	P
3	1	2	P	P	P	P
4	1	3	F	F	F	F
5	1	4	F	F	F	F
6	1	5	F	F	F	F
7	1	6	P	P	P	P
8	1	7	P	P	P	P
9	1	8	P	P	P	P
10	1	9	F	F	F	F
11	1	10	P	P	P	P
12	1	11	P	P	P	P
13	1	12	F	F	F	F
14	1	13	P	P	P	P
15	1	14	P	P	P	P
16	1	15	P	P	P	P
17	1	16	P	P	P	P
18	1	17	P	P	P	P
19	1	18	P	P	P	P
20	1	19	P	P	P	P
21	1	20	P	P	P	P
22	1	21	P	P	P	F
23	1	22	F	F	F	P
24	1	23	P	P	P	P
25	1	24	P	P	P	P
26	1	25	F	F	F	F
27	1	26	F	F	F	F
28	1	27	P	P	P	P
29	1	28	P	P	P	P
30	1	29	P	P	P	P

Example

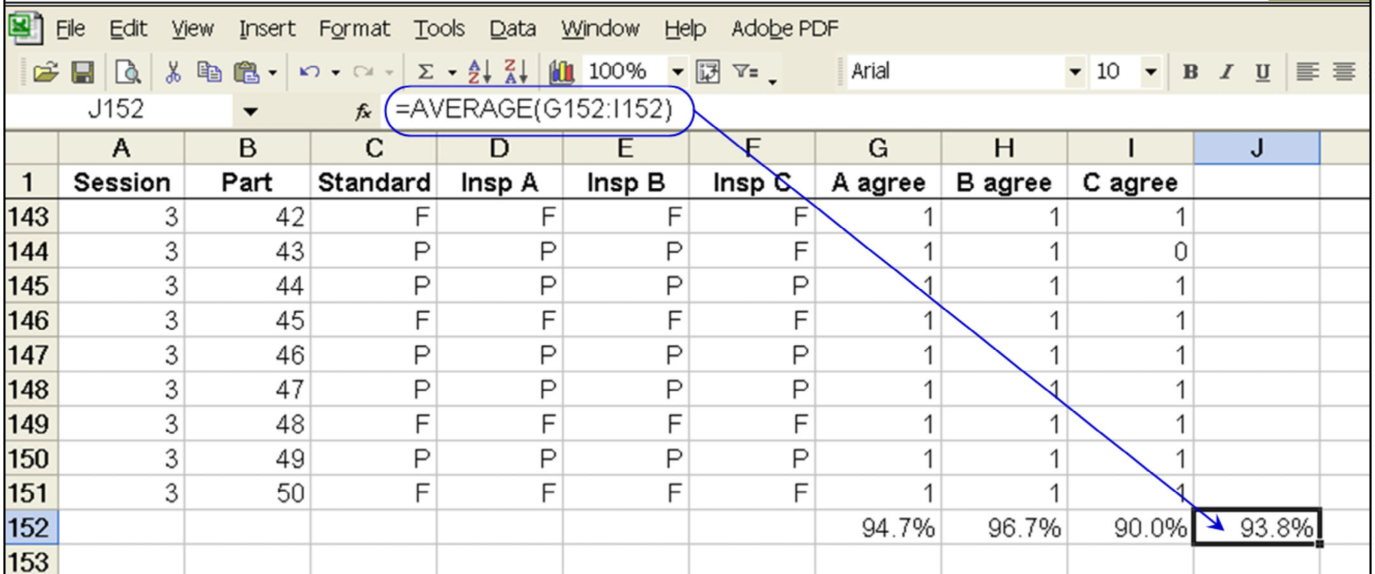
G2 =IF(D2=$C2,1,0)

	A	B	C	D	E	F	G	H	I	J
1	Session	Part	Standard	Insp A	Insp B	Insp C	A agree	B agree	C agree	
2	1	1	P	P	P	P	1	1	1	
3	1	2	P	P	P	P	1	1	1	
4	1	3	F	F	F	F	1	1	1	
5	1	4	F	F	F	F	1	1	1	
6	1	5	F	F	F	F	1	1	1	
7	1	6	P	P	P	P	1	1	1	
8	1	7	P	P	P	P	1	1	1	
9	1	8	P	P	P	P	1	1	1	

- The first step is to define new columns indicating whether A, B and C agree or disagree with *Standard* in each case

- 1 = agree, 0 = disagree

Example



J152 =AVERAGE(G152:I152)

	A	B	C	D	E	F	G	H	I	J
1	Session	Part	Standard	Insp A	Insp B	Insp C	A agree	B agree	C agree	
143	3	42	F	F	F	F	1	1	1	
144	3	43	P	P	P	F	1	1	0	
145	3	44	P	P	P	P	1	1	1	
146	3	45	F	F	F	F	1	1	1	
147	3	46	P	P	P	P	1	1	1	
148	3	47	P	P	P	P	1	1	1	
149	3	48	F	F	F	F	1	1	1	
150	3	49	P	P	P	P	1	1	1	
151	3	50	F	F	F	F	1	1	1	
152							94.7%	96.7%	90.0%	93.8%
153										

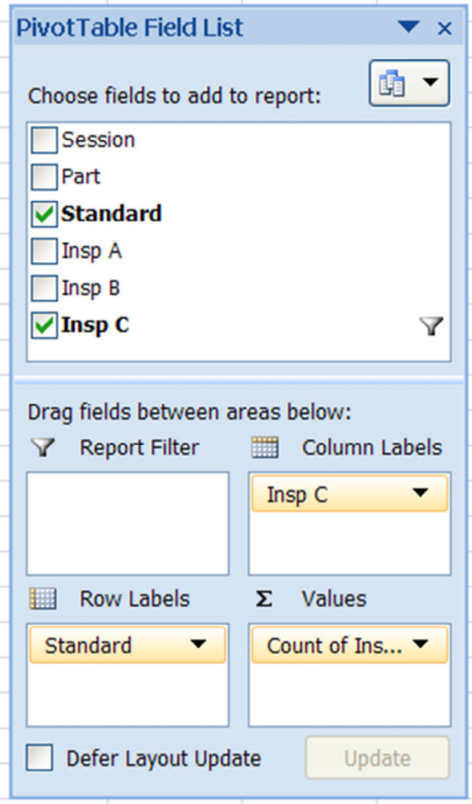
- The next step is to calculate % agreement by inspector and overall
- Use the *Average* function on your *AutoSum* button to get the results for each inspector, then use it again to get the overall %
- If improvement is needed, Inspector C is the greatest opportunity

Notes

Example

Count of Insp C	Insp C		
Standard	F	P	Grand Total
F	42	6	48
P	9	93	102
Grand Total	51	99	150

- Create a pivot table set up as shown here
- This tallies the bad parts failed (42), the bad parts passed (6), the good parts failed (9), and the good parts passed (93)

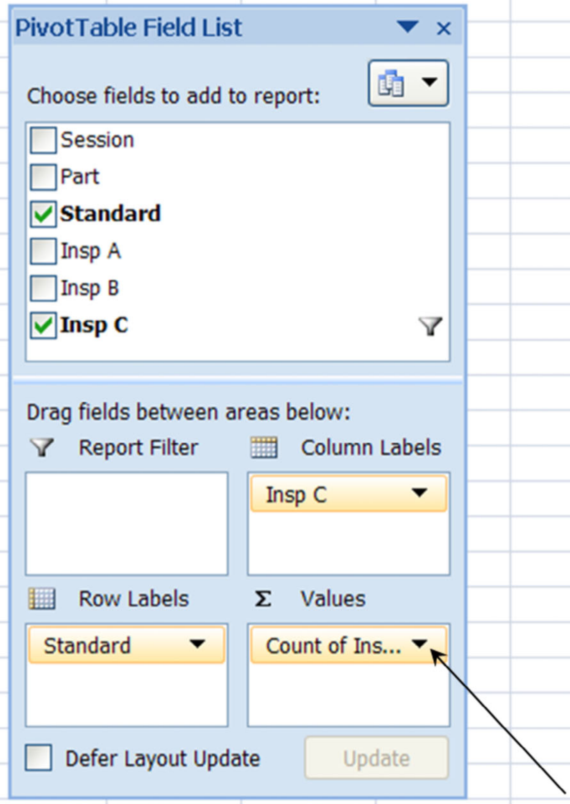


Example

Drop Page Fields Here

Count of Insp C	Insp C		
Standard	F	P	Grand Total
F	87.50%	12.50%	100.00%
P	8.82%	91.18%	100.00%
Grand Total	34.00%	66.00%	100.00%

- Click on *Count of Insp C* (in the Values area) → *Value Field Settings* → *Show values as* → % of row
- This shows the % of bad parts that were passed (12.5) and the % of good parts that were failed (8.8)
- It looks like *Insp C* has problems in both areas



Exercise 4

Open *print samples 1*. These are visual inspections of print samples by 3 inspectors. The standards were determined by a committee of experienced print quality evaluators.

(a) Calculate the % agreement by inspector and overall.

(b) Which inspector offers the greatest opportunity for improvement? Make a pivot table to determine whether the main problem is passing bad samples, failing good ones, or both.

(c) Save your work.

Exercise 5

Open *print samples 2*. These are visual inspections of new print samples by the same 3 inspectors after additional training.

(a) Calculate the % agreement by inspector and overall. Have we improved?

(b) There is something interesting about the data for sample 18 (not row 18). What are the possible explanations?

(c) Reclassify sample 18 as passing. What is the % agreement now?

(d) Save your work.

Exercise 6

Open *rating data.* Each of 15 employment applications was rated twice on a five point scale (1 = worst, 5 = best) by each of five appraisers.

a) Calculate the % agreement by appraiser and overall.

b) Which inspector offers the greatest opportunity for improvement? Make a pivot table to determine what the main problem is.

c) Save your work.

Notes

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6 Workshop

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Notes

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