MSA

Measurement System Analysis
(overview)

Suppliers

Training rules

Active engagement

Duration: 2 Days
(2 hr / Day)

Keep the microphone mute and activate when you have doubts or comments

Keep open mind to virtual training (Time to the self-learning at home is important)

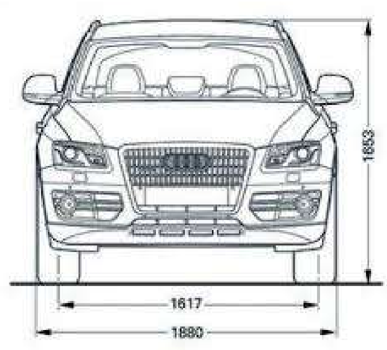
If you have have doubts or comments, please share with us

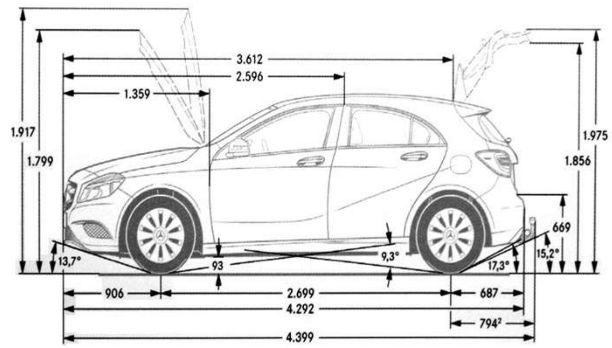
Introduce yourself

- Name
- Position in your Company
- Department
- Previous MSA training
- Training expectation

What is MSA?

What is measurement?





What is a system?

What is an analysis?

MSA

BOCAR GROUP

Measurement: the assignment of numbers or values to material things

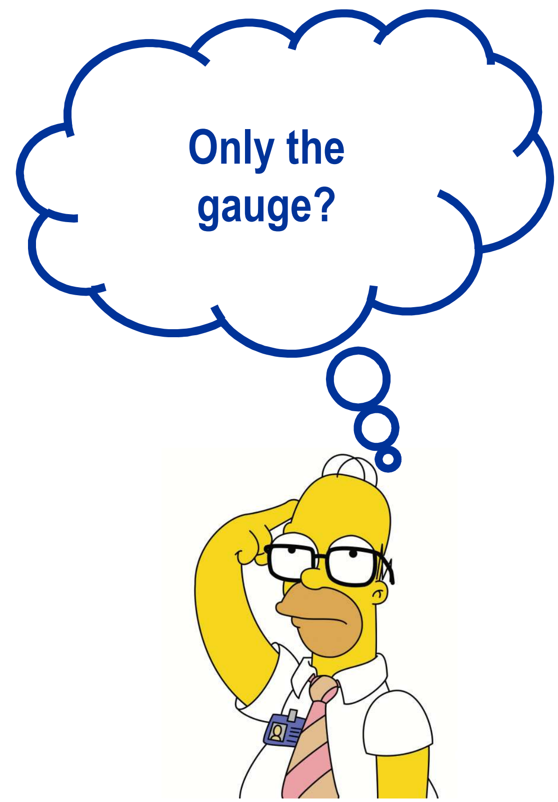
System: is a set of elements working together (interacting or interrelated); in order to form a whole

Analysis: a statistical study to quantify or qualify the factors that affect a process

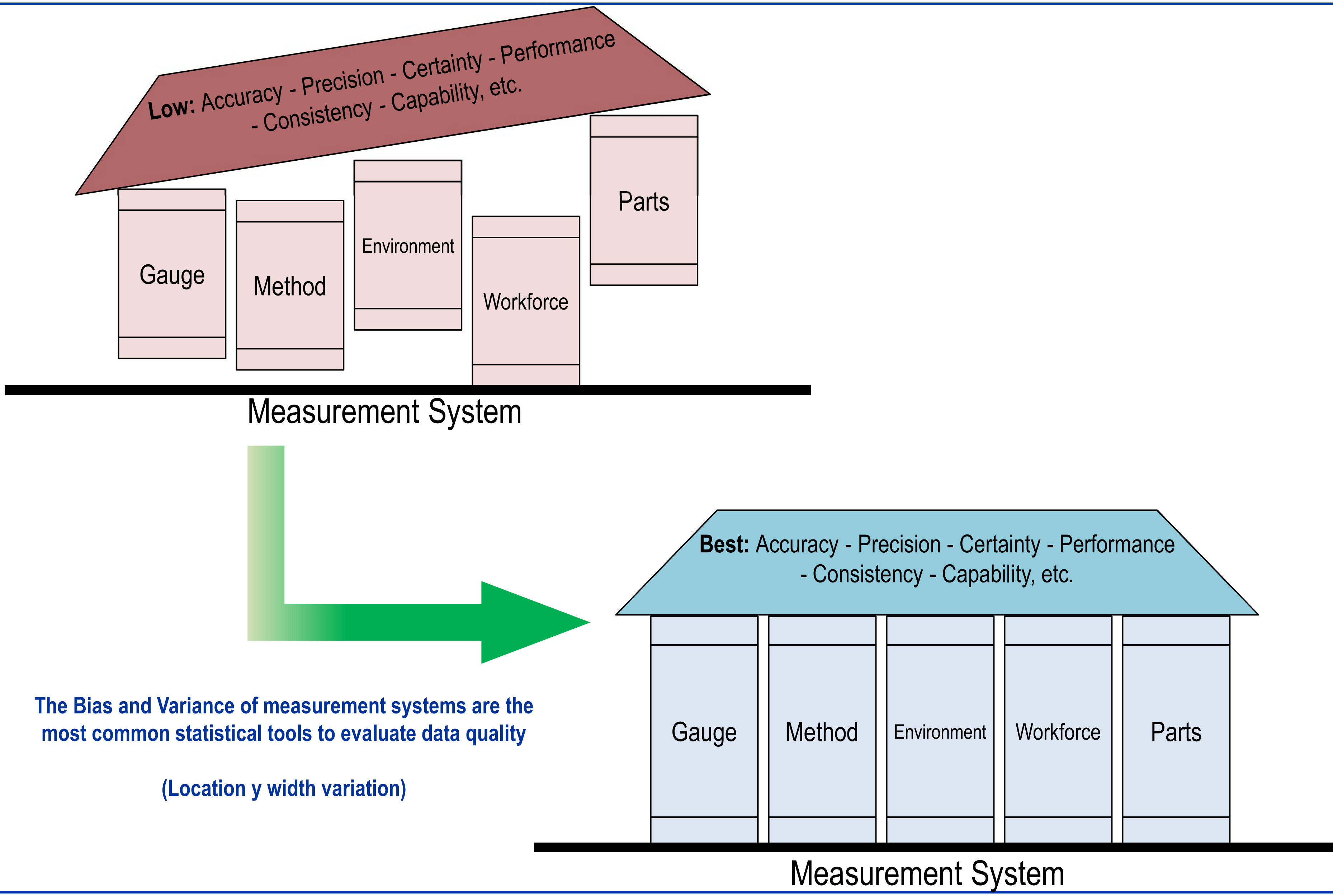
Measurement System Analysis (MSA)

Measurement assurance, which uses statistical tools in order to demonstrate that measurements have the accuracy / precision required to control of a feature / process

Measurement System



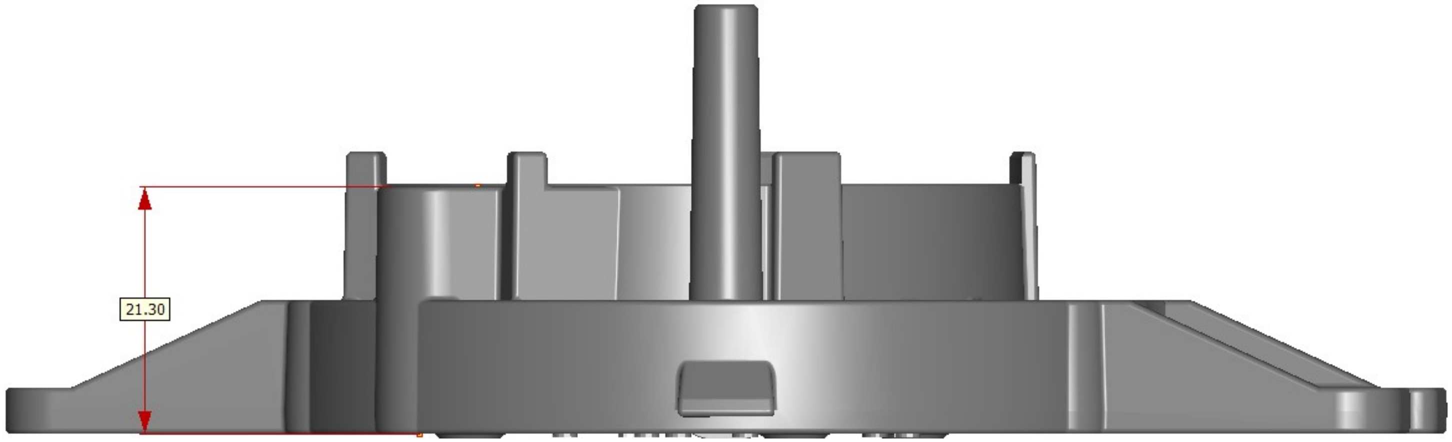
High quality data

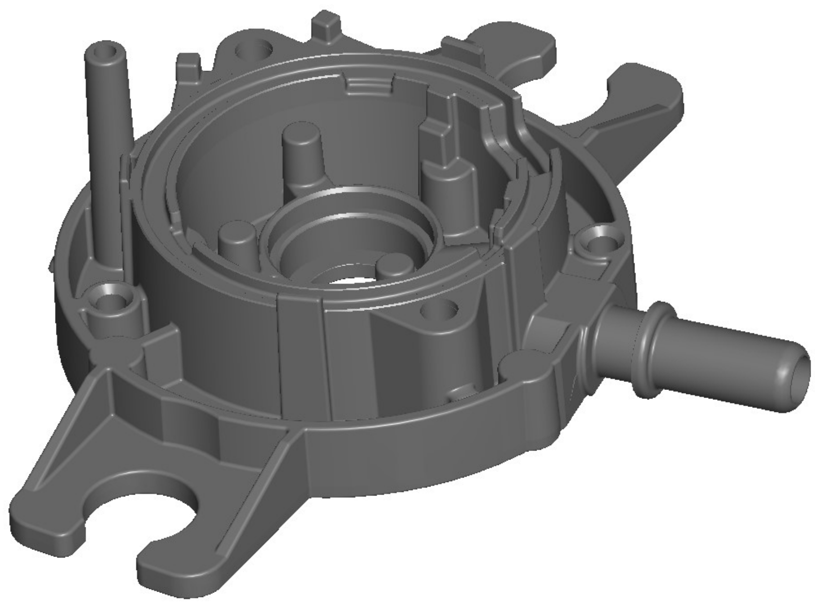


The Bias and Variance of measurement systems are the most common statistical tools to evaluate data quality

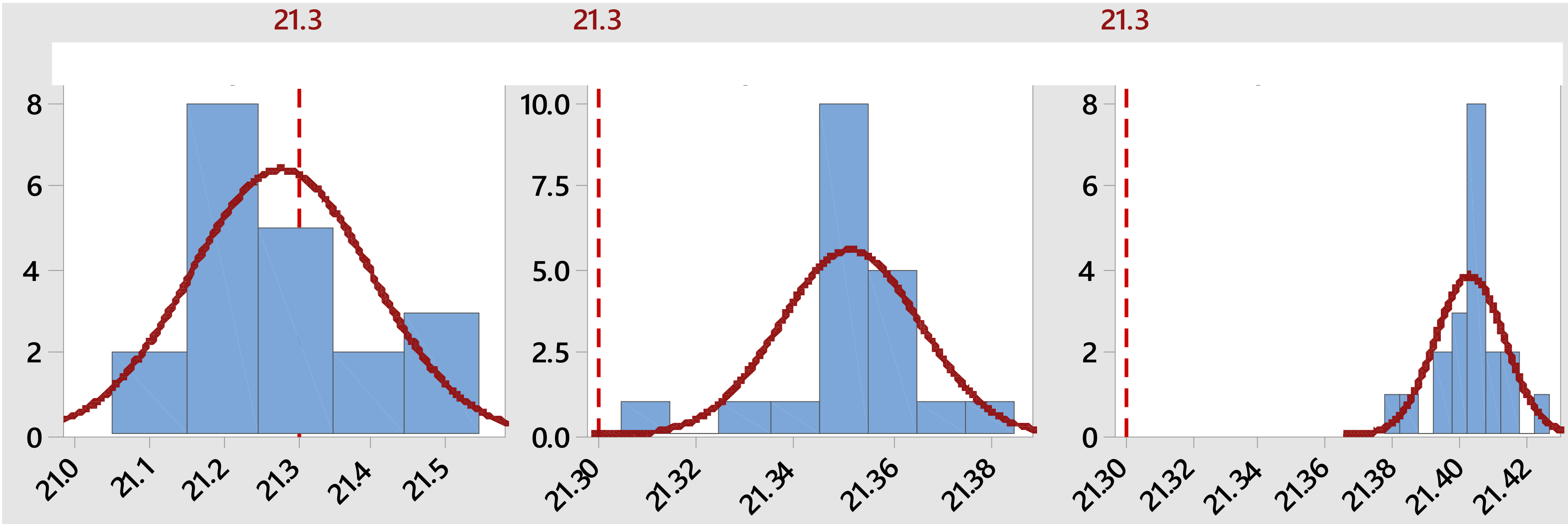
(Location y width variation)

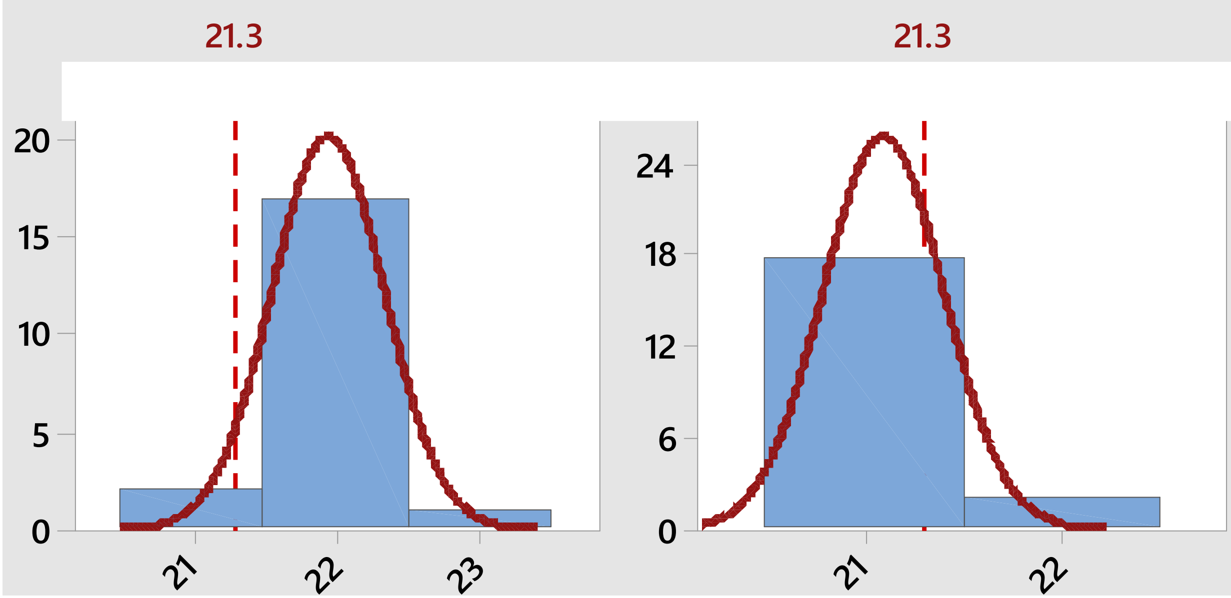
Exercise 1 – Measure the height / width





Exercise 1 – Which is the part value?

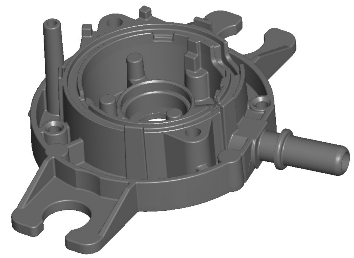


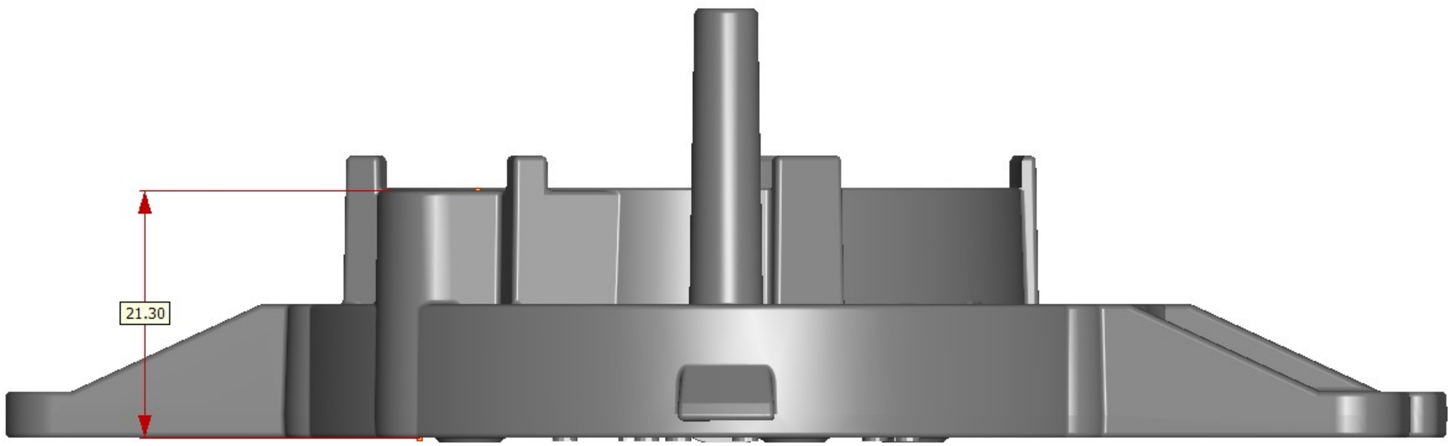


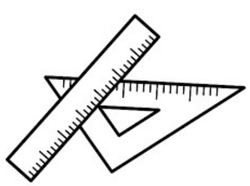
Average
21.28
21.35
21.40
21.95
21.10

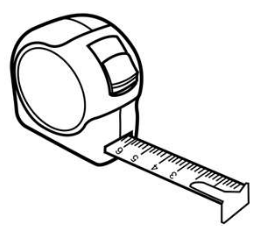
?

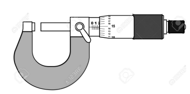
With what kind of gauge was it measured?

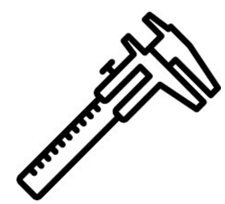




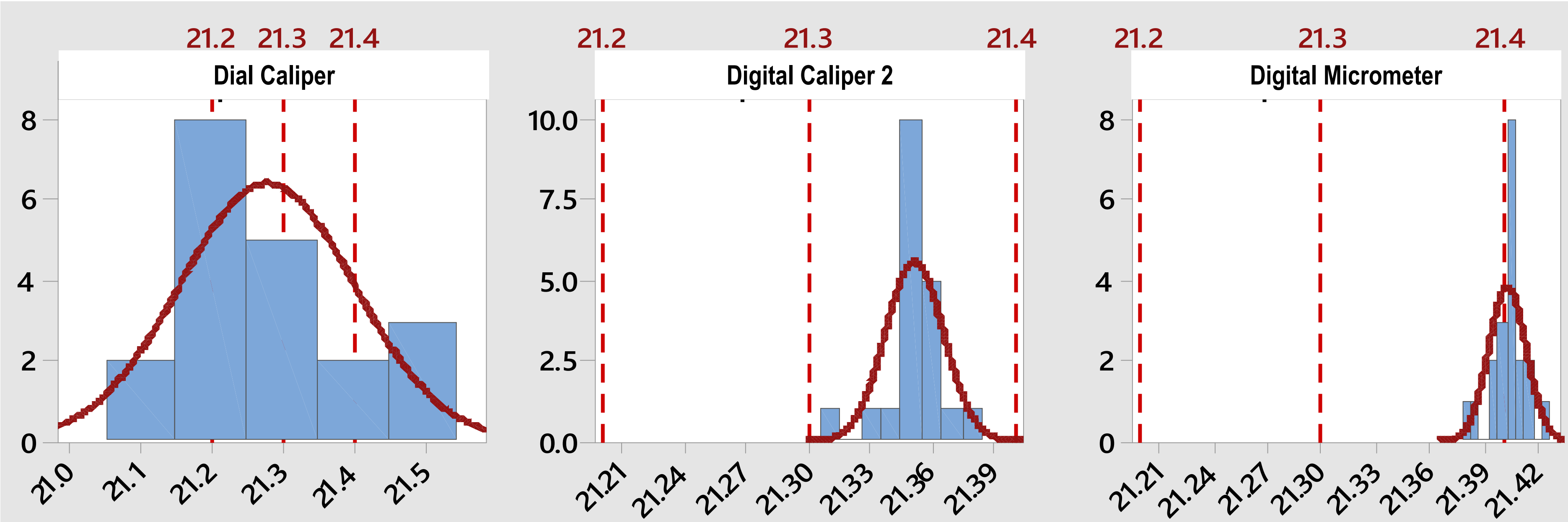


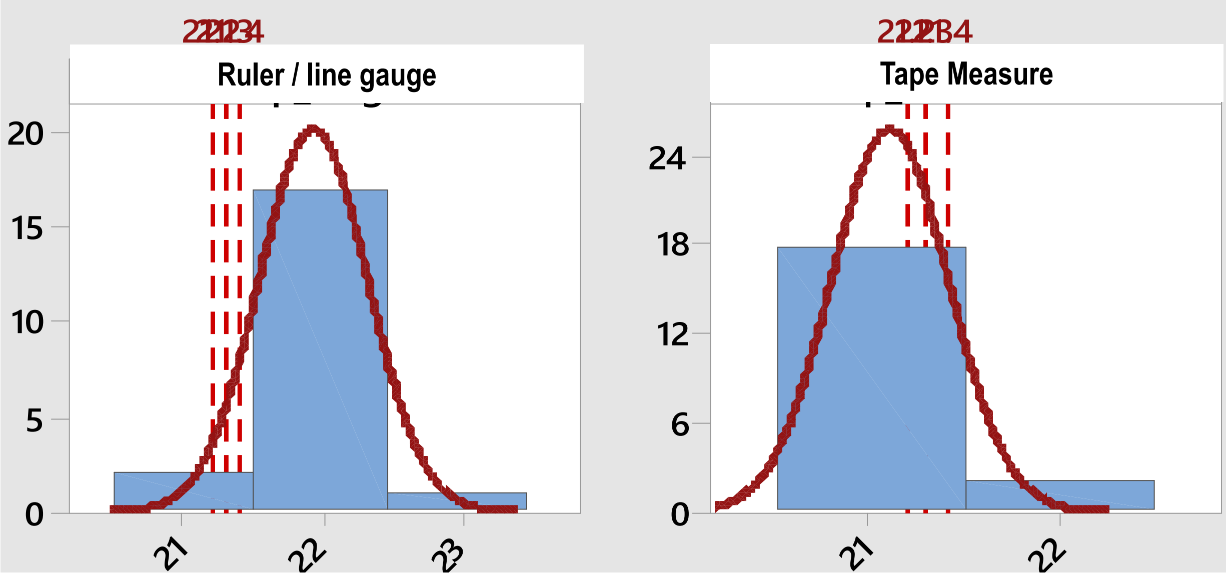






Exercise 1 – Is the part good or rejected?



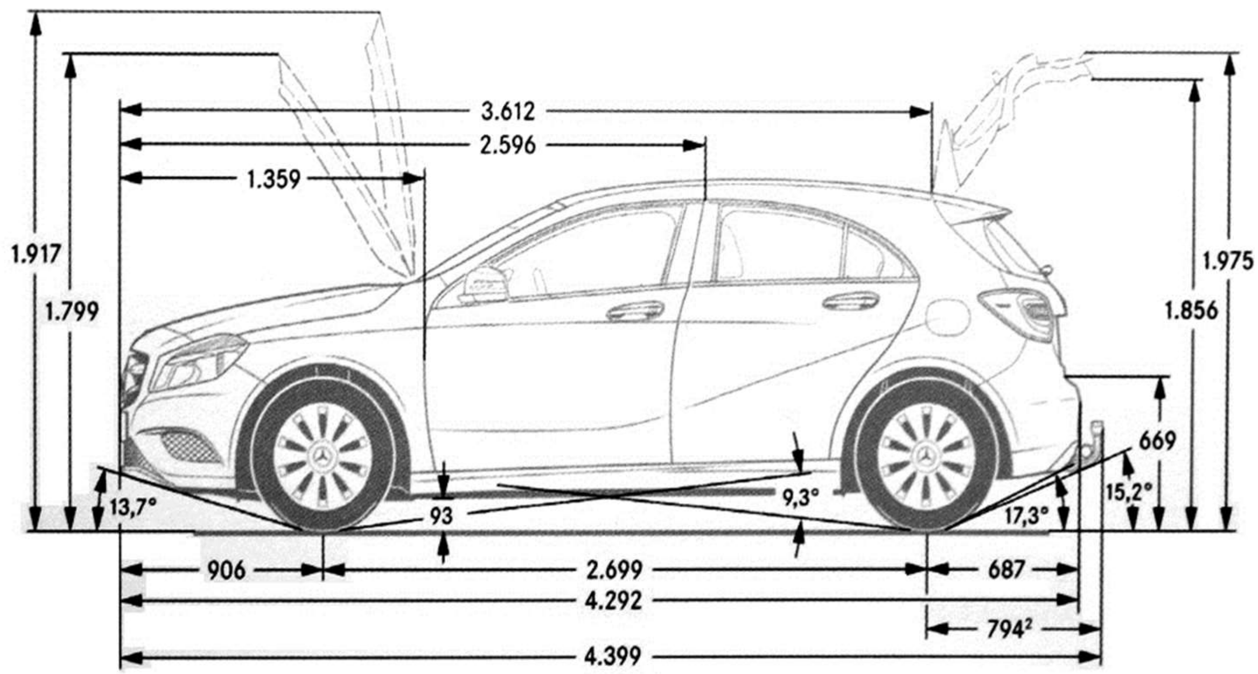


	Average
Dial Caliper	21.28
Digital Caliper 2	21.35
Digital Micrometer	21.40
Ruler	21.95
Tape Measure	21.10

Appropriate gauge / equipment

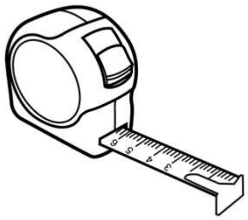
Before you selecting the equipment, it is important to analyze:

What do you want to measure? Why (purpose)? Who? Requirements (method, environment, use conditions, frequencies, qualified workforce, etc.) other variations?



Appropriate gauge / equipment

BOCAR GROUP



¿unit of measure?

m, cm, mm, µm

¿Discrimination, readability, resolution?

1 m

100 cm = 1 m

1,000 mm = 1 m

1,000,000 µm = 1 m

Discrimination, readability, resolution: Smallest scale unit of measure or output for an instrument

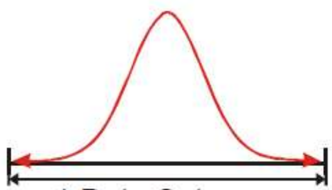
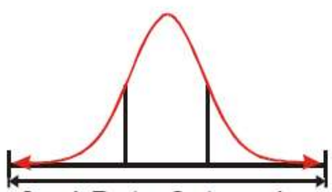
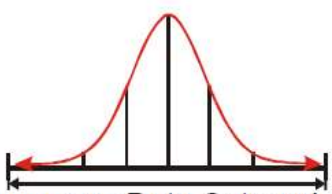
10 to 1 rule of thumb

Apparent resolution: X.XXX (3 Digits / numbers)

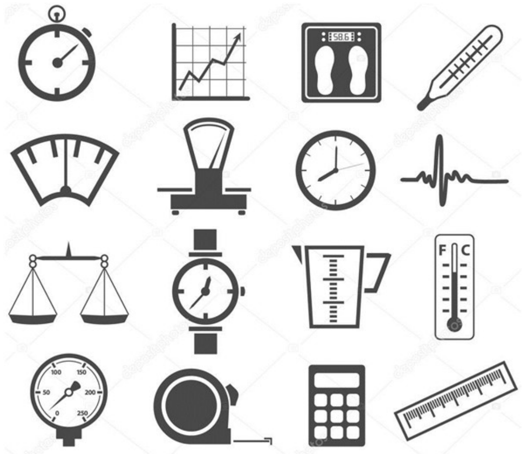
Effective resolution: 0.005 / 0.010 / 0.001 / 0.002

Number of Categories

ndc: With the number of categories we must to know if the equipment is the appropriate for the measure (to detect the process variation)

Number of Categories	Control	Analysis
 1 Data Category	Can be used for control only if: • The process variation is small when compared to the specifications • The loss function is flat over the expected process variation • The main source of variation causes a mean shift	• ***Unacceptable*** for estimating process parameters and indices • Only indicates whether the process is producing conforming or nonconforming parts
 2 - 4 Data Categories	• Can be used with semi-variable control techniques based on the process distribution • Can produce insensitive variables control charts	• Generally unacceptable for estimating process parameters and indices since it only provides coarse estimates
 5 or more Data Categories	• Can be used with variables control charts	• ***Recommended***

The measure value – Is it real?



Reference value (V_R): also known as the accepted reference value or master value, is a value of an artifact or ensemble that serves as an agreed upon reference for comparison.

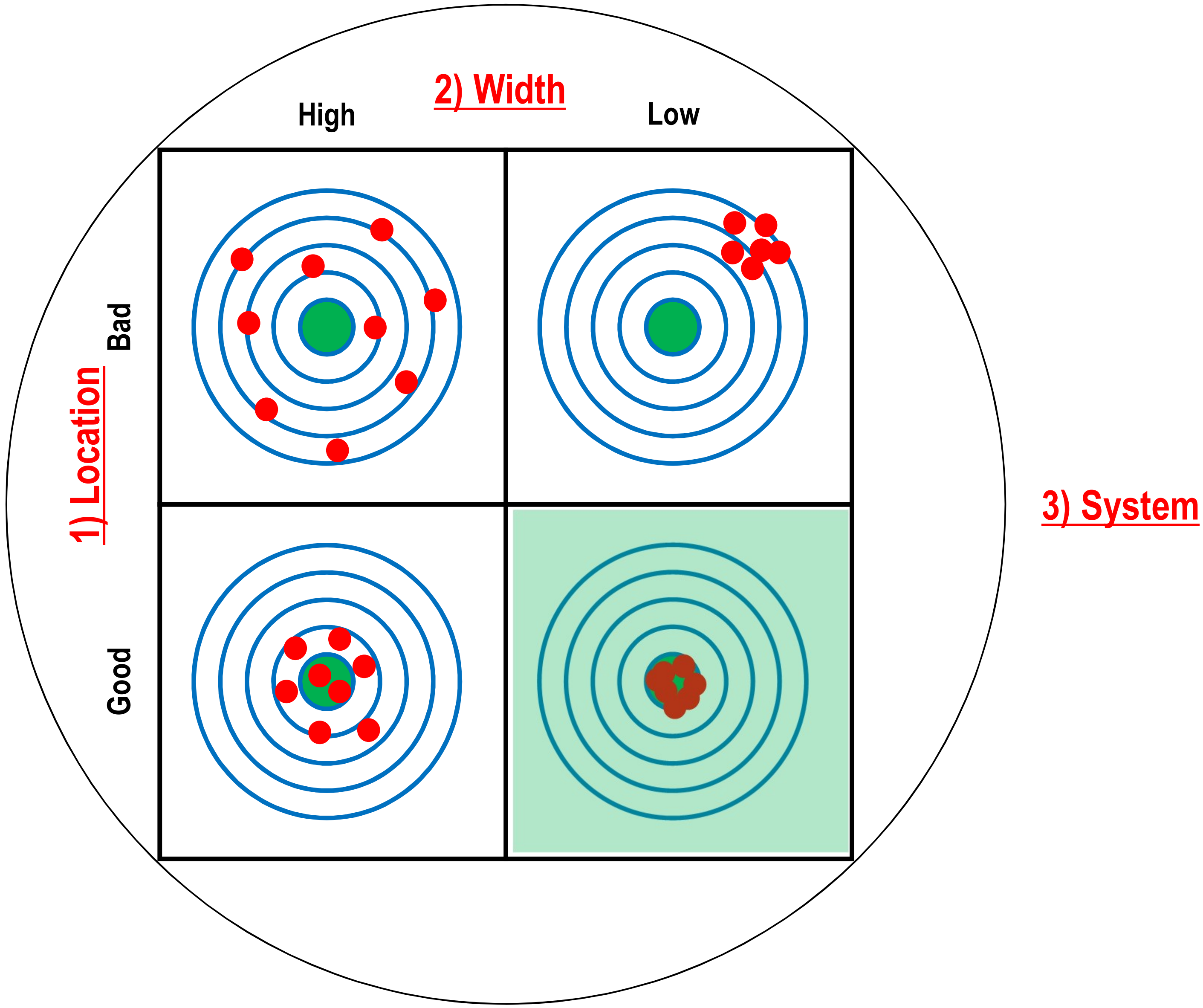
Calibration

Is a set of operations that establish, under specified conditions, the relationship between a measuring device and a traceable standard of known reference value and uncertainty

Calibration may also include steps to detect, correlate, report, or eliminate by adjustment any discrepancy in accuracy of the measuring device being compared.

The calibration system determines measurement traceability to the measurement systems through the use of calibration methods and standards.

Variations



Test of Hypothesis

Null hypothesis (H0)

It is an affirmation that you are testing in order to determine if it is true or not

Example: (Variation = 0 / It is significant or not)

$$H0: \mu = \mu\ 0$$

Alternative hypothesis (Ha / H1)

There is a real effect and the observations are affected by some conditions and present some variation

Example:

$$H_1: \mu \neq \mu_0 \quad \text{or} \quad H_1: \mu > \mu_0 \quad \text{or} \quad H_1: \mu < \mu_0$$

To take decision, use p value

- If **$p<0.05$** something is happen, therefore we <u>**reject the null hypothesis**</u> (H0); and accept the alternative hypothesis (H_1).

- The Alternate Hypothesis (H_1) is accepted based on data when them show a significant change, for this reason our decision is reject the H0.

- <u>In others words we are approving with >95% certainty that something changed.</u>

Examples:

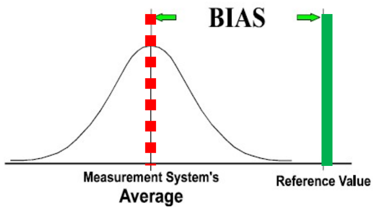
$p_{value} = 0.035$ - Rejected H0

$p_{value} = 0.002$ - Rejected H0

$p_{value} = 0.051$ - Accepted H0

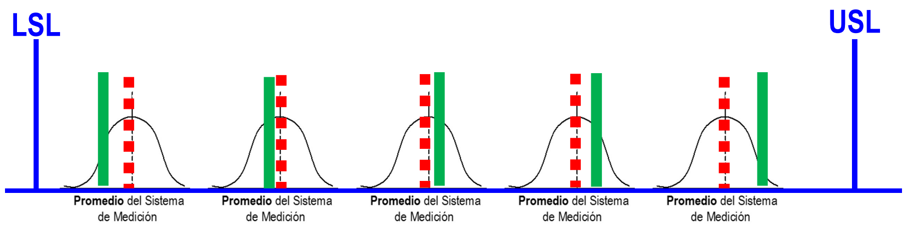
$p_{value} = 0.125$ - Accepted H0

Location Variation



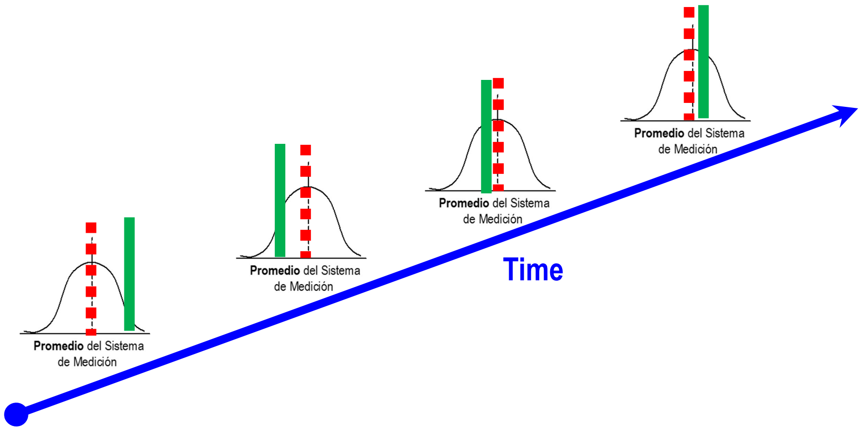
Accuracy: The closeness of agreement between an observed value and the accepted reference value.

Bias / Deviation: Difference between the observed average of measurements and the reference value



Linearity: The change in bias over the normal operating range

Stability: The change in bias over time



Conducting Study - Bias / Type 1

Test Hypothesis:

H0: Bias = 0
H1: Bias ≠ 0

1) Obtain a sample and establish its reference value(s) relative to a traceable standard.
    1) If one is not available, select a production part, that falls in the mid-range of the production measurements and designate it as the master sample for stability analysis.
    2) Measure the part n ≥10 times in the gage or tool room (Example: Metrology Laboratory), and compute the average of the n readings. Use this average as the "reference value."

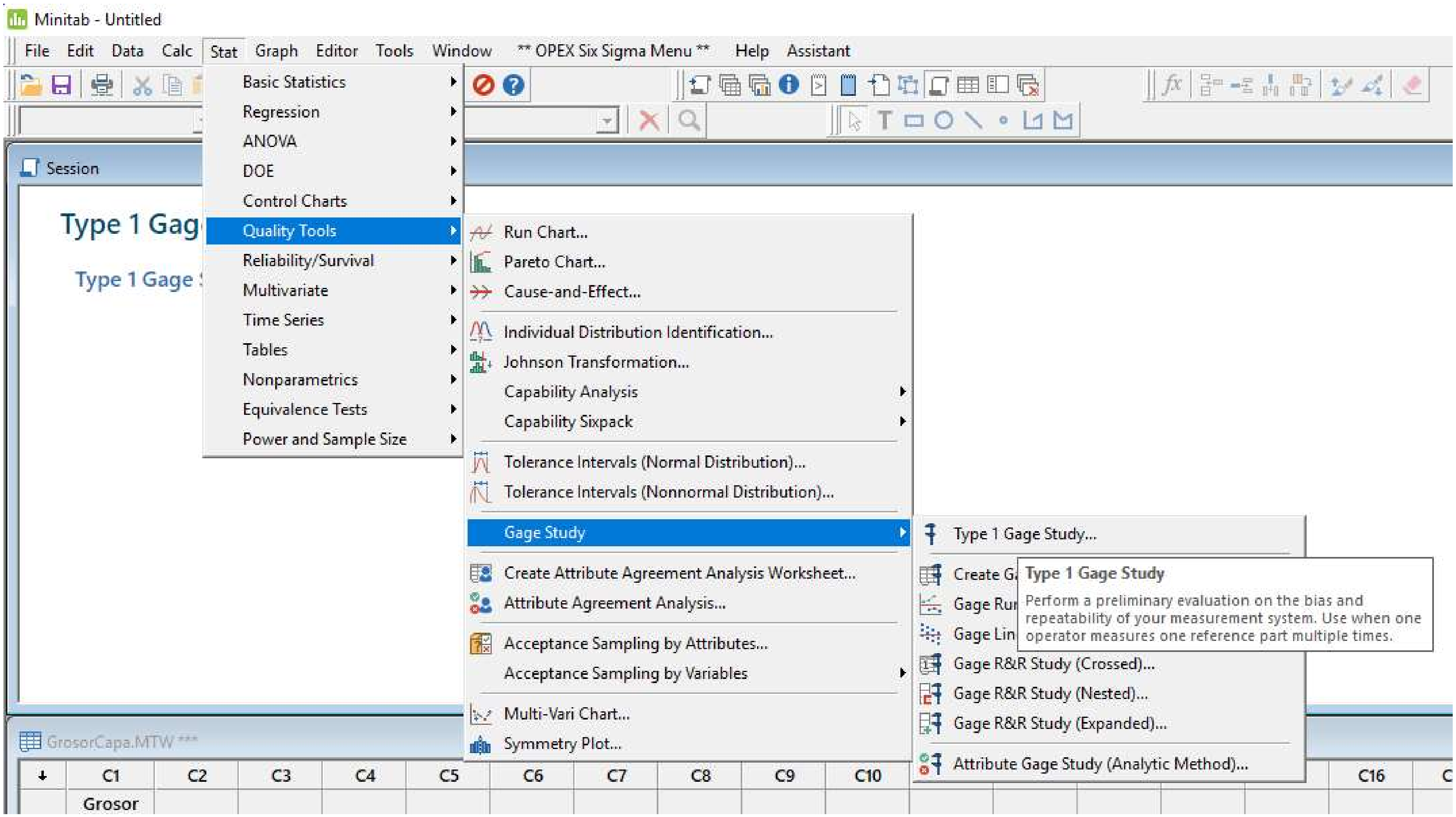
2) Have a single appraiser measure the sample n ≥10 times in the normal manner (suggestion: 50 times). With the same appraiser, same gauge, with the same process (method) and in the same operative conditions.

3) Use a software or internal spreadsheet (In order to compute the results)

4) Make the analysis: chart and numerical

5) Take actions in order to improve the measurement system (if it is necessary or standardize)

Minitab

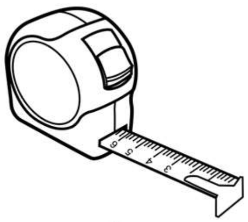

Minitab - Untitled
File Edit Data Calc Stat Graph Editor Tools Window ** OPEX Six Sigma Menu ** Help Assistant
Session
Type 1 Gag
Type 1 Gage
Basic Statistics
Regression
ANOVA
DOE
Control Charts
Quality Tools
Reliability/Survival
Multivariate
Time Series
Tables
Nonparametrics
Equivalence Tests
Power and Sample Size
Run Chart...
Pareto Chart...
Cause-and-Effect...
Individual Distribution Identification...
Johnson Transformation...
Capability Analysis
Capability Sixpack
Tolerance Intervals (Normal Distribution)...
Tolerance Intervals (Nonnormal Distribution)...
Gage Study
Create Attribute Agreement Analysis Worksheet...
Attribute Agreement Analysis...
Acceptance Sampling by Attributes...
Acceptance Sampling by Variables
Multi-Vari Chart...
Symmetry Plot...
Type 1 Gage Study...
Create G
Gage Ru
Gage Lin
Gage R&R Study (Crossed)...
Gage R&R Study (Nested)...
Gage R&R Study (Expanded)...
Attribute Gage Study (Analytic Method)...
Type 1 Gage Study
Perform a preliminary evaluation on the bias and repeatability of your measurement system. Use when one operator measures one reference part multiple times.
GrosorCapa.MTW ***
C1 C2 C3 C4 C5 C6 C7 C8 C9 C10 C16
Grosor

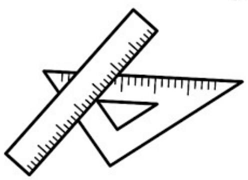
Exercise 2 – Bias study / Type 1

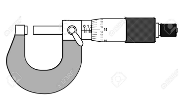
Measure the distance or width (of one part)

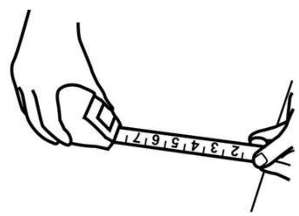
Take 50 measurements

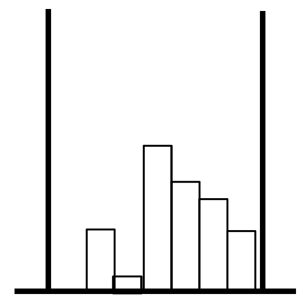
Make the Bias analysis











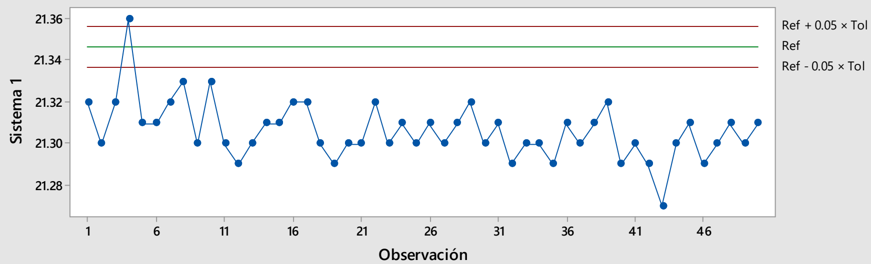
Exercise 2 – Bias study / Type 1

Estudio tipo 1 del sistema de medición para Sistema 1

Nombre del sistema de medición :
Fecha del estudio:

Notificado por:
Tolerancia: 0.2
Misc:

Gráfica de corridas de Sistema 1



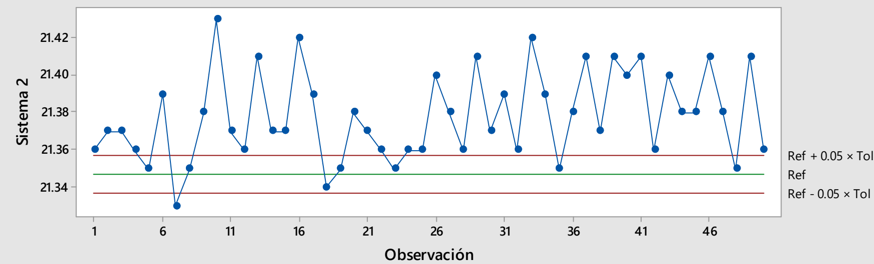
Estadísticas básicas		Sesgo		Capacidad	
Referencia	21.347	Sesgo	-0.04080	Cg	0.24
Media	21.30620	T	20.635063	Cgk	-0.73
Desv.Est.	0.013981	ValorP	0.000		
6 × Desv.Est. (VE)	0.083886	(sesgo de la prueba=0)		%Var(Repetibilidad)	41.94%
Tolerancia (Tol)	0.2			%Var(Repetibilidad y sesgo)	-13.62%

Estudio tipo 1 del sistema de medición para Sistema 2

Nombre del sistema de medición :
Fecha del estudio:

Notificado por:
Tolerancia: 0.2
Misc:

Gráfica de corridas de Sistema 2



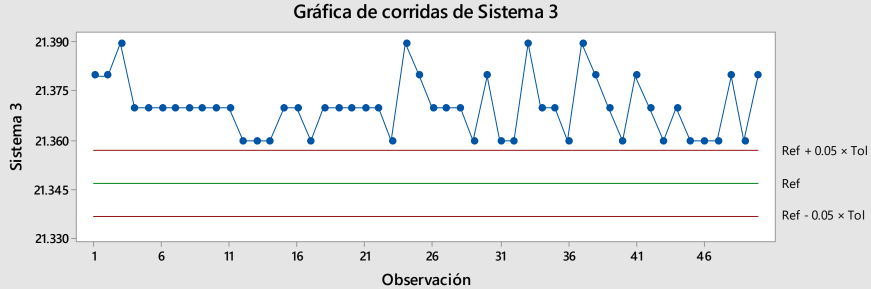
Estadísticas básicas		Sesgo		Capacidad	
Referencia	21.347	Sesgo	0.03080	Cg	0.14
Media	21.37780	T	9.166919	Cgk	-0.29
Desv.Est.	0.023758	ValorP	0.000		
6 × Desv.Est. (VE)	0.142549	(sesgo de la prueba=0)		%Var(Repetibilidad)	71.27%
Tolerancia (Tol)	0.2			%Var(Repetibilidad y sesgo)	-34.27%

Estudio tipo 1 del sistema de medición para Sistema 3

Nombre del sistema de medición :
Fecha del estudio:

Notificado por:
Tolerancia: 0.2
Misc:

Gráfica de corridas de Sistema 3



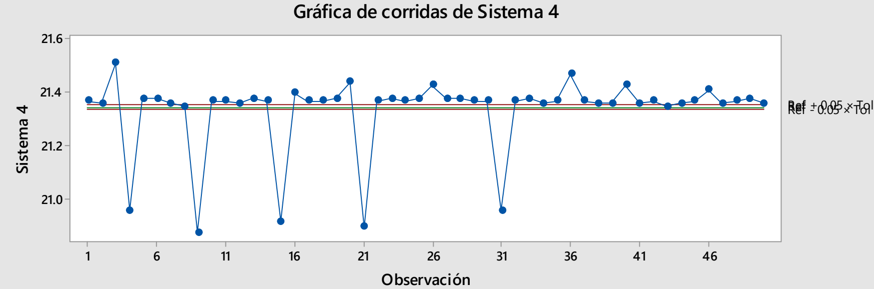
Estadísticas básicas		Sesgo		Capacidad	
Referencia	21.347	Sesgo	0.02320	Cg	0.37
Media	21.37020	T	18.392896	Cgk	-0.49
Desv.Est.	0.008919	ValorP	0.000		
6 × Desv.Est. (VE)	0.053515	(sesgo de la prueba=0)		%Var(Repetibilidad)	26.76%
Tolerancia (Tol)	0.2			%Var(Repetibilidad y sesgo)	-20.27%

Estudio tipo 1 del sistema de medición para Sistema 4

Nombre del sistema de medición :
Fecha del estudio:

Notificado por:
Tolerancia: 0.2
Misc:

Gráfica de corridas de Sistema 4



Estadísticas básicas		Sesgo		Capacidad	
Referencia	21.347	Sesgo	-0.01240	Cg	0.02
Media	21.33460	T	0.618725	Cgk	-0.01
Desv.Est.	0.141713	ValorP	0.539		
6 × Desv.Est. (VE)	0.850276	(sesgo de la prueba=0)		%Var(Repetibilidad)	425.14%
Tolerancia (Tol)	0.2			%Var(Repetibilidad y sesgo)	-1771.41%

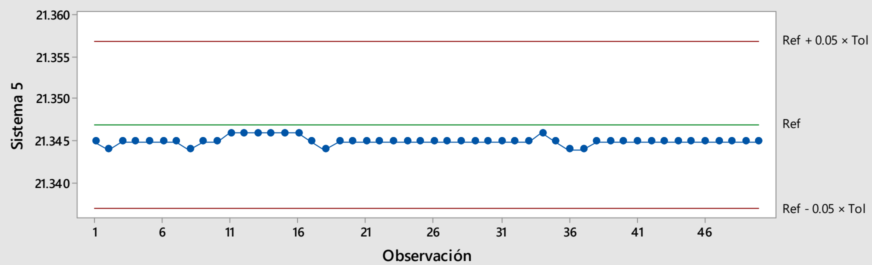
Exercise 2 – Bias study / Type 1

Estudio tipo 1 del sistema de medición para Sistema 5

Nombre del sistema de medición :
Fecha del estudio:

Notificado por:
Tolerancia: 0.2
Misc:

Gráfica de corridas de Sistema 5



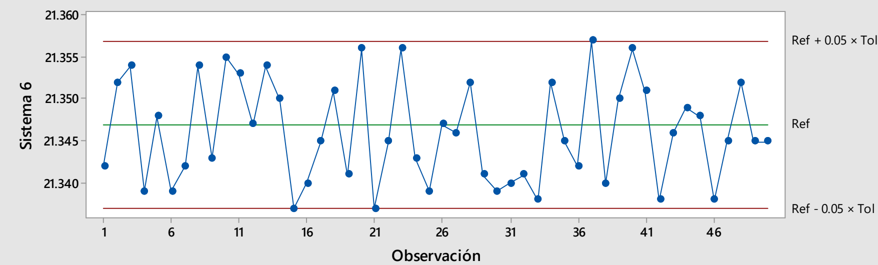
Estadísticas básicas		Sesgo		Capacidad	
Referencia	21.347	Sesgo	-0.00196	Cg	6.76
Media	21.34504	T	28.099655	Cgk	5.43
Desv.Est.	0.000493	ValorP	0.000		
6 × Desv.Est. (VE)	0.002959	(sesgo de la prueba=0)		%Var(Repetibilidad)	1.48%
Tolerancia (Tol)	0.2			%Var(Repetibilidad y sesgo)	1.84%

Estudio tipo 1 del sistema de medición para Sistema 6

Nombre del sistema de medición :
Fecha del estudio:

Notificado por:
Tolerancia: 0.2
Misc:

Gráfica de corridas de Sistema 6



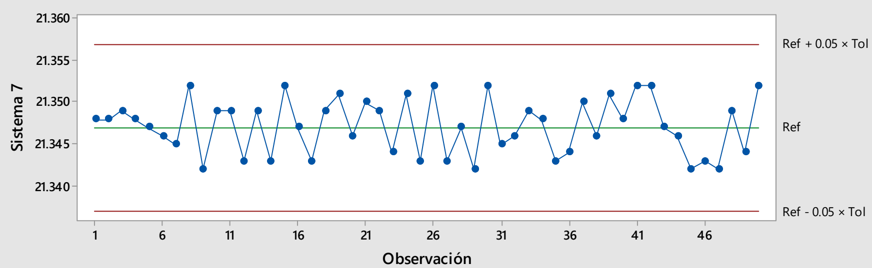
Estadísticas básicas		Sesgo		Capacidad	
Referencia	21.347	Sesgo	-0.00090	Cg	0.55
Media	21.34610	T	1.052194	Cgk	0.50
Desv.Est.	0.006048	ValorP	0.298		
6 × Desv.Est. (VE)	0.036290	(sesgo de la prueba=0)		%Var(Repetibilidad)	18.14%
Tolerancia (Tol)	0.2			%Var(Repetibilidad y sesgo)	19.94%

Estudio tipo 1 del sistema de medición para Sistema 7

Nombre del sistema de medición :
Fecha del estudio:

Notificado por:
Tolerancia: 0.2
Misc:

Gráfica de corridas de Sistema 7



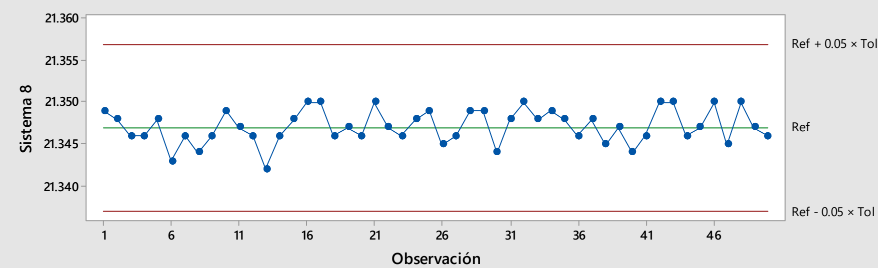
Estadísticas básicas		Sesgo		Capacidad	
Referencia	21.347	Sesgo	0.00016	Cg	1.01
Media	21.34716	T	0.344421	Cgk	1.00
Desv.Est.	0.003285	ValorP	0.732		
6 × Desv.Est. (VE)	0.019709	(sesgo de la prueba=0)		%Var(Repetibilidad)	9.85%
Tolerancia (Tol)	0.2			%Var(Repetibilidad y sesgo)	10.01%

Estudio tipo 1 del sistema de medición para Sistema 8

Nombre del sistema de medición :
Fecha del estudio:

Notificado por:
Tolerancia: 0.2
Misc:

Gráfica de corridas de Sistema 8



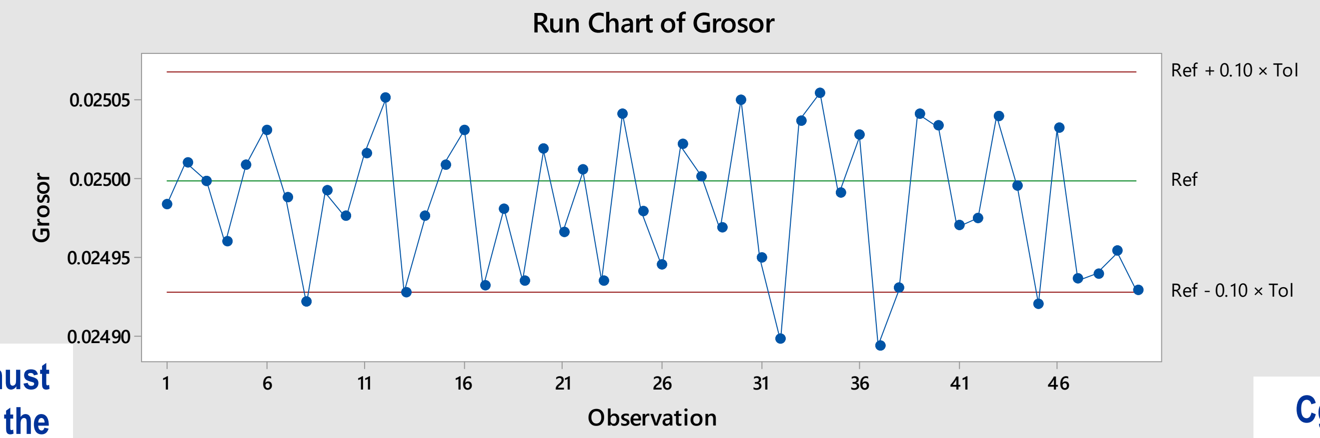
Estadísticas básicas		Sesgo		Capacidad	
Referencia	21.347	Sesgo	0.00012	Cg	1.66
Media	21.34712	T	0.422885	Cgk	1.64
Desv.Est.	0.002007	ValorP	0.674		
6 × Desv.Est. (VE)	0.012039	(sesgo de la prueba=0)		%Var(Repetibilidad)	6.02%
Tolerancia (Tol)	0.2			%Var(Repetibilidad y sesgo)	6.09%

Minitab Analysis

Type 1 Gage Study for Grosor

Gage name:
Date of study:

Reported by:
Tolerance: 0.0007
Misc:



The Bias value must be compare with the confidence bounds – is acceptable if it falls within confidence bounds

Basic Statistics	
Reference	0.025
Mean	0.024985
StDev	0.0000438
6 × StDev (SV)	0.0002625
Tolerance (Tol)	0.0007

Bias	
Bias	-0.000015
T	2.3847019
PValue	0.021
(Test Bias = 0)	

Capability	
Cg	0.53
Cgk	0.42

%Var(Repeatability)	37.50%
%Var(Repeatability and Bias)	47.52%

Cg y Cgk must be upper than 1.33 / 1.67

P value must be less than 0.050 to reject the H0

% Repeatability and Bias must be less than 10%**

Interpretation (Example): the repeatability of the measurement system is significant (high variation); therefore we reject H0. Considering the tight tolerance: 0.0007

Minitab Interpretation

- In the run chart, most of the thickness measurements fall within the ± 10% tolerance range. However, some of the measurements are lower than expected (lower than the reference - 10% tolerance limit). The lower measurements may indicate a problem with the measurement system.

- The mean value of the thickness measurements is 0.024985, which is slightly lower than the reference value of 0.025. The standard deviation is 0.0000438, which is very small. However, because the tolerance range of 0.0007 is also very small, not much variation is allowed in the measurements

- The following results indicate that the measurement system should be improved because it cannot measure parts consistently and accurately

- P-value for bias = 0.021. Because the p-value is less than a significance level of 0.05, the null hypothesis for the test of bias=0 must be rejected. The engineer can conclude that there is statistically significant bias present in the measurement system.

- Cg = 0.53 and Cgk = 0.42. Both capability indices are less than the commonly used benchmark value of 1.33, so the engineer concludes that the measurement system is not capable and needs improvement.

- %Var (Repeatability) = 37.50% and %Var (Repeatability and Bias) = 47.52%. These values are much larger than 15% (a commonly used benchmark), and indicate that the variation due to the measurement system is large.

Minitab Interpretation

- Tolerance (Tol): Is the difference between the upper specification and the lower specification

- The bias is a measure of a measurement system's accuracy. Bias is calculated as the difference between the known standard value of a reference part and the observed average measurement. Ideally, the bias value is close to 0.
  - Values other than 0 indicate the following:
    - A positive bias indicates that the gage measures high.
    - A negative bias indicates that the gage measures low.
    - For a gage that measures accurately, the %bias will be small.
    - To determine whether the bias is statistically significant, use the p-valu

- The t-statistic for testing the null hypothesis that bias = 0 versus the alternative hypothesis that bias ≠ 0.
  - t follows the t-distribution with γ degrees of freedom, where $\gamma = n - 1$.

- The p-value is associated with the t-statistic. It is the probability of obtaining a t-statistic as large or larger than the calculated one, assuming that the bias is zero. As the t-statistic increases, the p-value decreases. The smaller the p-value, the greater the evidence against the null hypothesis that the bias = 0.

- A guideline for the resolution is that it should not be greater than 5% of the tolerance. So, if you specify both the resolution and the tolerance, Minitab calculates whether the resolution is less than, greater than, or equal to 5% of the tolerance.

Internal spreadsheet

ELEGIR UNA RAZÓN SOCIAL
ELEGIR UNA PLANTA
ESTUDIO DE LOCALIZACIÓN Y AMPLITUD GENERAL

METROLOGÍA

Fecha: DD/MM/AAAA

Número de Equipo	a	Descripción Equipo	
Frecuencia	a	Temperatura	20
Área de la empresa		Próximo estudio	
Resolución		Alcance	
Tolerancia Sup.	0.4	Tolerancia Inf.	0

Evaluación del error sin ajuste

Referencia 0
Promedio
Error

Resultado: Llenar Datos

Inspección visual

Actividad	Cumplimiento		
	Si	No	No Aplica
Ajuste a cero (escalas longitudinales y/o ángulos)	☐	☐	☐
Calibrado y ajuste electrónico	☐	☐	☐
Funcionamiento del freno	☐	☐	☐
Desplazamiento suave del tornillo o ejes	☐	☐	☐
Grabado y graduaciones sin defecto	☐	☐	☐
Libre de rayaduras y enmohecimiento	☐	☐	☐
Holgura uniforme entre cilindro y tambor	☐	☐	☐
Funcionamiento de tambor de fricción o Trinquete	☐	☐	☐
Superficies de medición o palpadores sin golpes	☐	☐	☐
Libre de liquidos y suciedad interior	☐	☐	☐
Funcionamiento del plato graduado	☐	☐	☐
Libre desplazamiento del plato graduado	☐	☐	☐
Plato graduado sujeto firme al plato móvil	☐	☐	☐
Desplazamiento suave y libre rotación de las agujas	☐	☐	☐

Linealidad del instrumento

Pendiente: #DIV/0! ta (absoluta):
Intersección tb(absoluta):
%Bias 0.233% t: 2.2281
% de linealidad= #DIV/0!
Resultado de linealidad: Rechazado

Bias del Instrumento

Media: 0.001 Desviación estánda 0.0597 Desviación estándar del bi: 0.0172
-0.038052 ≤ 0 ≤ 0.039918
Resultado de Bias: Aceptado

Incertidumbre del Instrumento

Fuente de incertidumbre	Valor	Incertidumbre original	Tipo de distribución	Incertidumbre estándar	Coeficiente de sensibilidad	Contribución	Grados de libertad
Resolución	0.000	00.00 mm	B, Uniforme	0.0000	1	0.0000	100
Dif. Temperatura	0.0°C	± 1.0°C	B, Rectangular	0.5774	0.010%	0.0002	12

Lista de comprobación

Calibrar ☐ Poner etiqueta ☐ Capturar sistema ☐ Archivar ☐

Trazabilidad al patrón:
Resultado general del Estudio: Rechazado
Elaboró
Revisó
Observaciones:

FO.MA.AC.MG.001.09 Revision 2 Página 1 de 1

ELEGIR UNA RAZÓN SOCIAL
ELEGIR UNA PLANTA
RECOLECCIÓN DE DATOS

METROLOGÍA

Fecha: DD/MM/AAAA

Recolección de datos Linealidad y Bias

Parte		1	2	3	4	5
Referencia		0				
Intentos	1	-0.002				
	2	0				
	3	-0.1				
	4	-0.005				
	5	0.003				
	6	0.1				
	7	0.005				
	8	0.0002				
	9	0				
	10	0.004				
	11	0.002				
	12	0.004				
Promedio		0.000933				
Bias		0.000933				

Datos para calculo de Bias

Valor de t=	2.262	m=	12	g=	1	n=	12	d2*=	3.35016	df=	9

Valor de referencia	Media	Bias	sr	sb	Estadistico t
0	0.000933333	0.000933333	0.059698641	0.0172	0.0542

If apply
(have to validate)

Evaluacion de error sin ajuste		
Referencia		
Intento	1	
	2	
	3	
	4	
	5	
Promedio		
Error		

Internal spreadsheet

ELEGIR UNA RAZÓN SOCIAL
ELEGIR UNA PLANTA
RECOLECCIÓN DE DATOS

METROLOGÍA

Fecha: DD/MM/AAAA

Recolección de datos Linealidad y Bias

Parte		1	2	3	4	5
Referencia		6				
Intentos	1	5.8				
	2	5.7				
	3	5.9				
	4	5.9				
	5	6				
	6	6.4				
	7	6				
	8	6.1				
	9	6.4				
	10	6.3				
	11	6				
	12	6.1				
Promedio		6.050000				
Bias		0.050000				

Datos para calculo de Bias

Valor de t=	m=	g=	n=	d2*=	df=
2.262	12	1	12	3.35016	9

Valor de referencia	Media	Bias	sr	sb	Estadístico t
6	6.05	0.05	0.208945244	0.0603	0.8289

Evaluacion de error sin ajuste

Referencia		
Intentos	1	6
	2	
	3	
	4	
	5	
Promedio		6
Error		6

ELEGIR UNA RAZÓN SOCIAL
ELEGIR UNA PLANTA
ESTUDIO DE LOCALIZACIÓN Y AMPLITUD GENERAL

METROLOGÍA

Fecha: 10/02/2020

Número de Equipo	XXX-XXX-XXX-001	Descripción Equipo	VERNIER
Frecuencia	1	Temperatura	20
Área de la empresa	MAQUINADO	Próximo estudio	15/03/2020
Resolución	0.1	Alcance	
Tolerancia Sup.	10	Tolerancia Inf.	0

Evaluación del error sin ajuste

Referencia 0
Promedio 6
Error 6.0000

Resultado: Llenar Datos

Inspección visual

Actividad	Cumplimiento: Si	No	No Aplica
Ajuste a cero (escalas longitudinales y/o ángulos)	☐	☐	☐
Calibrado y ajuste electrónico	☐	☐	☐
Funcionamiento del freno	☐	☐	☐
Desplazamiento suave del tornillo o ejes	☐	☐	☐
Grabado y graduaciones sin defecto	☐	☐	☐
Libre de rayaduras y enmohecimiento	☐	☐	☐
Holgura uniforme entre cilindro y tambor	☐	☐	☐
Funcionamiento de tambor de fricción o Trinquete	☐	☐	☐
Superficies de medición o palpadores sin golpes	☐	☐	☐
Libre de líquidos y suciedad interior	☐	☐	☐
Funcionamiento del plato graduado	☐	☐	☐
Libre desplazamiento del plato graduado	☐	☐	☐
Plato graduado sujeto fime al plato móvil	☐	☐	☐
Desplazamiento suave y libre rotación de las agujas	☐	☐	☐

Linealidad del instrumento

Pendiente: #DIV/0! ta (absoluta):
Intersección tb(absoluta):
%Bias 0.500% t: 2.2281
% de linealidad= #DIV/0!
Resultado de linealidad: Rechazado

Bias del Instrumento

Media: 6.050 Desviación estánda 0.2089 Desviación estándar del bi: 0.0603
-0.086447 ≤ 0 ≤ 0.186447
Resultado de Bias: Aceptado

Incertidumbre del Instrumento

Fuente de incertidumbre	Valor	Incertidumbre original	Tipo de distribución	Incertidumbre estándar	Coeficiente de sensibilidad	Contribución	Grados de libertad
Resolución	0.100	00.10 mm	B, Uniforme	0.0289	1	0.0289	100
Dif. Temperatura	0.0°C	± 1.0°C	B, Rectangular	0.5774	0.010%	0.0002	12

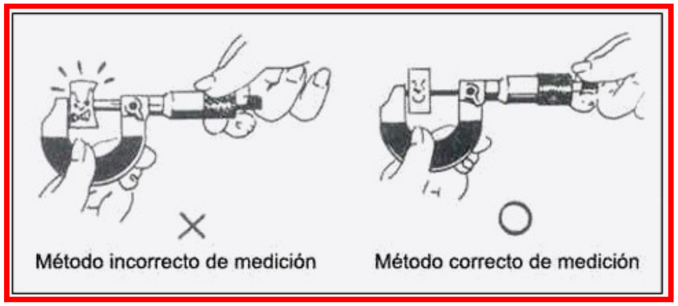
Lista de comprobación

Calibrar ☐ Poner etiqueta ☐ Capturar sistema ☐ Archivar ☐

Trazabilidad al patrón:
Resultado general del Estudio: Rechazado
Elaboró:
Revisó:
Observaciones:

Possible variation causes (Bias / Type 1)

If the bias is statistically non-zero, look for these possible causes:



- Instrument needs calibration
- Worn instrument, equipment or fixture
- Worn or damaged master, error in master
- Improper calibration or use of the setting master
- Poor quality instrument – design or conformance
- Linearity error
- Wrong gage for the application
- Different measurement method – setup, loading, clamping, technique
- Measuring the wrong characteristic
- Distortion (gage or part)
- Environment – temperature, humidity, vibration, cleanliness
- Violation of an assumption, error in an applied constant
- Application – part size, position, operator skill, fatigue, observation error (readability, parallax).

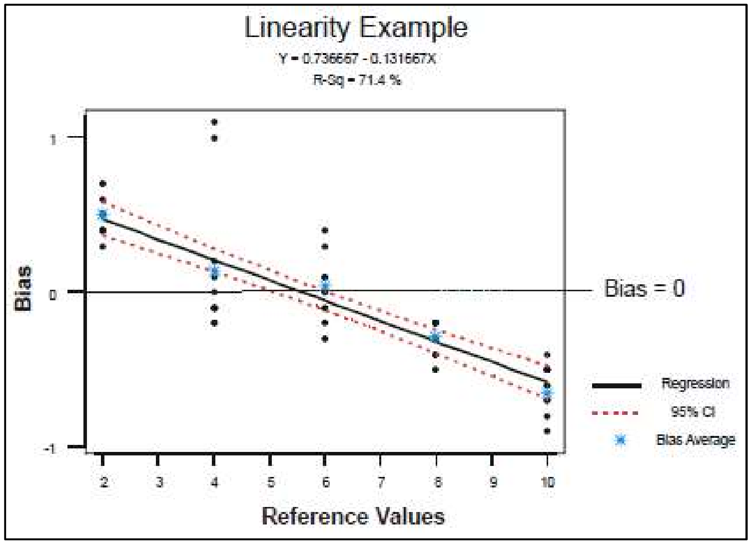
Conducting the Linearity Study

Test of Hypothesis: over the operating range (Tolerance / fit line)

H0: $\overline{y_i} = ax_i + b \quad = 0$ Where a y b = 0 (Slope and intercept)

H1: $\overline{y_i} = ax_i + b \quad \neq 0$ Where a y b ≠ 0 (Slope and intercept)

1) Select $g \geq 5$ parts whose measurements, due to process variation, cover the operating range of the gage.
   1) Have each part measured by layout inspection to determine its reference value and to confirm that the operating range of the subject gage is encompassed.
2) Have each part measured $m \geq 10$ times on the subject gage by one of the operators who normally use the gage (same conditions).
3) Use a software or internal spreadsheet (In order to compute the results)
4) Make the analysis: chart and numerical
5) Take actions in order to improve the measurement system
   1) (if it is necessary or standardize)

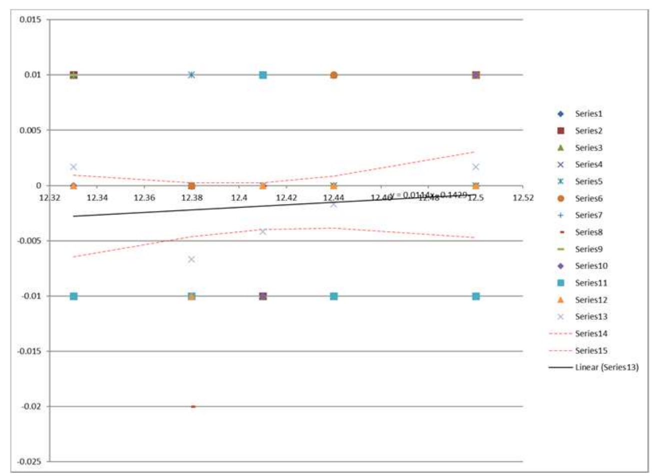


Example - Linearity Study

Número de Equipo	Vernier-00235	Descripción Equipo	Vernier
Frecuencia	Anual	Temperatura	23°
Área de la empresa	Maquinado	Próximo estudio	15/06/2021
Resolución	0.01	Alcance	
Tolerancia Sup.	12.5	Tolerancia Inf.	12.3

Recolección de datos Linealidad y Bias

Parte		1	2	3	4	5
Referencia		12.33	12.38	12.41	12.44	12.5
Intentos	1	12.33	12.37	12.4	12.44	12.5
	2	12.34	12.37	12.4	12.43	12.51
	3	12.34	12.38	12.4	12.45	12.51
	4	12.34	12.38	12.4	12.44	12.5
	5	12.32	12.39	12.41	12.44	12.5
	6	12.32	12.38	12.42	12.45	12.51
	7	12.33	12.37	12.4	12.44	12.49
	8	12.34	12.36	12.41	12.43	12.5
	9	12.34	12.37	12.4	12.44	12.5
	10	12.33	12.37	12.4	12.43	12.51
	11	12.32	12.37	12.42	12.43	12.49
	12	12.33	12.37	12.41	12.44	12.5
Promedio		12.332	12.373	12.406	12.438	12.502
Bias		0.0017	-0.0067	-0.0042	-0.0017	0.0017



Example - Linearity Study

Linealidad del instrumento					
Pendiente:	0.0114	Intersección:	-0.1429	%Bias	3.333%
ta (absoluta):	0.615	tb(absoluta):	0.623	t:	2.0017
% de linealidad=	0.647%	Resultado de linealidad:		Aceptado	

Bias del Instrumento					
Media:	12.373	esviación estándar:	0.0090	esviación estándar del bias:	0.0026
-0.012514	≤ 0 ≤	-0.000819	Resultado de Bias:	Rechazado	

Conducting the Stability Study

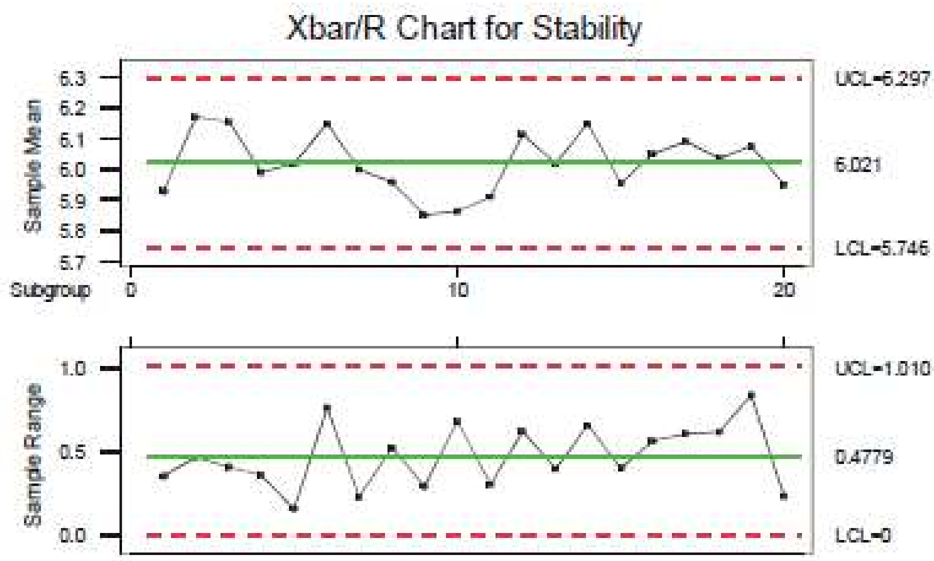
1) Obtain a sample and establish its reference value(s) relative to a traceable standard. If one is not available, select a production part that falls in the mid-range of the production measurements and designate it as the master sample for stability analysis. The known reference value is not required for tracking measurement system stability.

2) On a periodic basis (daily, weekly), measure the master sample three to five times. The sample size and frequency should be based on knowledge of the measurement system. Factors could include how often recalibration or repair has been required, how frequently the measurement system is used, and how stressful the operating conditions are. The readings need to be taken at differing times to represent when the measurement system is actually being used. This will account for warm-up, ambient or other factors that may change during the day.

3) Plot the data on an X &R or X & S control chart in time order.

4) Make the analysis: chart and numerical

5) Take actions in order to improve the measurement system
   1) (if it is necessary or standardize)



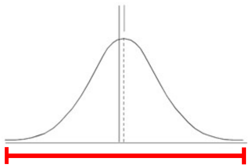
Possible causes for instability and linearity error:

Possible causes for instability include:

- Instrument needs calibration, reduce the calibration interval
- Worn instrument, equipment or fixture
- Normal aging or obsolescence
- Poor maintenance – air, power, hydraulic, filters, corrosion, rust, cleanliness
- Worn or damaged master, error in master
- Improper calibration or use of the setting master
- Poor quality instrument – design or conformance
- Instrument design or method lacks robustness
- Different measurement method – setup, loading, clamping, technique
- Distortion (gage or part)
- Environmental drift – temperature, humidity, vibration, cleanliness
- Violation of an assumption, error in an applied constant
- Application – part size, position, operator skill, fatigue, observation error (readability, parallax)

Doubts or comments

Width variation



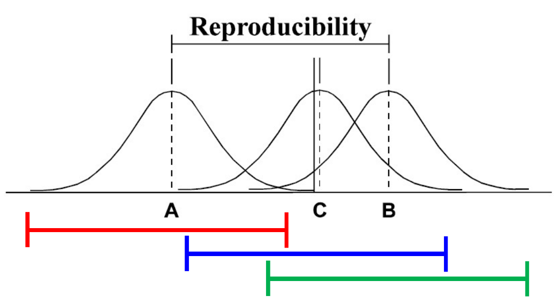
Precision: “Closeness” of repeated readings to each other

Repeatability: Variation in measurements obtained with one measuring instrument when used several times by an appraiser while measuring the identical characteristic on the same part

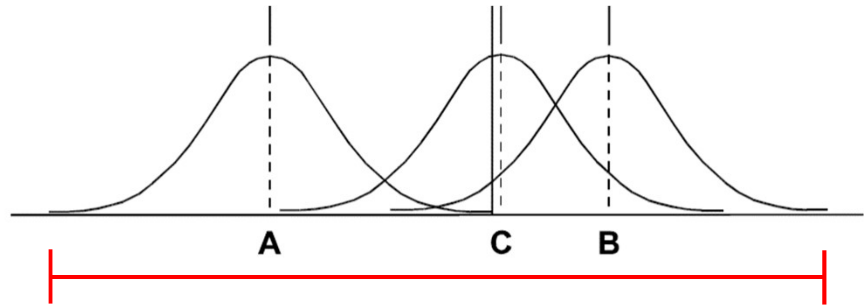
Commonly referred to as E.V. – Equipment Variation

Reproducibility: Variation in the average of the measurements made by different appraisers using the same gage when measuring a characteristic on one part

Commonly referred to as A.V. – Appraiser Variation



Width variation



Gage R&R / GRR: Gage repeatability and reproducibility: the combined estimate of measurement system repeatability and reproducibility

The Variable gage study can be performed using three methods:

- ✓ Range Method (5 Parts, 2 Appraisers and measure each part once)
  - Gage study which will provide a quick approximation of measurement variability
  - It does not decompose the variability into repeatability and reproducibility

- ✓ Average and Range method (including the Control Chart method) (10 parts, 3 Appraisers, and measure each part 3 times)
  - Is an approach which will provide an estimate of both repeatability and reproducibility for a measurement system
  - Analysis of Results – Graphical
  - However, variation due to the interaction between the appraiser and the part/gage is not accounted for in the analysis.

- ✓ ANOVA method
  - Can be used to determine the interaction between the gage and appraisers
  - The ANOVA table is used to decompose the total variation into four components: parts, appraisers, interaction of appraisers and parts, and repeatability due to the instrument.

Analysis of the Results (Width)

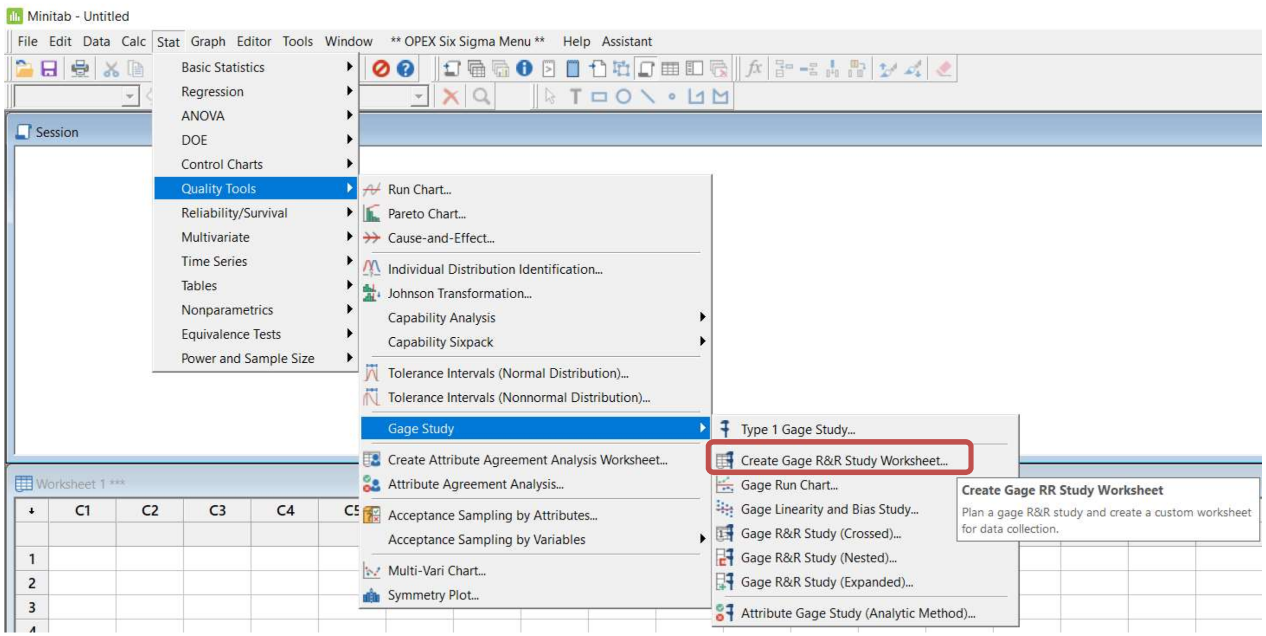
Caution: it is important to analyze the measurement system application.

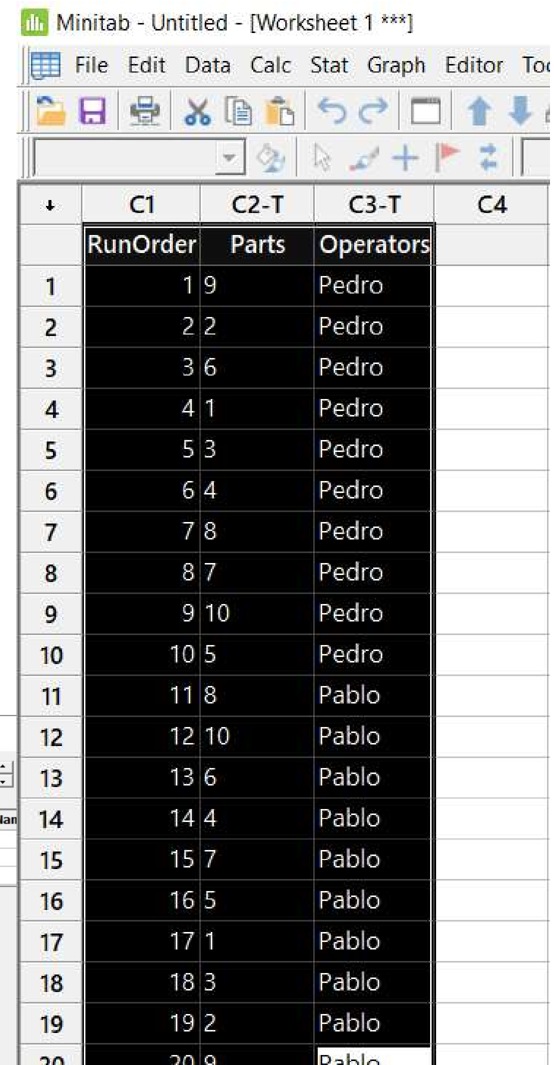
GRR	Decision	Comments
Under 10 percent	Generally considered to be an acceptable measurement system.	Recommended, especially useful when trying to sort or classify parts or when tightened process control is required.
10 percent to 30 percent	May be acceptable for some applications	Decision should be based upon, for example, importance of application measurement, cost of measurement device, cost of rework or repair. Should be approved by the customer.
Over 30 percent	Considered to be unacceptable	Every effort should be made to improve the measurement system. This condition may be addressed by the use of an appropriate measurement strategy; for example, using the average result of several readings of the same part characteristic in order to reduce final measurement variation.

Another statistic of the measurement system variability is the number of distinct categories (ndc)

Graphical Analysis

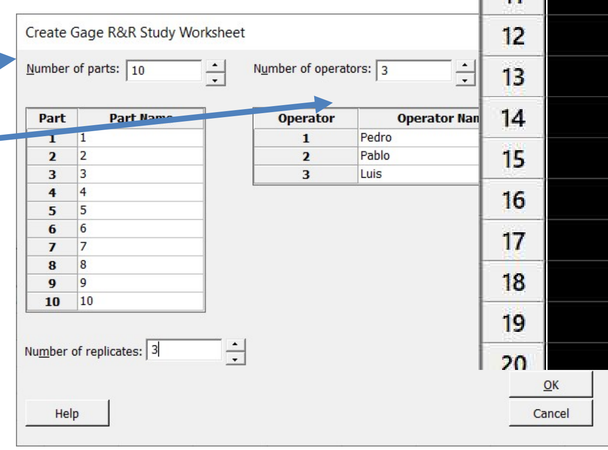
Conducting the Study - R&R ANOVA



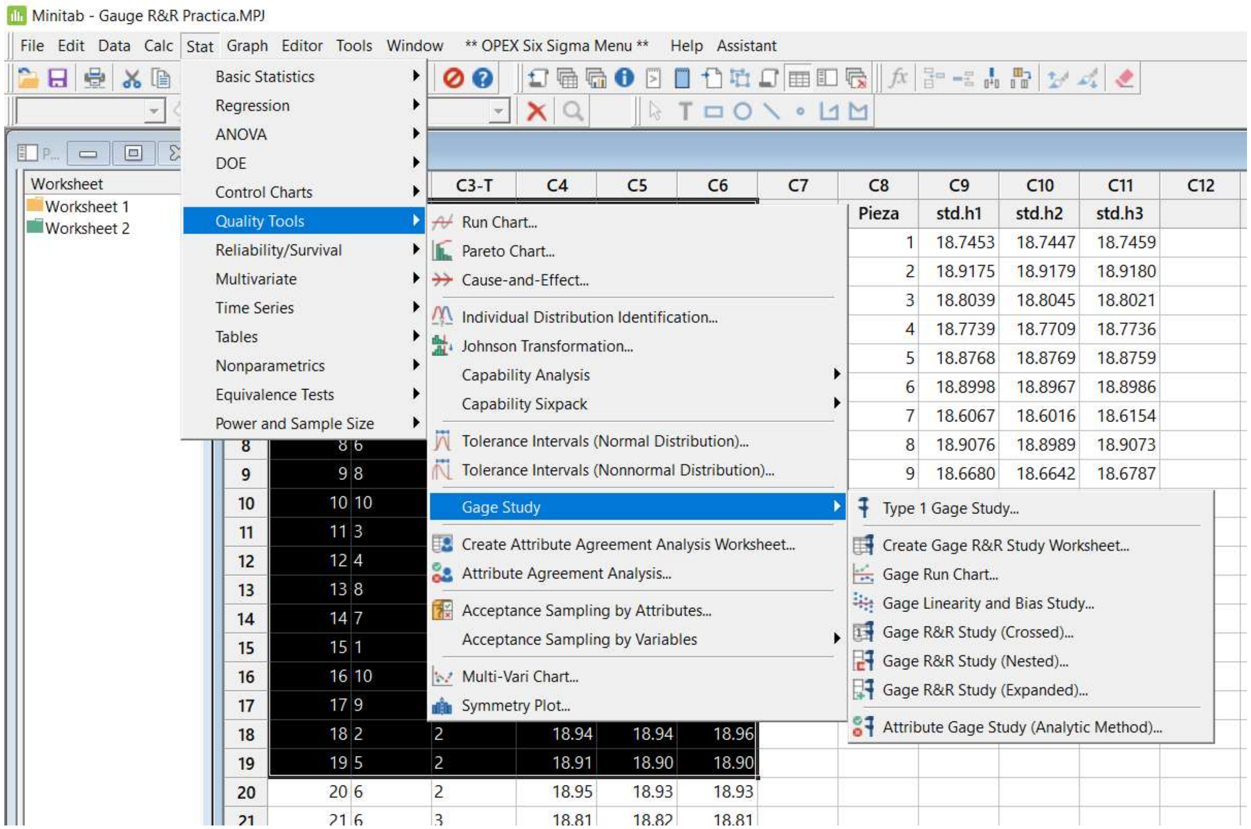


Create a worksheet

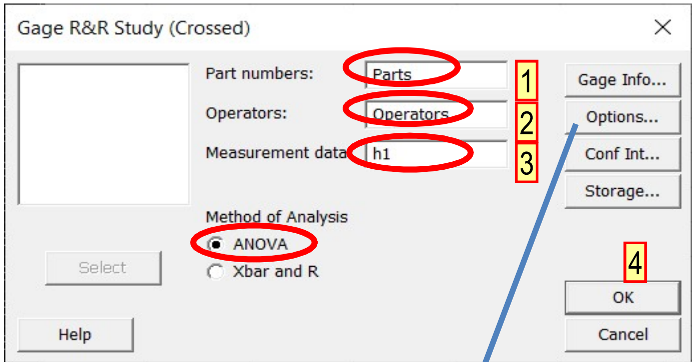
- 10 Parts
- 3 Appraisers,
- 3 Trials



Conducting the Study - R&R ANOVA

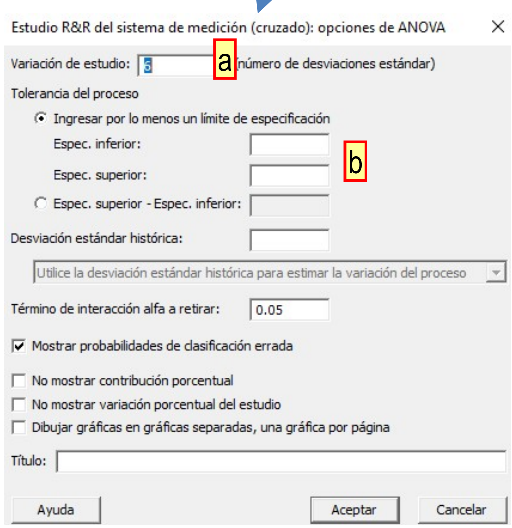


Conducting the Study - R&R ANOVA



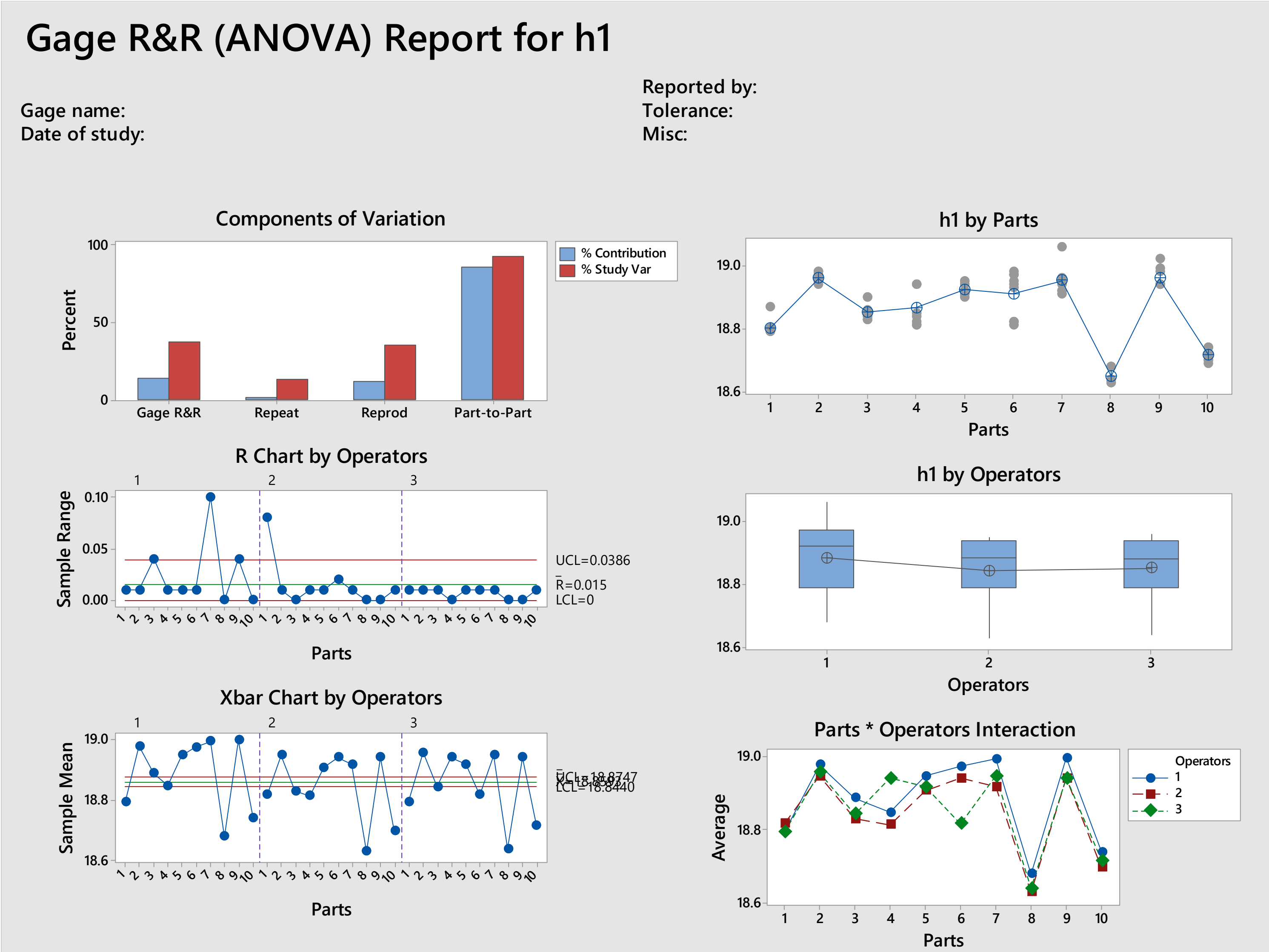
1. In Part numbers, enter the column that contains the part names or numbers.
2. In Operators, enter the column that contains the operator names or numbers.
3. In Measurement data, enter the column that contains the observed measurements
4. Haga clic en OK

Select the R&R ANOVA method



A. Select 6S (The standard deviation)
B. Enter the specification limits or the tolerance range to compare the measurement system variation to customer specifications

Graphs - R&R ANOVA



Analysis of the Results - R&R ANOVA

Gage R&R Study - ANOVA Method

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Parts	9	0.92407	0.102675	25.3997	0.000
Operators	2	0.02673	0.013363	3.3058	0.060
Parts * Operators	18	0.07276	0.004042	17.0803	0.000
Repeatability	60	0.01420	0.000237		
Total	89	1.03776			

α to remove interaction term = 0.05

Gage R&R

Variance Components

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0018159	14.21
Repeatability	0.0002367	1.85
Reproducibility	0.0015793	12.36
Operators	0.0003107	2.43
Operators*Parts	0.0012686	9.93
Part-To-Part	0.0109591	85.79
Total Variation	0.0127751	100.00

Gage Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.042614	0.255682	37.70
Repeatability	0.015384	0.092304	13.61
Reproducibility	0.039740	0.238439	35.16
Operators	0.017627	0.105760	15.60
Operators*Parts	0.035617	0.213701	31.51
Part-To-Part	0.104686	0.628115	92.62
Total Variation	0.113027	0.678161	100.00

Number of Distinct Categories = 3

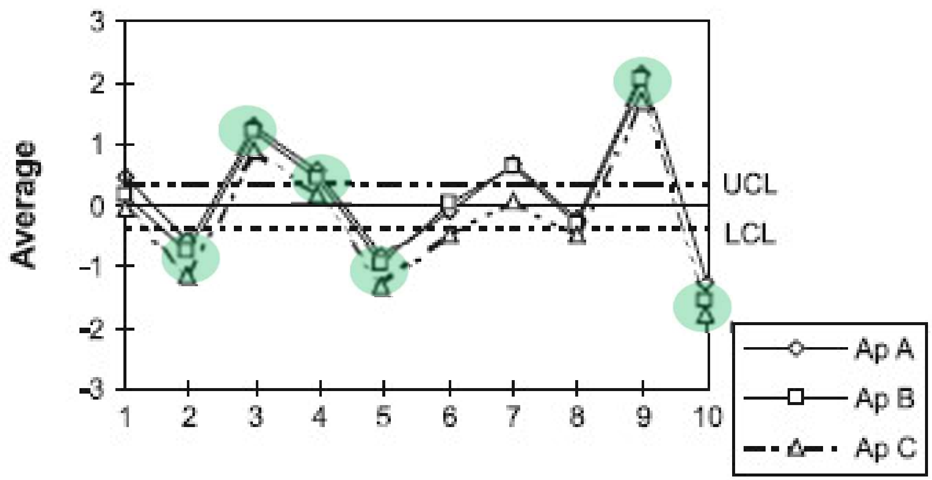
Analysis of the Results (Width)

Average Chart

Approximately one half or more of the averages should fall outside the control limits. If the data show this pattern, then the measurement system should be adequate to detect part-to-part variation

If less than half fall outside the control limits then either the measurement system lacks adequate effective resolution or the sample does not represent the expected process variation.

The points for each appraiser average measurement per part are connected to form k (number of appraisers) lines. The way to interpret the graph is if the k lines are parallel there is no interaction term. When the lines are nonparallel, the interaction can be significant



Analysis of the Results (Width)

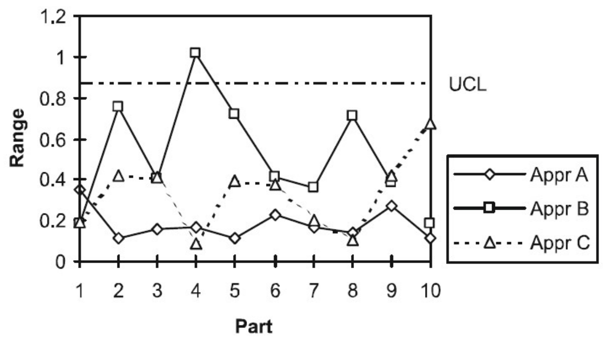
Range Chart

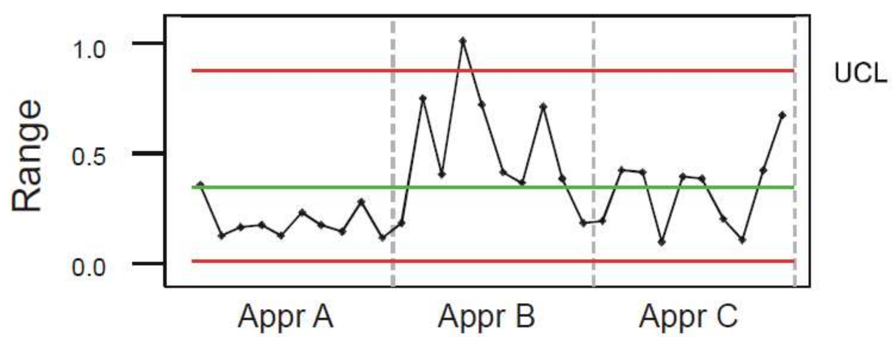
The range control chart is used to determine whether the process is in control. The reason being that no matter how large the measurement error may be, the control limits will allow for that error. That is why the special causes need to be identified and removed before a measurement study can be relevant

If all ranges are in control, all appraisers are doing the same job.

If one appraiser is out-of-control, the method used differs from the others.

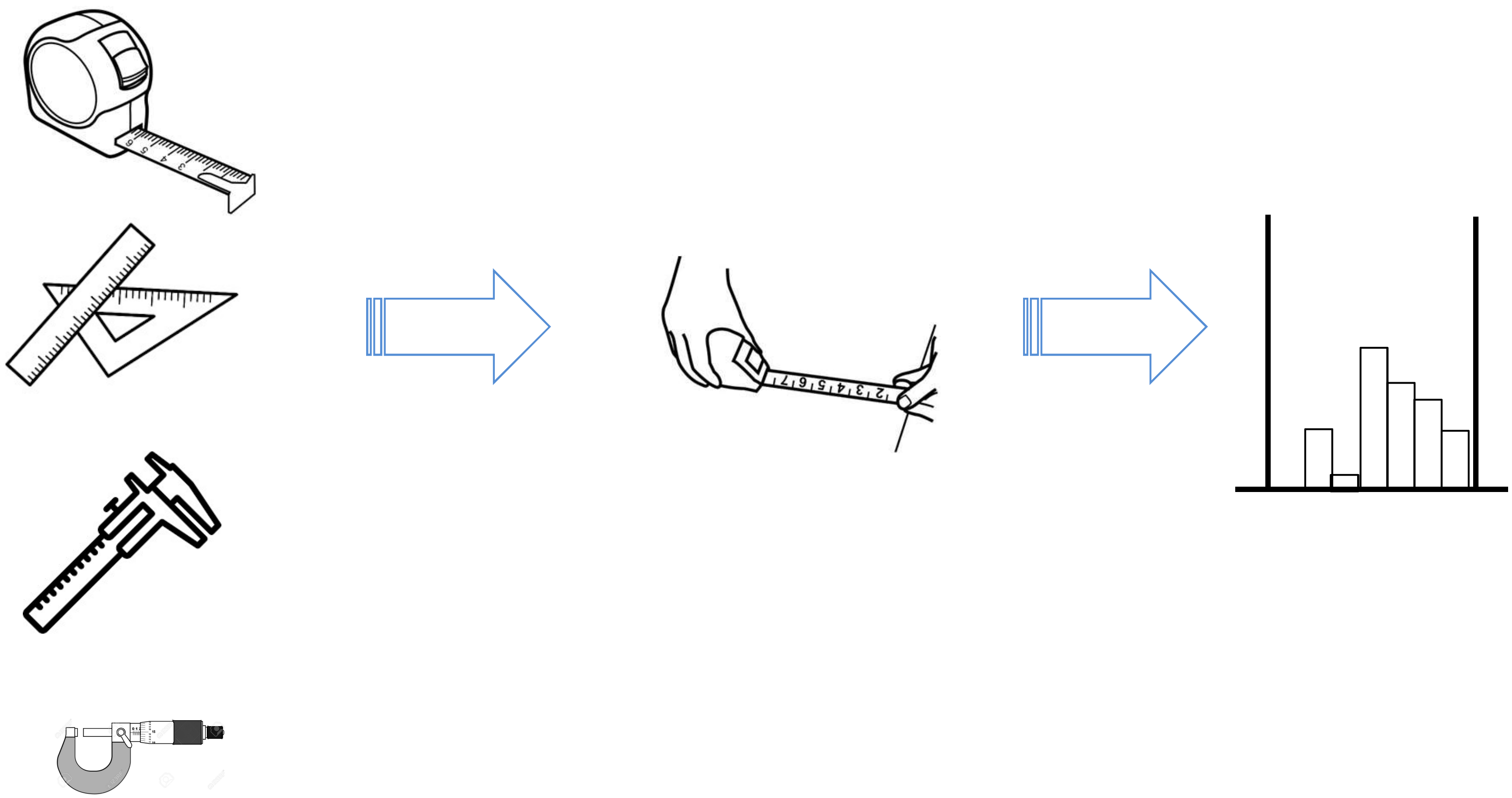
If all appraisers have some out of control ranges, the measurement system is sensitive to appraiser technique and needs improvement to obtain useful data





Example 3 – R&R Anova method

Use Minitab software



Example 3 – R&R Anova method

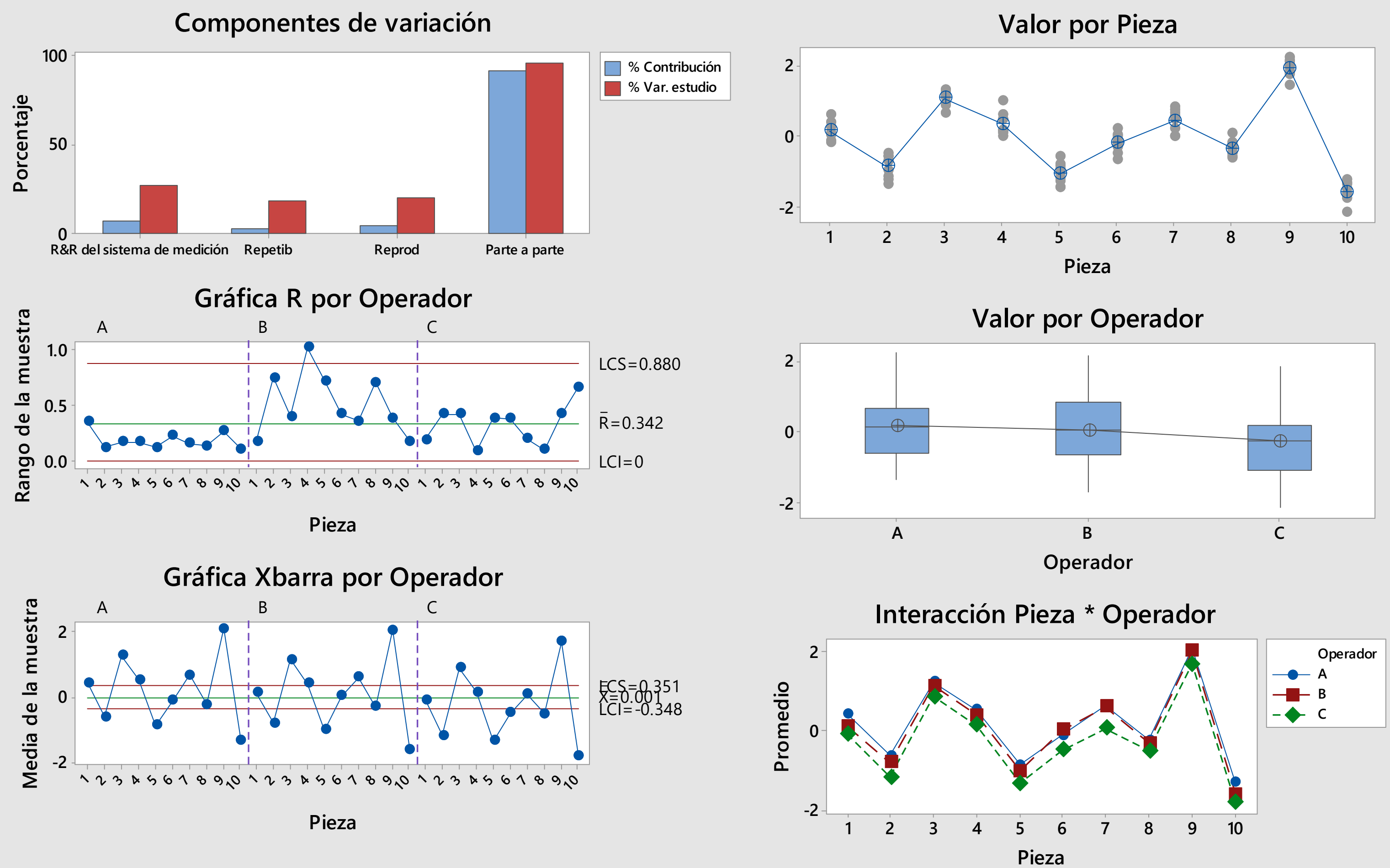
	Appraiser /Trial #		PART									
			1	2	3	4	5	6	7	8	9	10
1	A	1	0.29	-0.56	1.34	0.47	-0.80	0.02	0.59	-0.31	2.26	-1.36
2		2	0.41	-0.68	1.17	0.50	-0.92	-0.11	0.75	-0.20	1.99	-1.25
3		3	0.64	-0.58	1.27	0.64	-0.84	-0.21	0.66	-0.17	2.01	-1.31
4		Average										
5		Range										
6	B	1	0.08	-0.47	1.19	0.01	-0.56	-0.20	0.47	-0.63	1.80	-1.68
7		2	0.25	-1.22	0.94	1.03	-1.20	0.22	0.55	0.08	2.12	-1.62
8		3	0.07	-0.68	1.34	0.20	-1.28	0.06	0.83	-0.34	2.19	-1.50
9		Average										
10		Range										
11	C	1	0.04	-1.38	0.88	0.14	-1.46	-0.29	0.02	-0.46	1.77	-1.49
12		2	-0.11	-1.13	1.09	0.20	-1.07	-0.67	0.01	-0.56	1.45	-1.77
13		3	-0.15	-0.96	0.67	0.11	-1.45	-0.49	0.21	-0.49	1.87	-2.16

Example 3 – R&R Anova method

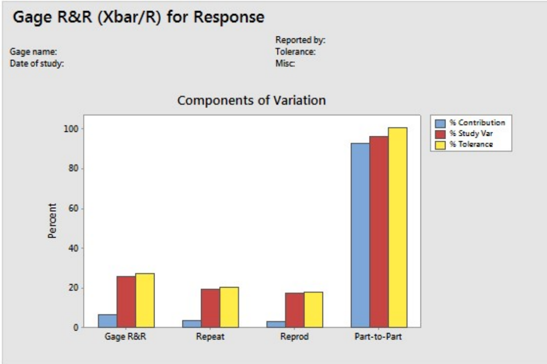
Informe de R&R del sistema de medición (ANOVA) para Valor

Nombre del sistema de medición :
Fecha del estudio:

Notificado por:
Tolerancia:
Misc:



Analysis of Results – Graphical R&R



The components of variation chart is a graphical summary of the results of a gage R&R study.

The sources of variation that are represented in the graph are:

- Total Gage R&R: The variability from the measurement system that includes multiple operators using the same gage.
- Repeatability: The variability in measurements when the same operator measures the same part multiple times.
- Reproducibility: The variability in measurements when different operators measure the same part.
- Part-to-Part: The variability in measurements due to different parts

Interpretation - Separate colored bars represent:

%Contribution: is the percentage of overall variation from each variance component. It is calculated as the variance component for each source divided by the total variation, then multiplied by 100.

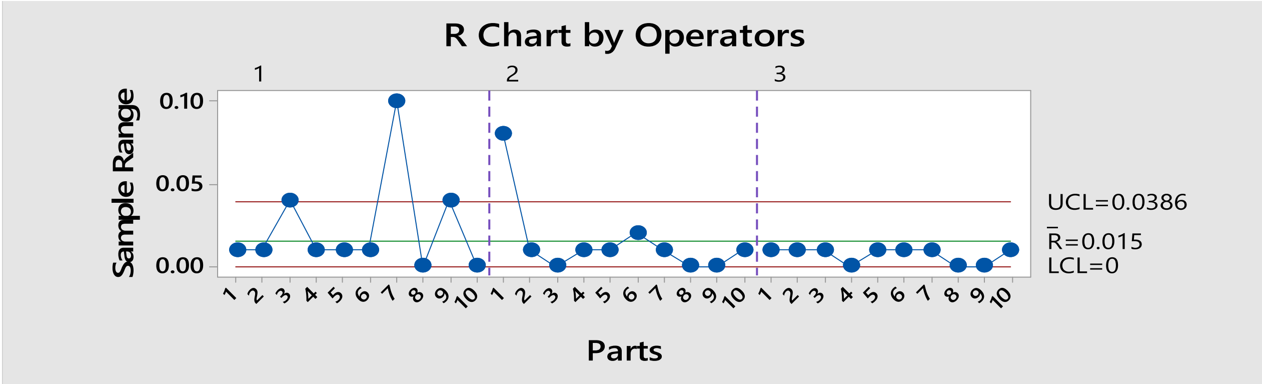
%Study Variation: is the percentage of study variation from each source. It is calculated as the study variation for each source divided by the total study variation, then multiplied by 100.

%Tolerance: compares measurement system variation to specifications. It is calculated as the study variation for each source divided by the process tolerance, then multiplied by 100. Minitab calculates this value when you specify a process tolerance range or specification limit.

%Process: compares measurement system variation to the total variation. It is calculated as the study variation for each source divided by the historical process variation, then multiplied by 100. Minitab calculates this value when you specify a historical standard deviation and select Use parts in the study to estimate process variation.

In an acceptable measurement system, the largest component of variation is part-to-part variation.

Analysis of Results – Graphical R&R



The R chart is a control chart of ranges that displays operator consistency.

Plotted points
For each operator, the difference between the largest and smallest measurements of each part. The R chart plots the points by operator so you can see how consistent each operator is.

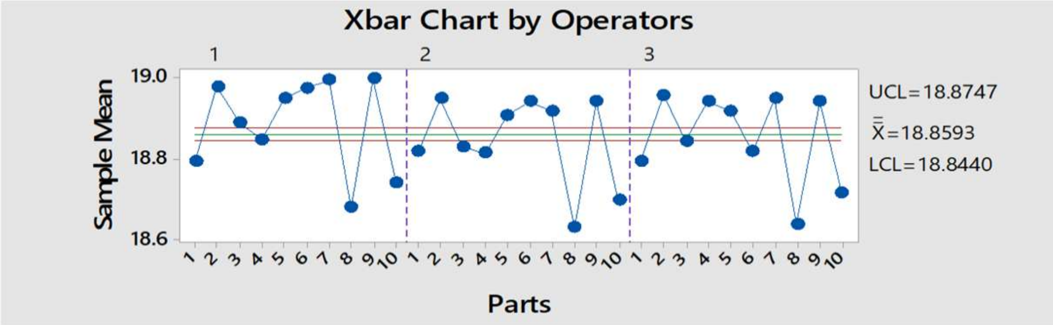
Center line (Rbar)
The grand average for the process (that is, average of all the sample ranges).

Control limits (LCL and UCL)
The amount of variation that you can expect for the sample ranges. To calculate the control limits, Minitab uses the variation within samples

Note: If each operator measures each part 9 times or more, Minitab displays an S chart instead of an R chart

Interpretation
A small average range indicates that the measurement system has low variation. A point that is higher than the upper control limit (UCL) indicates that the operator does not measure parts consistently. The calculation of the UCL includes the number of measurements per part by each operator, and part-to-part variation. If the operators measure parts consistently, then the range between the highest and lowest measurements is small, relative to the study variation, and the points should be in control.

Analysis of Results – Graphical R&R



The Xbar chart compares the part-to-part variation to the repeatability component

Plotted points
The average measurement of each part, plotted by each operator

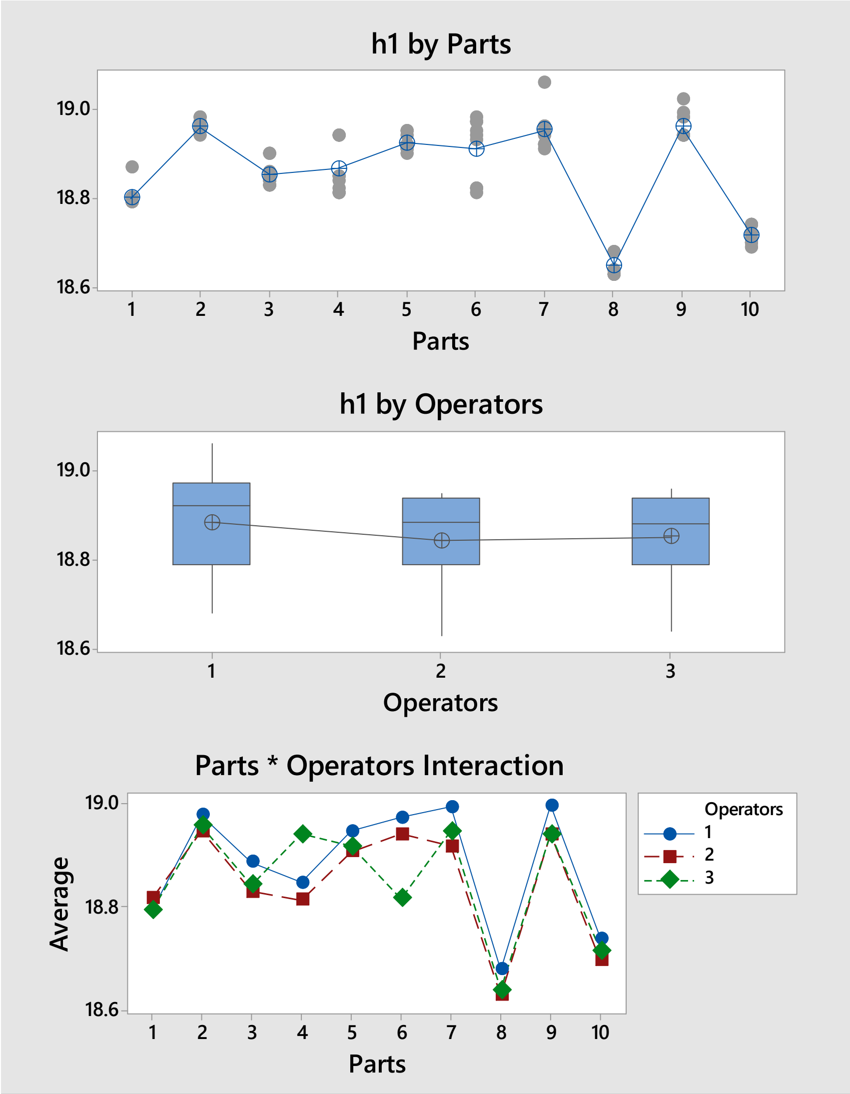
Center line (Xbar)
The overall average for all part measurements by all operators.

Control limits (LCL and UCL)
The control limits are based on the repeatability estimate and the number of measurements in each average..

Interpretation
The parts that are chosen for a Gage R&R study should represent the entire range of possible parts. Thus, this graph should indicate more variation between part averages than what is expected from repeatability variation alone.

Ideally, the graph has narrow control limits with many out-of-control points that indicate a measurement system with low variation.

Analysis of Results – Graphical R&R



Analysis of Results – Numerical R&R

Gage R&R Study - ANOVA Method

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Parts	9	0.92407	0.102675	25.3997	0.000
Operators	2	0.02673	0.013363	3.3058	0.060
Parts * Operators	18	0.07276	0.004042	17.0803	0.000
Repeatability	60	0.01420	0.000237		
Total	89	1.03776			

α to remove interaction term = 0.05

Gage R&R

Variance Components

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0018159	14.21
Repeatability	0.0002367	1.85
Reproducibility	0.0015793	12.36
Operators	0.0003107	2.43
Operators*Parts	0.0012686	9.93
Part-To-Part	0.0109591	85.79
Total Variation	0.0127751	100.00

Gage Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.042614	0.255682	37.70
Repeatability	0.015384	0.092304	13.61
Reproducibility	0.039740	0.238439	35.16
Operators	0.017627	0.105760	15.60
Operators*Parts	0.035617	0.213701	31.51
Part-To-Part	0.104686	0.628115	92.62
Total Variation	0.113027	0.678161	100.00

Number of Distinct Categories = 3

Analysis of Results – Numerical R&R

Gage R&R Study - ANOVA Method

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Parts	9	0.92407	0.102675	25.3997	0.000
Operators	2	0.02673	0.013363	3.3058	0.060
Parts * Operators	18	0.07276	0.004042	17.0803	0.000
Repeatability	60	0.01420	0.000237		
Total	89	1.03776			

α to remove interaction term = 0.05

Measurements are not significantly between appraisers (different)

Measurements between appraisers and parts are different

Gage R&R

Variance Components

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0018159	14.21
Repeatability	0.0002367	1.85
Reproducibility	0.0015793	12.36
Operators	0.0003107	2.43
Operators*Parts	0.0012686	9.93
Part-To-Part	0.0109591	85.79
Total Variation	0.0127751	100.00

Gage Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.042614	0.255682	37.70
Repeatability	0.015384	0.092304	13.61
Reproducibility	0.039740	0.238439	35.16
Operators	0.017627	0.105760	15.60
Operators*Parts	0.035617	0.213701	31.51
Part-To-Part	0.104686	0.628115	92.62
Total Variation	0.113027	0.678161	100.00

Number of Distinct Categories = 3

Analysis of Results – Numerical R&R

DF: The degrees of freedom (DF) for each SS (sums of squares). In general, DF measures how much information is available to calculate each SS.

SS: The sum of squares (SS) is the sum of squared distances, and is a measure of the variability that is from different sources. Total SS indicates the amount of variability in the data from the overall mean. SS Operator indicates the amount of variability between the average measurement for each operator and the overall mean.

SS Total = SS Part + SS Operator + SS Operator * Part + SS Repeatability

MS: The mean squares (MS) is the variability in the data from different sources. MS accounts for the fact that different sources have different numbers of levels or possible values.

MS = SS/DF for each source of variability

F: The F-statistic is used to determine whether the effects of Operator, Part, or Operator*Part are statistically significant. The larger the F statistic, the more likely it is that the factor contributes significantly to the variability in the response or measurement variable.

P: The p-value is the probability of obtaining a test statistic (such as the F-statistic) that is at least as extreme as the value that is calculated from the sample, if the null hypothesis is true.

Interpretation

Use the p-value in the ANOVA table to determine whether the average measurements are significantly different. Minitab displays an ANOVA table only if you select the ANOVA option for Method of Analysis.

Analysis of Results – Numerical R&R

A low p-value indicates that the assumption of all parts, operators, or interactions sharing the same mean is probably not true.

To determine whether the average measurements are significantly different, compare the p-value to your significance level (denoted as α or alpha) to assess the null hypothesis. The null hypothesis states that the group means are all equal. Usually, a significance level of 0.05 works well. A significance level of 0.05 indicates a 5% risk of concluding that a difference exists when it does not.

P-value ≤ α: At least one mean is statistically different
If the p-value is less than or equal to the significance level, you reject the null hypothesis and conclude that at least one of the means is significantly different from the others. For example, at least one operator measures differently

P-value > α: The means are not significantly different
If the p-value is greater than the significance level, you fail to reject the null hypothesis because you do not have enough evidence to conclude that the population means are different. For example, you can not conclude that the operators measure differently.

However, you also cannot conclude that the means are the same. A difference might exist, but your test might not have enough power to detect it.

Analysis of Results – Numerical R&R

VarComp
VarComp is the estimated variance components for each source in an ANOVA table.

Interpretation
Use the variance components to assess the variation for each source of measurement error.
In an acceptable measurement system, the largest component of variation is Part-to-Part variation. If repeatability and reproducibility contribute large amounts of variation, you need to investigate the source of the problem and take corrective action.

%Contribution (of VarComp)
%Contribution is the percentage of overall variation from each variance component. It is calculated as the variance component for each source divided by the total variation, then multiplied by 100 to express as a percentage.

Interpretation
Use the %Contribution to assess the variation for each source of measurement error.
In an acceptable measurement system, the largest component of variation is Part-to-Part variation. If repeatability and reproducibility contribute large amounts of variation, you need to investigate the source of the problem and take corrective action.

StdDev (SD)
StdDev (SD) is the standard deviation for each source of variation. The standard deviation is equal to the square root of the variance component for that source.

The standard deviation is a convenient measure of variation because it has the same units as the part measurements and tolerance.

Analysis of Results – Numerical R&R

Study Var (6 * SD)
The study variation is calculated as the standard deviation for each source of variation multiplied by 6 or the multiplier that you specify in Study variation.

Usually, process variation is defined as 6s, where s is the standard deviation as an estimate of the population standard deviation (denoted by σ or sigma). When data are normally distributed, approximately 99.73% of the data fall within 6 standard deviations of the mean. To define a different percentage of data, use another multiplier of standard deviation. For example, if you want to know where 99% of the data fall, you would use a multiplier of 5.15, instead of the default multiplier of 6.

%Study Var (%SV)
The %study variation is calculated as the study variation for each source of variation, divided by the total variation and multiplied by 100.

%Study Var is the square root of the calculated variance component (VarComp) for that source. Thus, the %Contribution of VarComp values sum to 100, but the %Study Var values do not.

Interpretation

Use %Study Var to compare the measurement system variation to the total variation. If you use the measurement system to evaluate process improvements, such as reducing part-to-part variation, %Study Var is a better estimate of measurement precision. If you want to evaluate the capability of the measurement system to evaluate parts compared to specification, %Tolerance is the appropriate metric.

Analysis of Results – Numerical R&R

%Tolerance (SV/Toler)
%Tolerance is calculated as the study variation for each source, divided by the process tolerance and multiplied by 100.

If you enter the tolerance, Minitab calculates %Tolerance, which compares measurement system variation to the specifications.

Interpretation
Use %Tolerance to evaluate parts relative to specifications. If you use the measurement system for process improvement, such as reducing part-to-part variation, %StudyVar is the appropriate metric.

%Process (SV/Proc)
If you enter a historical standard deviation but use the parts in the study to estimate the process variation, then Minitab calculates %Process. %Process compares measurement system variation to the historical process variation. %Process is calculated as the study variation for each source, divided by the historical process variation and multiplied by 100. By default, the process variation is equal to 6 times the historical standard deviation.

If you use a historical standard deviation to estimate process variation, then Minitab does not show %Process because %Process is identical to %Study Var.

Analysis of Results – Numerical R&R

IC/ CI 95%

95% confidence intervals (95% CI) are the ranges of values that are likely to contain the true value of each measurement error metric.

Minitab provides confidence intervals for the variance components, the %contribution of the variance components, the standard deviation, the study variation, the %study variation, the %tolerance, and the number of distinct categories.

Interpretation

Because samples of data are random, two gage studies are unlikely to yield identical confidence intervals. But, if you repeat your studies many times, a certain percentage of the resulting confidence intervals contain the unknown true measurement error. The percentage of these confidence intervals that contain the parameter is the confidence level of the interval.

For example, with a 95% confidence level, you can be 95% confident that the confidence interval contains the true value. The confidence interval helps you assess the practical significance of your results. Use your specialized knowledge to determine whether the confidence interval includes values that have practical significance for your situation. If the interval is too wide to be useful, consider increasing your sample size.

Suppose that the VarComp for Repeatability is 0.044727 and the corresponding 95% CI is (0.035, 0.060). The estimate of variation for repeatability is calculated from the data to be 0.044727. You can be 95% confident that the interval of 0.035 to 0.060 contains the true variation for repeatability.

.

Analysis of Results – Numerical R&R

Number of distinct categories

The number of distinct categories is a metric that is used in gage R&R studies to identify a measurement system's ability to detect a difference in the measured characteristic. The number of distinct categories represents the number of non-overlapping confidence intervals that span the range of product variation, as defined by the samples that you chose. The number of distinct categories also represents the number of groups within your process data that your measurement system can discern.

Interpretation

The Measurement Systems Analysis Manual1 published by the Automobile Industry Action Group (AIAG) states that 5 or more categories indicates an acceptable measurement system. If the number of distinct categories is less than 5, the measurement system might not have enough resolution.

Usually, when the number of distinct categories is less than 2, the measurement system is of no value for controlling the process, because it cannot distinguish between parts. When the number of distinct categories is 2, you can split the parts into only two groups, such as high and low. When the number of distinct categories is 3, you can split the parts into 3 groups, such as low, middle, and high.

Analysis of Results – Numerical R&R

Probabilities of misclassification
When you specify at least one specification limit, Minitab can calculate the probabilities of misclassifying product. Because of the gage variation, the measured value of the part does not always equal the true value of the part. The discrepancy between the measured value and the actual value creates the potential for misclassifying the part.

Minitab calculates both the joint probabilities and the conditional probabilities of misclassification.

Joint probability
Use the joint probability when you don't have prior knowledge about the acceptability of the parts. For example, you are sampling from the line and don't know whether each particular part is good or bad. There are two misclassifications that you can make:

- The probability that the part is bad, and you accept it.
- The probability that the part is good, and you reject it.

Conditional probability
Use the conditional probability when you do have prior knowledge about the acceptability of the parts. For example, you are sampling from a pile of rework or from a pile of product that will soon be shipped as good. There are two misclassifications that you can make:

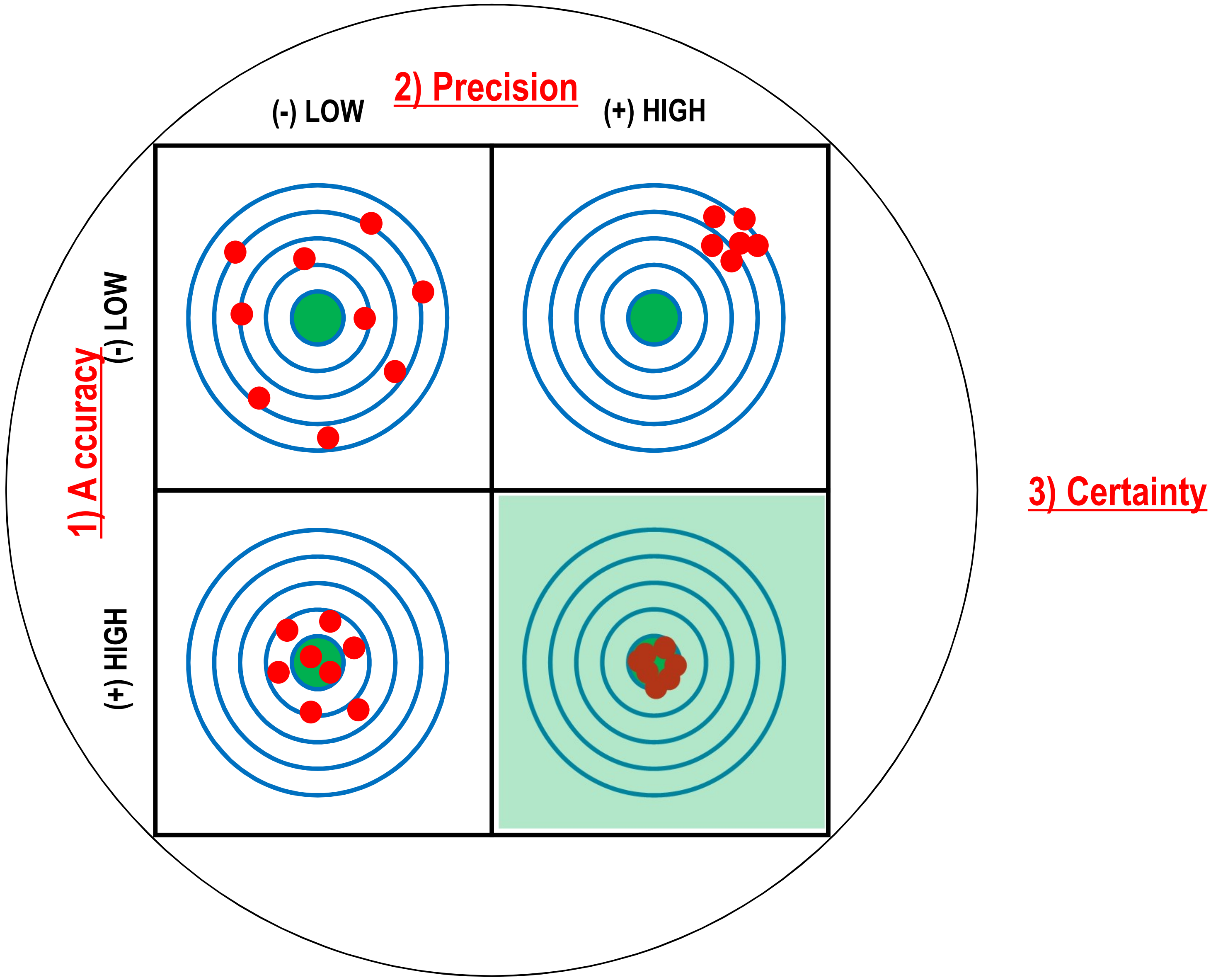
- The probability that you accept a part that was sampled from a pile of bad product that needs to be reworked (also called false accept).
- The probability that you reject a part that was sampled from a pile of good product that is about to be shipped (also called false reject).

Interpretation
Three operators measure ten parts, three times per part. The following graph shows the spread of the measurements compared to the specification limits. In general, the probabilities of misclassification are higher with a process that has more variation and produces more parts close to the specification limits.

Possible causes – Width Variation

- Within-part (sample): form, position, surface finish, taper, sample consistency
- Within-instrument: repair; wear, equipment or fixture failure, poor quality or maintenance
- Within-standard: quality, class, wear
- Within-method: variation in setup, technique, zeroing, holding, clamping
- Within-appraiser: technique, position, lack of experience, manipulation skill or training, feel, fatigue
- Within-environment: short-cycle fluctuations in temperature, humidity, vibration, lighting, cleanliness
- Violation of an assumption – stable, proper operation
- Instrument design or method lacks robustness, poor uniformity
- Wrong gage for the application
- Distortion (gage or part), lack of rigidity
- Application – part size, position, observation error (readability, parallax)

Variations



System variation

Capability: Variability in readings taken over a short period of time

$$\sigma^2_{capability} = \sigma^2_{bias\,(linearity)} + \sigma^2_{GRR}$$

Performance: Variability in readings taken over a long period of time

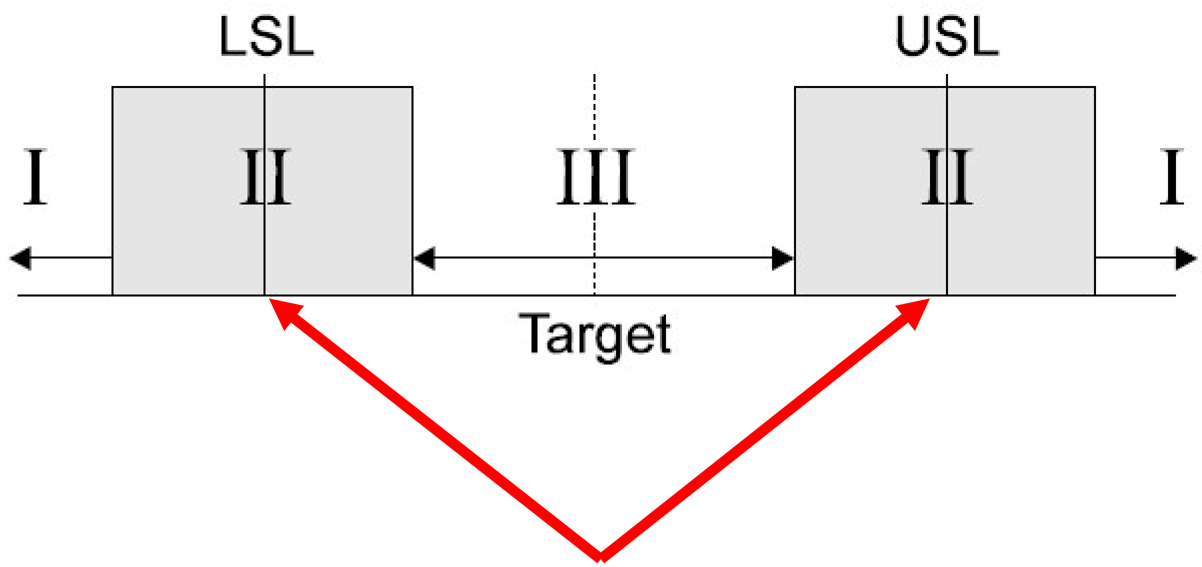
Based on total variation

$$\sigma^2_{performance} = \sigma^2_{capability} + \sigma^2_{stability} + \sigma^2_{consistency}$$

Uncertainty: An estimated range of values about the measured value in which the true value is believed to be contained

- Uncertainty is a quantified expression of measurement reliability
- The range expected to contain the true measurement result
- Experimental procedure that gives us the value of a magnitude

Attribute Measurement Systems Study

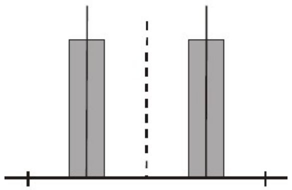


The attribute gage have "Gray" areas where wrong decisions can be made

Attribute Measurement Systems Study

The most common of these is a go/no-go gage

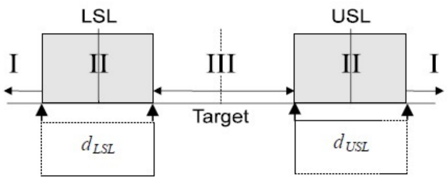
Other attribute systems, for example visual standards, may result in five to seven classifications, such as very good, good, fair, poor, very poor.



Risk Analysis Methods:

- ❑ Hypothesis Test Analyses
  - ❑ Cross-Tab Method (50 parts, 3 Appraisers, 3 times - VR)
    - ❑ Use the (Cohen's) kappa which measures the agreement between the evaluations of two raters when both are rating the same object. A value of 1 indicates perfect agreement.
    - ❑ The process team then calculated the effectiveness of the measurement system.

Decision Measurement system	Effectiveness	Miss Rate	False Alarm Rate
Acceptable for the appraiser	≥ 90%	≤ 2%	≤ 5%
Marginally acceptable for the appraiser – may need improvement	≥80%	≤ 5%	≤ 10%
Unacceptable for the appraiser – needs improvement	< 80%	> 5%	> 10%



- ❑ Signal Detection Theory
  - ❑ Use Signal Detection theory to determine an approximation of the width of the region II area.

Used when there is not significant sample of process (with known values)

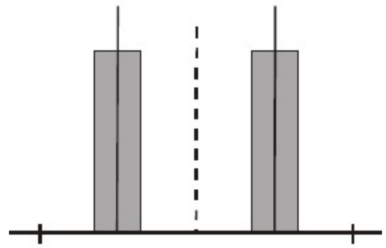
Attribute Measurement Systems Study

Analytic Method:

Is used to assess the amount of repeatability and bias of the measurement system. This analysis can be used on both single and double limit measurement systems. For a double limit measurement system, only one limit need be examined with the assumptions of linearity and uniformity of error.

Conducting the Study / Cross-Tab Method

1) Obtain a sample and establish its reference value(s) relative to a traceable standard (n =50 parts).
    1) A high percentage of the parts must be close to the specification limits (gray areas). The reason is to evaluate the performance gauge in the critical process areas.



    2) If it is not possible to make parts close to the specification limits the team should reconsider the use of attribute gaging for this process.

2) Measure the parts 3 times with each appraiser. An acceptable decision was designated with a one (1) and an unacceptable decision with zero (0).

3) Put in table every reference decision and variable reference

4) Use a software or internal spreadsheet (In order to compute the results)

5) Take actions in order to improve the measurement system (if it is necessary or standardize)

The results – presented in a matrix format

BOCAR GROUP

Trials / Appraisers

Part	A - 1	A - 2	A - 3	B - 1	B - 2	B - 3	C - 1	C - 2	C - 3	Reference	Ref Value	Code
1	1	1	1	1	1	1	1	1	1	1	0.476901	+
2	1	1	1	1	1	1	1	1	1	1	0.509015	+
3	0	0	0	0	0	0	0	0	0	0	0.576459	-
4	0	0	0	0	0	0	0	0	0	0	0.566152	-
5	0	0	0	0	0	0	0	0	0	0	0.570360	-
6	1	1	0	1	1	0	1	0	0	1	0.544951	x
7	1	1	1	1	1	1	1	0	1	1	0.465454	x
8	1	1	1	1	1	1	1	1	1	1	0.502295	+
9	0	0	0	0	0	0	0	0	0	0	0.437817	-
10	1	1	1	1	1	1	1	1	1	1	0.515573	+
11	1	1	1	1	1	1	1	1	1	1	0.488905	+
12	0	0	0	0	0	0	0	1	0	0	0.559918	x
13	1	1	1	1	1	1	1	1	1	1	0.542704	+
14	1	1	0	1	1	1	1	0	0	1	0.454518	x
15	1	1	1	1	1	1	1	1	1	1	0.517377	+
16	1	1	1	1	1	1	1	1	1	1	0.531939	+
17	1	1	1	1	1	1	1	1	1	1	0.519694	+
[illegible]	[illegible]	1	1	1	1	1	1	1	1	1	0.484167	+
[illegible]	[illegible]	1	1	1	1	1	1	1	1	1	0.520496	+
[illegible]	[illegible]	1	1	1	1	1	1	1	1	1	0.477236	+
[illegible]	[illegible]	1	0	1	0	1	0	1	0	1	0.452310	x
[illegible]	[illegible]	0	1	0	1	0	1	1	0	0	0.545[illegible]	[illegible]
[illegible]	[illegible]	1	1	1	1	1	1	1	1	1	0.52906[illegible]	+
[illegible]	[illegible]	1	1	1	1	1	1	1	1	1	0.514192	+
[illegible]	[illegible]	0	0	0	0	0	0	0	0	0	0.599581	-
[illegible]	[illegible]	1	0	0	0	0	0	0	1	0	0.547204	x
[illegible]	[illegible]	1	1	1	1	1	1	1	1	1	0.502436	+
[illegible]	[illegible]	1	1	1	1	1	1	1	1	1	0.521642	+
[illegible]	[illegible]	1	1	1	1	1	1	1	1	1	0.523754	+
[illegible]	[illegible]	0	0	0	0	1	0	0	0	0	0.561457	x
31	1	1	1	1	1	1	1	1	1	1	0.503091	+
32	1	1	1	1	1	1	1	1	1	1	0.505850	+
33	1	1	1	1	1	1	1	1	1	1	0.487613	+
34	0	0	1	0	0	1	0	1	1	0	0.449696	x
35	1	1	1	1	1	1	1	1	1	1	0.498698	+
36	1	1	0	1	1	1	1	0	1	1	0.543077	x
37	0	0	0	0	0	0	0	0	0	0	0.409238	-
38	1	1	1	1	1	1	1	1	1	1	0.488184	+
39	0	0	0	0	0	0	0	0	0	0	0.427687	-
40	1	1	1	1	1	1	1	1	1	1	0.501132	+
41	1	1	1	1	1	1	1	1	1	1	0.513779	+
42	0	0	0	0	0	0	0	0	0	0	0.566575	-
43	1	0	1	1	1	1	1	1	0	1	0.462410	x
44	1	1	1	1	1	1	1	1	1	1	0.470832	+
45	0	0	0	0	0	0	0	0	0	0	0.412453	-
46	1	1	1	1	1	1	1	1	1	1	0.493441	+
47	1	1	1	1	1	1	1	1	1	1	0.486379	+
48	0	0	0	0	0	0	0	0	0	0	0.587893	-
49	1	1	1	1	1	1	1	1	1	1	0.483803	+
50	[illegible]	0	0	0	0	0	0	0	0	0	0.446697	-

Take the decisions on the each part

1 / Ok= acceptable
0 / No Ok = unacceptable

Put the decisions on the each part according to the reference value

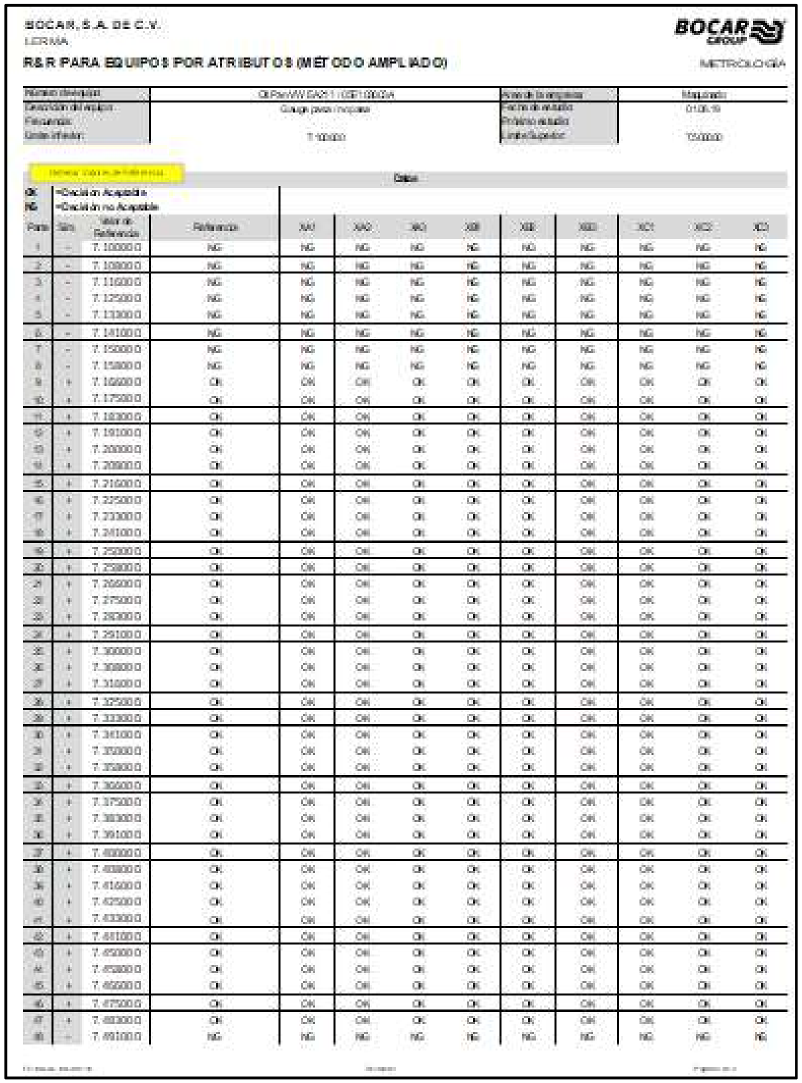
1 / Ok= acceptable
0 / No Ok = unacceptable

the reference value

Code according to the inspection agreement

+ When all appraisers accepted the parts
- When all appraisers rejected the parts
X When at least one of the decisions was different to the others

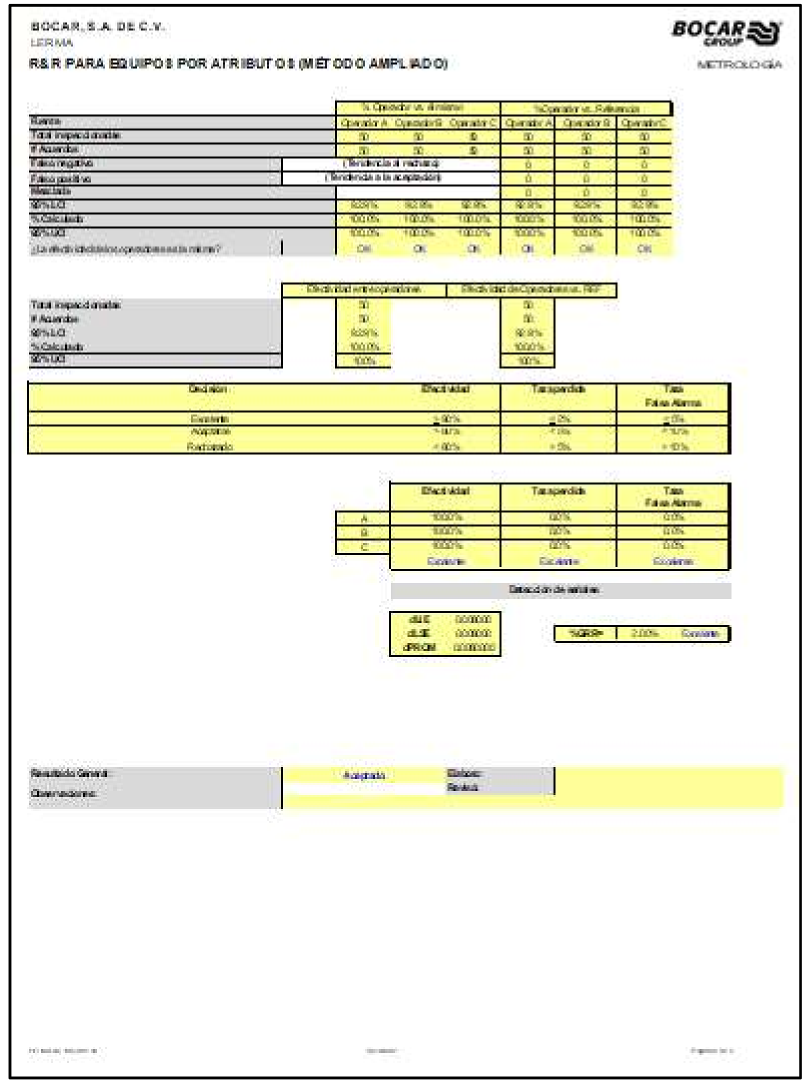
Example - spreadsheet



BOCAR, S.A. DE C.V.
LERMA
R&R PARA EQUIPOS POR ATRIBUTOS (MÉTODO AMPLIADO)
METROLOGÍA

OK =Decisión Aceptable
NG =Decisión no Aceptable

Parte	Sim.	Valor de Referencia	Referencia	XA1	XA2	XA3	XB1	XB2	XB3	XC1	XC2	XC3
1	-	7.100000	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
2	-	7.108000	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
3	-	7.116000	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
4	-	7.125000	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
5	-	7.133000	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
6	-	7.141000	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
7	-	7.150000	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
8	-	7.158000	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
9	+	7.166000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
10	+	7.175000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
11	+	7.183000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
12	+	7.191000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
13	+	7.200000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
14	+	7.208000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
15	+	7.216000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
16	+	7.225000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
17	+	7.233000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
18	+	7.241000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
19	+	7.250000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
20	+	7.258000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
21	+	7.266000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
22	+	7.275000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
23	+	7.283000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
24	+	7.291000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
25	+	7.300000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
26	+	7.308000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
27	+	7.316000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
28	+	7.325000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
29	+	7.333000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
30	+	7.341000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
31	+	7.350000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
32	+	7.358000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
33	+	7.366000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
34	+	7.375000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
35	+	7.383000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
36	+	7.391000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
37	+	7.400000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
38	+	7.408000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
39	+	7.416000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
40	+	7.425000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
41	+	7.433000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
42	+	7.441000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
43	+	7.450000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
44	+	7.458000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
45	+	7.466000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
46	+	7.475000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
47	+	7.483000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
48	-	7.491000	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG



BOCAR, S.A. DE C.V.
LERMA
R&R PARA EQUIPOS POR ATRIBUTOS (MÉTODO AMPLIADO)
METROLOGÍA

	% Operador vs. él mismo			% Operador vs. Referencia		
	Operador A	Operador B	Operador C	Operador A	Operador B	Operador C
Total inspeccionadas	50	50	50	50	50	50
# Acuerdos	50	50	50	50	50	50
Falso negativo	(Tendencia al rechazo)			0	0	0
Falso positivo	(Tendencia a la aceptación)			0	0	0
Mezclado				0	0	0
95% LCI	92.9%	92.9%	92.9%	92.9%	92.9%	92.9%
% Calculado	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
95% LCS	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

	Efectividad entre operadores	Efectividad de Operadores vs. REF
Total inspeccionadas	50	50
# Acuerdos	50	50
95% LCI	92.9%	92.9%
% Calculado	100.0%	100.0%
95% LCS	100%	100%

Decisión	Efectividad	Tasa perdida	Tasa Falsa Alarma
Excelente	≥ 90%	≤ 2%	≤ 5%
Aceptable	≥ 80%	≤ 5%	≤ 10%
Rechazado	< 80%	> 5%	> 10%

	Efectividad	Tasa perdida	Tasa Falsa Alarma
A	100.0%	0.0%	0.0%
B	100.0%	0.0%	0.0%
C	100.0%	0.0%	0.0%
	Excelente	Excelente	Excelente

Detección de señales

Resultado General: Aceptado
Observaciones:
Elaboró:
Revisó:

Analysis of Results – Numerical R&R

Kappa analysis

To Determine the level of agreement that team uses. Measures the agreement between the evaluations of two raters when both are rating the same object.

	A	B	C
kappa	.88	.92	.77

A general rule of thumb is that values of kappa greater than 0.75 indicate good to excellent agreement (with a maximum kappa = 1)

This analysis indicates that all the appraisers show good agreement between each other.

Analysis of Results – Numerical R&R

The effectiveness analysis

Source	% Appraiser[1]			% Score vs. Attribute[2]		
	Appraiser A	Appraiser B	Appraiser C	Appraiser A	Appraiser B	Appraiser C
Total Inspected	50	50	50	50	50	50
# Matched	42	45	40	42	45	40
False Negative (appraiser biased toward rejection)				0	0	0
False Positive (appraiser biased toward acceptance)				0	0	0
Mixed				8	5	10
95% UCI	93%	97%	90%	93%	97%	90%
Calculated Score	**84%**	**90%**	**80%**	**84%**	**90%**	**80%**
95% LCI	71%	78%	66%	71%	78%	66%

Effectiveness Criteria Guidelines

Decision Measurement system	**Effectiveness**	**Miss Rate**	**False Alarm Rate**
Acceptable for the appraiser	≥ 90%	≤ 2%	≤ 5%
Marginally acceptable for the appraiser – may need improvement	≥80%	≤ 5%	≤ 10%
Unacceptable for the appraiser – needs improvement	< 80%	> 5%	> 10%

Example

Tabulación Cruzada AB							
			B				
			NG	OK	Total	Kappa	
A	NG	Cuenta	27	3	30		
		Cuenta esperada	0.180	0.020	0.200	0.89	
	OK	Cuenta	2	118	120		
		Cuenta esperada	0.013	0.787	0.800	OK	
Total		Cuenta	29	121	150		
		Cuenta esperada	0.193	0.807	1.000		

Tabulación Cruzada BC							
			C				
			NG	OK	Total	Kappa	
B	NG	Cuenta	29	0	29		
		Cuenta esperada	0.193	0.000	0.193	0.96	
	OK	Cuenta	2	119	121		
		Cuenta esperada	0.013	0.793	0.807	OK	
Total		Cuenta	31	119	150		
		Cuenta esperada	0.207	0.793	1.000		

Tabulación Cruzada AC							
			C				
			NG	OK	Total	Kappa	
A	NG	Cuenta	28	2	30		
		Cuenta esperada	0.187	0.013	0.200	0.90	
	OK	Cuenta	3	117	120		
		Cuenta esperada	0.020	0.780	0.800	OK	
Total		Cuenta	31	119	150		
		Cuenta esperada	0.207	0.793	1.000		

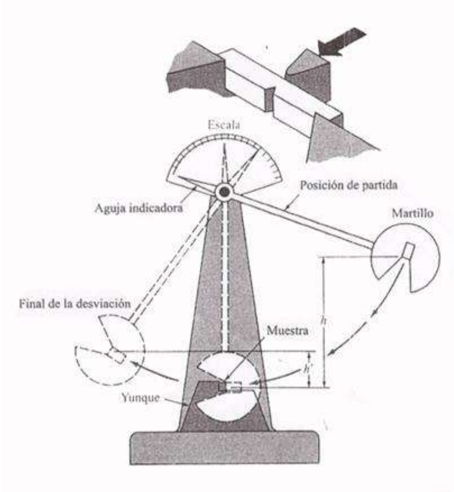
Example

	Efectividad	Taza perdida	Taza Falsa Alarma
A	94.0%	9.1%	0.0%
B	92.0%	12.1%	0.9%
C	96.0%	6.1%	0.0%
	Excelente	Rechazado	Excelente

Excelent Rejected Excelent

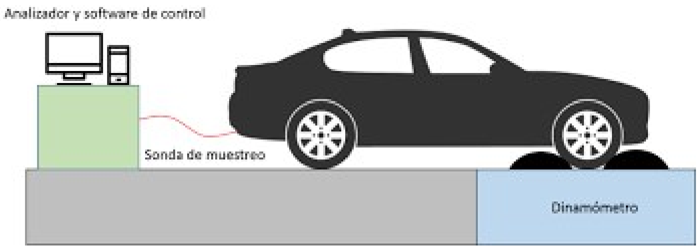
Non-Replicable Measurement Systems

Destructive measurement systems: When the part (characteristic) being measured is destroyed by the act of measuring the process is known as destructive measurement.



Example: destructive weld testing, destructive plating testing, salt spray/humidity booth testing, impact testing (gravelometer) or mass spectroscopy and other material characteristic testing processes

Systems where the part changes on use/test: the part is not harmed by the measurement process but the characteristic being measure will change.



Examples of this are: leak tests with qualitative data, testing using engine test stands, transmission test stands, vehicle dynamometers, etc.

Doubts or comments

¡Thank You!