Continuous Improvement Toolkit

Measurement System Analysis (MSA)


Managing Risk
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FMEA
RAID Logs
Fault Tree Analysis
Risk Assessment*
Traffic Light Assessment
Deciding & Selecting
Pros and Cons
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Break-even Analysis
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Decision Tree
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Kano Analysis
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Hoshin Kanri
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Sampling
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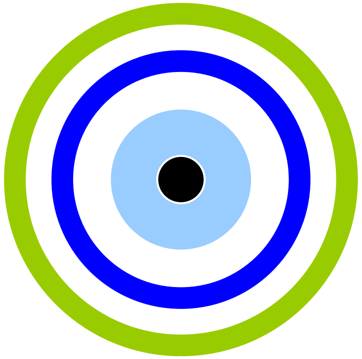
Analogy
SCAMPER***
Nominal Group Technique
Mind Mapping*
Affinity Diagram
Attribute Analysis
Lateral Thinking
Visioning
Creating Ideas**
Time Value Map
Process Redesign
IDEF0
Value Stream Mapping
SIPOC
Flow Process Chart
Process Mapping
Flowcharting
Service Blueprints
Designing & Analyzing Processes

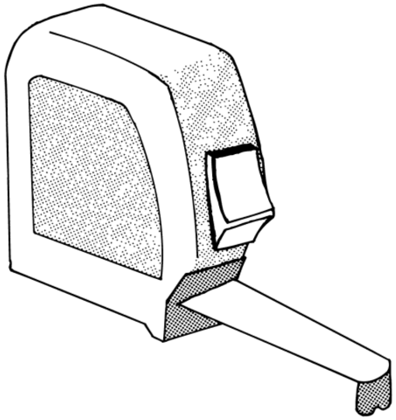
- Measurement System Analysis

- The success or failure of quality is dependent upon having a measurement system which provides reliable data.
- Too many problems are analyzed with data that is known to be suspect.
- If the data is poor quality, there is no other option but to stop and fix the measurement system.



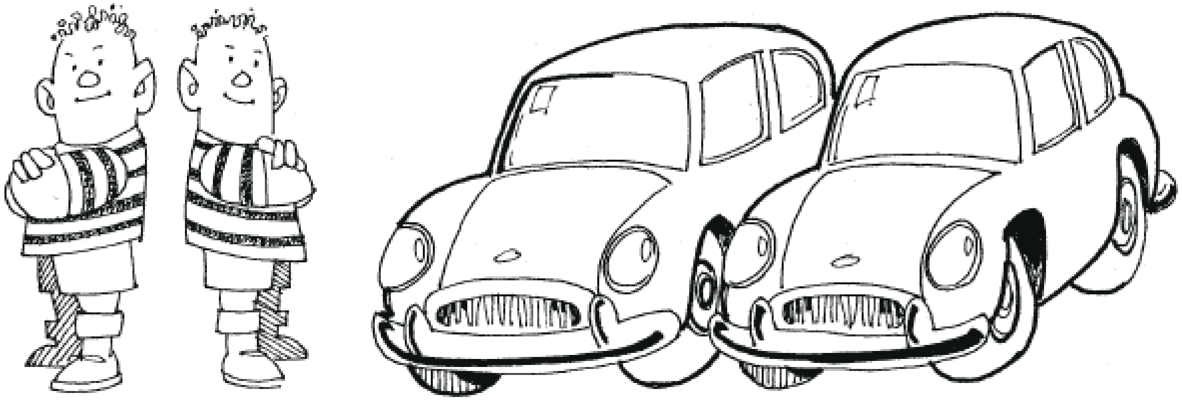
- Measurement System Analysis

- A **measurement system** is a process which produces data as its output.
- **MSA** is a systematic approach for determining the types of errors affecting measurement system.
- It refers to the techniques that can help to identify the source of errors in our data.
- **MSA will help to answer:**
  - How good is our measurement system?
  - Are we confident with the data collected?
  - Is the system fit for purpose?



- Measurement System Analysis

- No two things are alike, and even if they were, we would still get different values when we measure them.



Measurement System Resolution:

- The smallest units within the data represent the resolution of the measurement system.
- Resolution should be large enough to allow effective discrimination of the process variation.

0.40	**Ruler**
0.417	**Caliper**
0.4176	**Micrometer**

- **What causes poor resolution?**
  - Gauge is not capable to measure any finer measurement.
  - Sometimes data is being rounded during collection or recording.

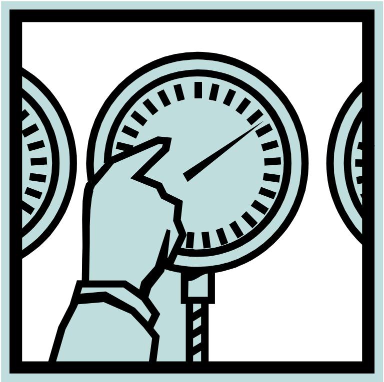
Examples – What are the Resolutions for the Below Data Sets?

46	12.05	0.0459
24	11.55	0.0438
41	12.80	0.0412
64	11.30	0.0423
51	11.95	0.0411
45	12.05	0.0398
72	12.10	0.0454
39	12.40	0.0413
58	11.75	0.0438
49	11.90	0.0444

Resolution: 1 **Resolution: 0.05** **Resolution: 0.0001**

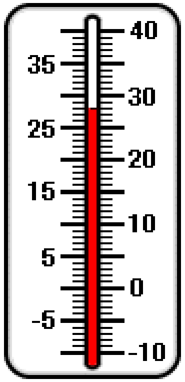
Measurement System Resolution:

- Always check if the resolution acceptable.
- Use full resolution of the measurement system.
- Check for rounding during data collection.
- If the instruments/equipment resolution is not sufficient, upgrade or replace it.



- Measurement System Analysis

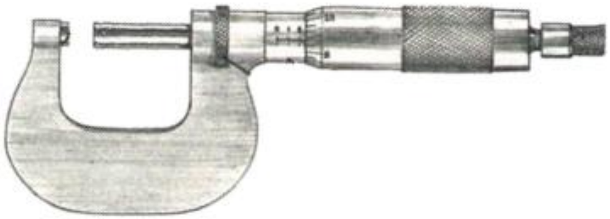
- The key to the effective use of any measurement system is an understanding of the source of variation contained within the measurement system.
- MSA is utilized for both variable and attribute data.
- Problems found with the measurement system must be corrected before use.



- Measurement System Analysis

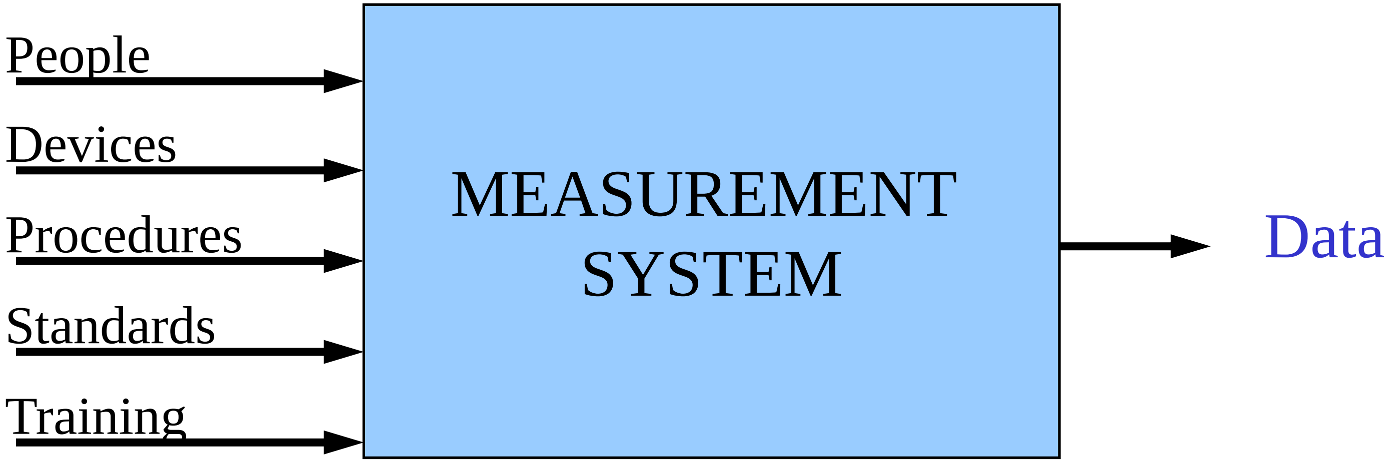
Common Problems:

- Unclear methods.
- Inadequately trained operators.
- Poor data recording.
- Poor data analysis.
- Calibration and maintenance issues.
- Deficiencies in gauges.
- Too little part-to-part variation.
- Inadequate control of the working environment (including basic housekeeping).



- Measurement System Analysis

- A measurement system is not just a device as a ruler or timer.
- It includes people, standards, and procedures that surround the measurement process itself.



- Measurement System Analysis

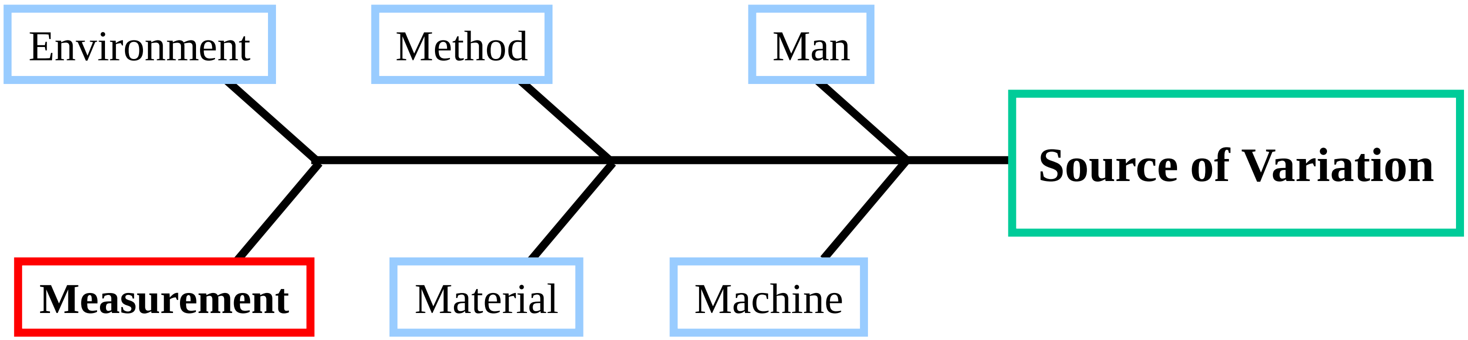
- Three potential source of error in measurement system:
  - The gauge
  - The operator
  - The method

- Measurement System Analysis

- Minimizing **variability of the measurement system** is critical for understanding true process capability.
- MSA usually comes before Process Control Charting and Capability Studies.

- Measurement System Analysis

- When measuring any process, there are two sources of variation:
  - The variation of the process itself (**part-to-part variation**).
  - The variation of the measurement system.
- Measurement system variability must be small compared with both process variability and specification limits.



- Measurement System Analysis

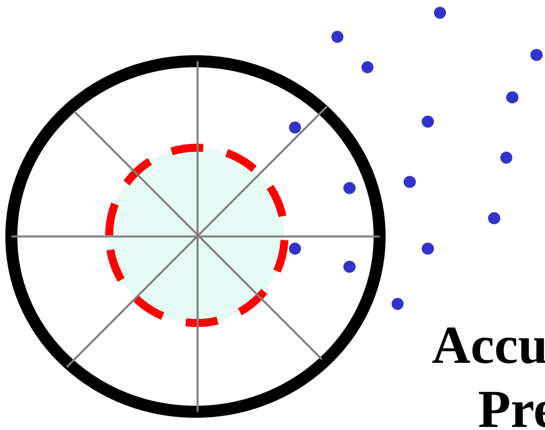
- Two factors that affect the quality of the measurement system:
  - **Accuracy:** The ability of to measure the **true value** of a part on average.
  - **Precision:** The variation observed when measuring the same part repeatedly with the same device.

Accurate

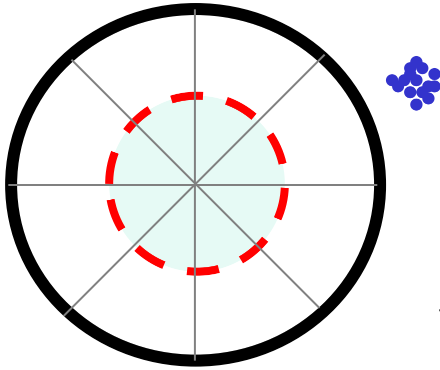
Precise

- Measurement System Analysis

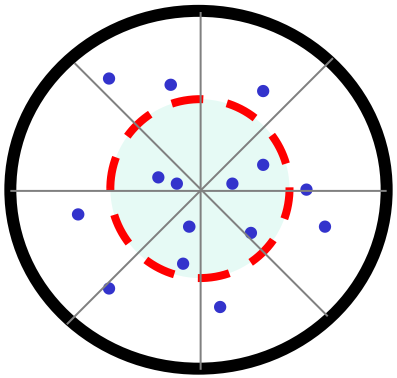
Accurate or Precise?



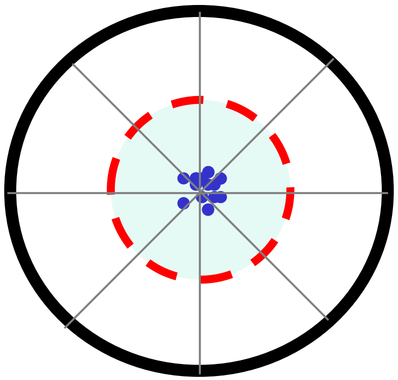
Accurate ✗
Precise ✗



Accurate ✗
Precise ✓



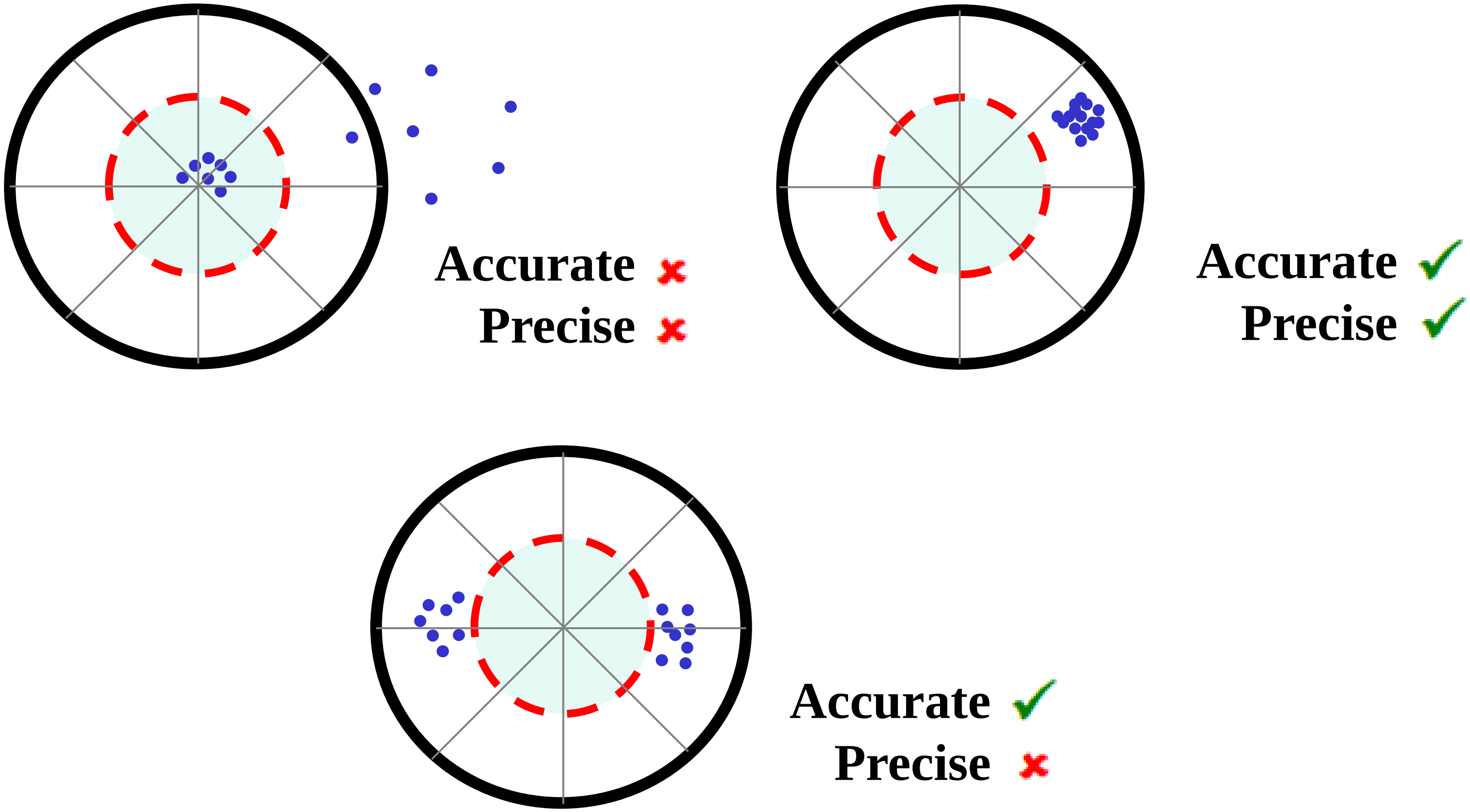
Accurate ✓
Precise ✗



Accurate ✓
Precise ✓

- Measurement System Analysis

Accurate or Precise?

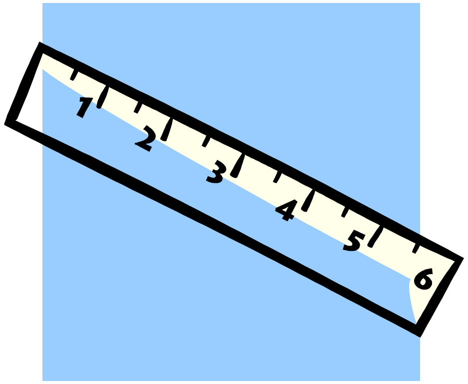


- Measurement System Analysis

Precision:

- Precision errors do not happen in the same way all the time.
- The variation in the data is more than is actually in the process.

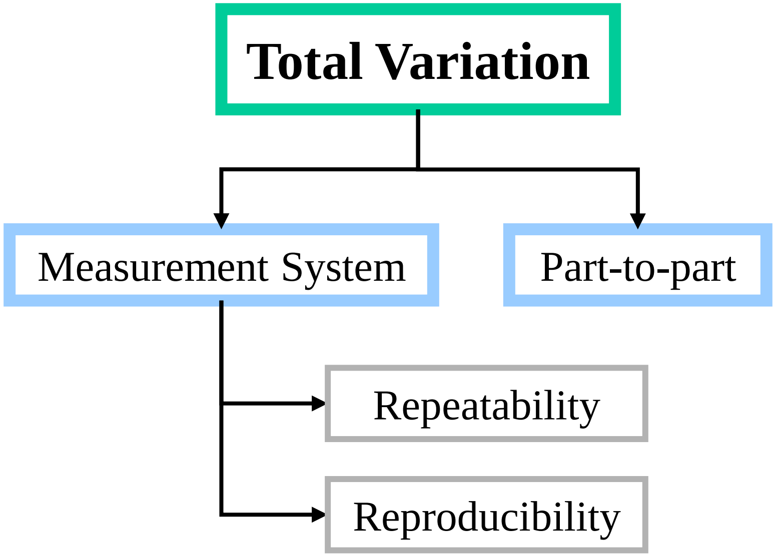
- **Examples:**
  - Some people measure from the end of a ruler and others start from the point at which zero is marked.
  - The start time for a customer complaint could be anything from 5 to 20 minutes after customer first called.



- Measurement System Analysis

Precision in a Measurement System Has Two Components:

- **Repeatability:** The variation observed when the same operator measures the same part with the same device multiple times.
- **Reproducibility:** The variation observed when different operators measure the same part with the same device.



Repeatability:

- Better described as 'Within System Variation'.
- Special cause of variation must be eliminated in order for the measurement system study to be valid.

Reproducibility:

- Better described as 'Between System Variation'.
- Not relevant when the appraiser is not a key source of variation (e.g. automated measurement systems).
- The variation is caused by an intentional change to the measurement process (between gauges, between methods, between operators, etc.).

- Measurement System Analysis

- The study for the precession of the measurement system is called **R&R** or **Gauge Capability study**.
- To calculate the gauge capability, we apply a Repeatability and Reproducibility test.
- **R&R test** is a statistical tool that measures the amount of variation in the measurement system arising from the measurement device and the people taking the measurement.

$$\sigma^2_{R\&R} = \sigma^2_{Repeatability} + \sigma^2_{Reproducibility}$$

- Measurement System Analysis

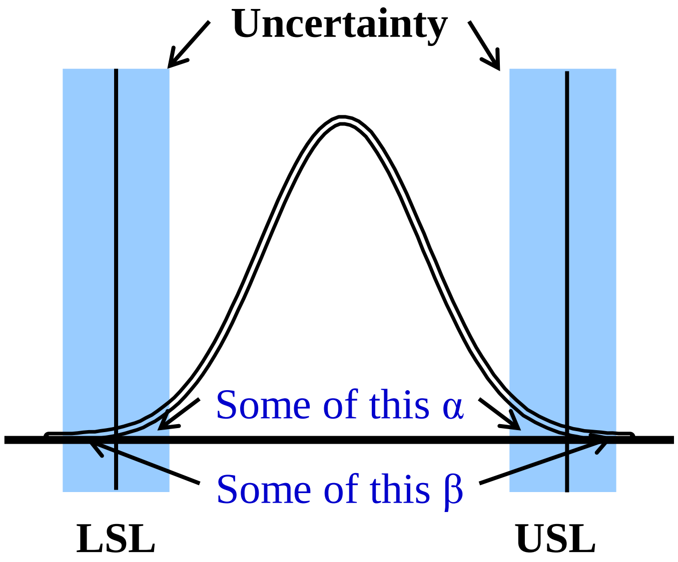
- With no error in the system that we use to measure, we will be able to decide whether product is good or bad with confidence.

- If there is some kind of error in the system we use to measure, we are left with uncertainty.

- Measurement System Analysis

Gauge R&R Study:

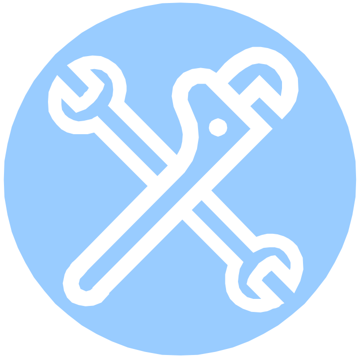
- The Gauge R&R Study allows us to quantify this uncertainty and assess the adequacy of the measurement system.
- It measures precision error by taking one part and measuring it several times with several different people.
- Given that the part is not changing size, any variation must represent the repeatability of the gauge or the reproducibility of the measurement by different people.
- Then it repeats this approach on several parts to assess the results.



- Measurement System Analysis

Approach (R&R):

- Calibrate the measuring instrument.
- Select M operators and N parts.
- Randomize the order of measurements.
- Measure each part by each operator for R trials.
- Compute the measurement system variation to quantify R&R.



A common standard for a GR&R study is to use 10 parts, measured by 3 different people, 3 time each, providing a total of 90 results

Resolution must be fine enough to detect and correctly indicate small changes

- Measurement System Analysis

Key Issues:

- Operators should be from the ones who normally carry out the task.
- Operators should be unaware of which sample is being measured.
- Samples should be numbered.
- Samples should represent the entire operating range of the measurement system.
- A rule of thumb: 3 appraisers measuring 10 sample 2 time each.

- Measurement System Analysis

Evaluate the results (Study Variation):

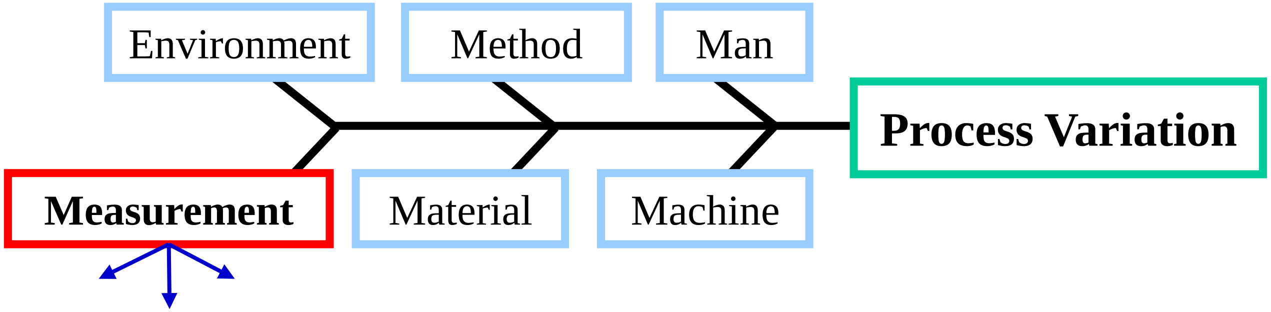
- If the measurement system variation is:
  - 10% or less: Excellent.
  - 10-30%: Marginal or based on the importance/repair cost.
  - 30% or greater: Unacceptable.

	% Variation	% Tolerance
World Class	**< 10%**	**< 10%**
Marginal	**10-30%**	**10-30%**
Unacceptable	**> 30%**	**> 30%**

- Measurement System Analysis

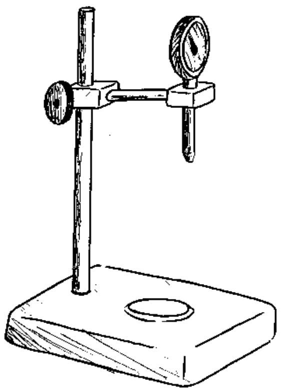
Common Causes for Poor Repeatability & Reproducibility:

- Sample variation: Form, position, surface finish, etc.
- Instrument variation: Equipment wear or failure, rigidity, poor design, etc.
- Method variation: Set-up, holding, zeroing, clamping, etc.
- Appraiser variation: Technique, fatigue, lack of training, experience, etc.
- Environment variation: Short-term fluctuation (temperature), cleanliness, etc.



- Measurement System Analysis

When Should We Apply the R&R Test:



- When new gauges are purchased.
- After a gauge is modified or serviced.
- When a new gauge SOP is introduced (change in method).
- After a certain time of use (one year for example).
- When comparing different measurement systems.
- To train gauge operators.
- **Process improvement initiatives and projects.**

- Measurement System Analysis

Guidelines When Taking Measures to Obtain Quality Data:

- Operators should follow exactly the procedures given for preparation, measurement and recording of data.
- Operators should take a representative samples in random order to minimize external factors.
- Operators should reset the measuring device after each measurement.
- Measured parts should be marked to avoid operator bias.
- Operators should record any changes in conditions that may occur, such as temperature and time of day.

Order	Part	Operator	Distance
1	6	4	4.99698
2	11	2	5.01507
3	9	4	4.98424
4	10	3	4.94513
5	5	4	4.98970
6	7	5	5.04092
7	7	1	5.01026
8	8	4	5.00105
9	9	5	4.98475
10	7	3	5.04382
11	4	4	5.01995
12	9	4	4.99821
13	6	2	4.98852
14	12	2	4.99106
15	6	3	5.00964

- Measurement System Analysis

Example:

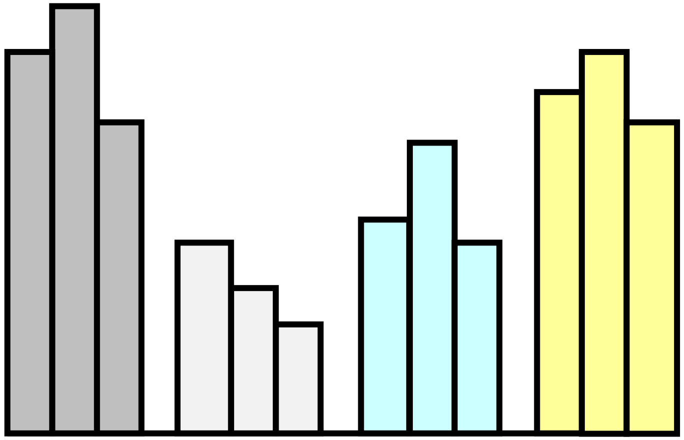
- R&R Study is to be conducted on a gauge being used to measure the distance between two components on circuit boards.
- **4** operators have taken repeat measurements (**3** times each) of distances between components on **10** circuit boards which have been selected randomly.
- The true distance between the two components in the circuit board is **5.0** mm. The company set their tolerance at **0.20** mm.
- How can we be sure that the distance measurement tool produces consistent measurements?

Order	Part	Operator	Distance
1	6	4	4.99698
2	11	2	5.01507
3	9	4	4.98424
4	10	3	4.94513
5	5	4	4.98970
6	6	3	5.00964

- Measurement System Analysis

R&R Tests Can Help Identify:

- The measurement system variation compared to the parts variation.
- The largest source of measurement system variation (repeatability or reproducibility).
- The measurement outcomes between the different operators.
- To assess the **precision** of the measurement system.



- Measurement System Analysis

Graphs Used to Evaluate Sources of Variation:

- **Components of variation graph:** Evaluates the contribution of each source of variation on the total variation in the measurement system.
- **X-bar and R chart:** Analyzes part-to-part variation and the repeatability of the measurement system.
- **Comparative plot:** Compares variation by part and by operator.
- **Operator-by-part interaction graph:** Evaluate the differences in the measurements of the parts by each operator.
- **Gauge run chart:** Get an overall picture of measurements made by each operator for each part.

- Measurement System Analysis

- This Gauge R&R table summarizes the sources of variation in the measurement system.

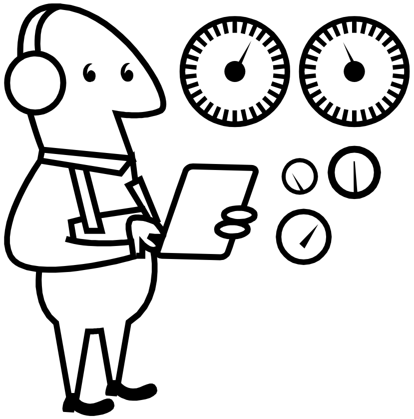
Source	**% Contribution**
Total Gage R&R	55.5
Repeatability	21.4
Reproducibility	34.1
Part to part	44.5
Total Variation	100

- **Question:** According to the numerical output from the Gauge R%R table, is the measurement system precise?
- **Answer:** No, the measurement system makes up 55.5% of the total study variation, it is unacceptable and needs improvement.

- Measurement System Analysis

Fixing Precision Errors:

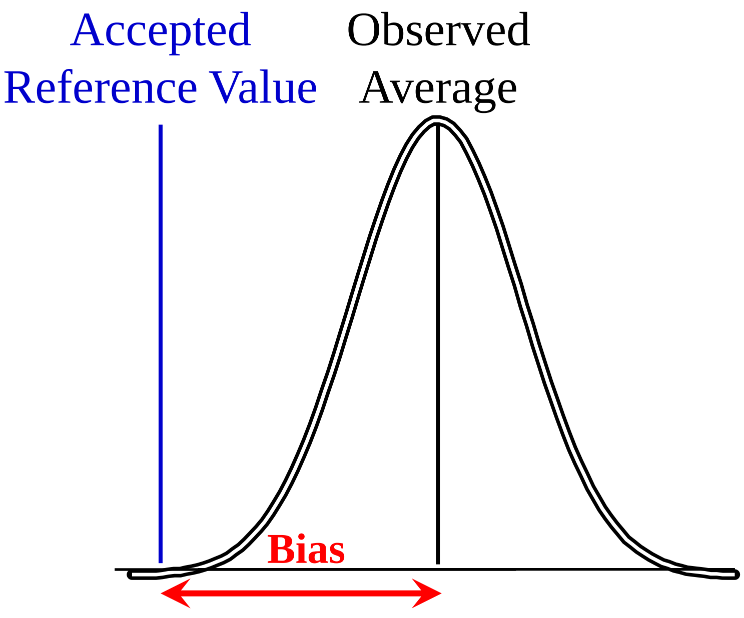
- Developing operational definitions and working standards.
- Training users of measurement system.
- Ensure measurement system is fit for purpose.
- Improving gauge resolution.
- Changing the gauges.



- Measurement System Analysis

Bias (Accuracy):

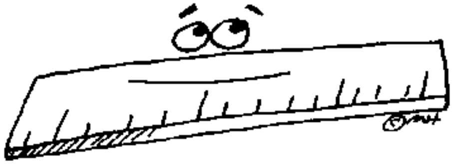
- Indicates how accurately a measuring device records values as compared to a reference value.
- It is the difference between the observed average measured value and the relevant reference value.
- Bias errors do not increase the variation, but do shift the data so that results are higher or lower.
- If possible calibrate to eliminate bias.



- Measurement System Analysis

Bias Examples:

- When your scales are not set up correctly and consistently over estimate your weight by 2 kilos.
- A ruler or a measuring tape that has 3 mm missing from it so it is consistently giving wrong results.



- The start time for resolving a customer complaint is consistently recorded 20 minutes after customer first called.

- Measurement System Analysis

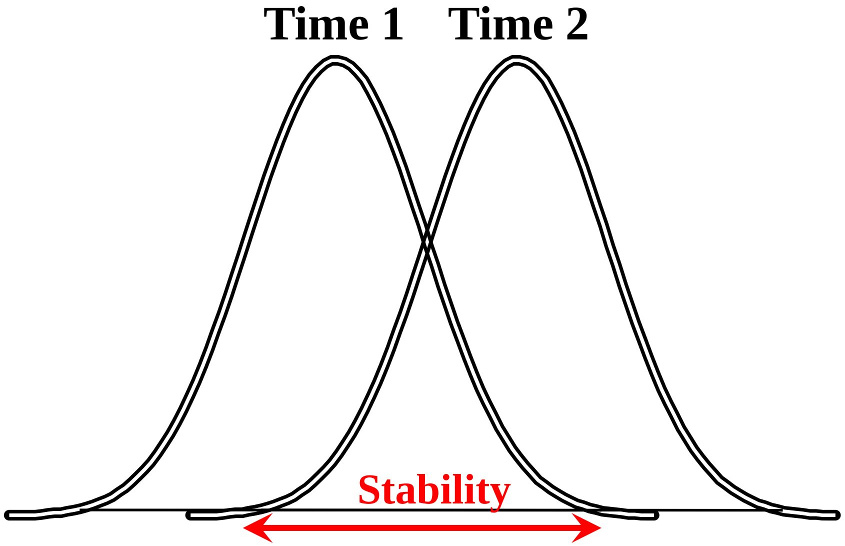
Common Causes for Bias:

- Poor quality or worn equipment, fixture or instrument.
- Wrong gauge.
- Gauge made at the wrong dimensions.
- Instrument out of calibration.
- Measuring the wrong characteristic.
- Incorrect or inadequate method being used.
- Cleanliness and environmental issues.
- Problem with instrument auto-correction.
- Error in reference value.

- Measurement System Analysis

Stability:

- Variation observed between the average of one set of measurement made at one point in time and the same set at a later point in time.
- It's the variation of bias values overtime.
- Stability should be monitored continuously.
- Any changes in bias should be investigated and corrected.



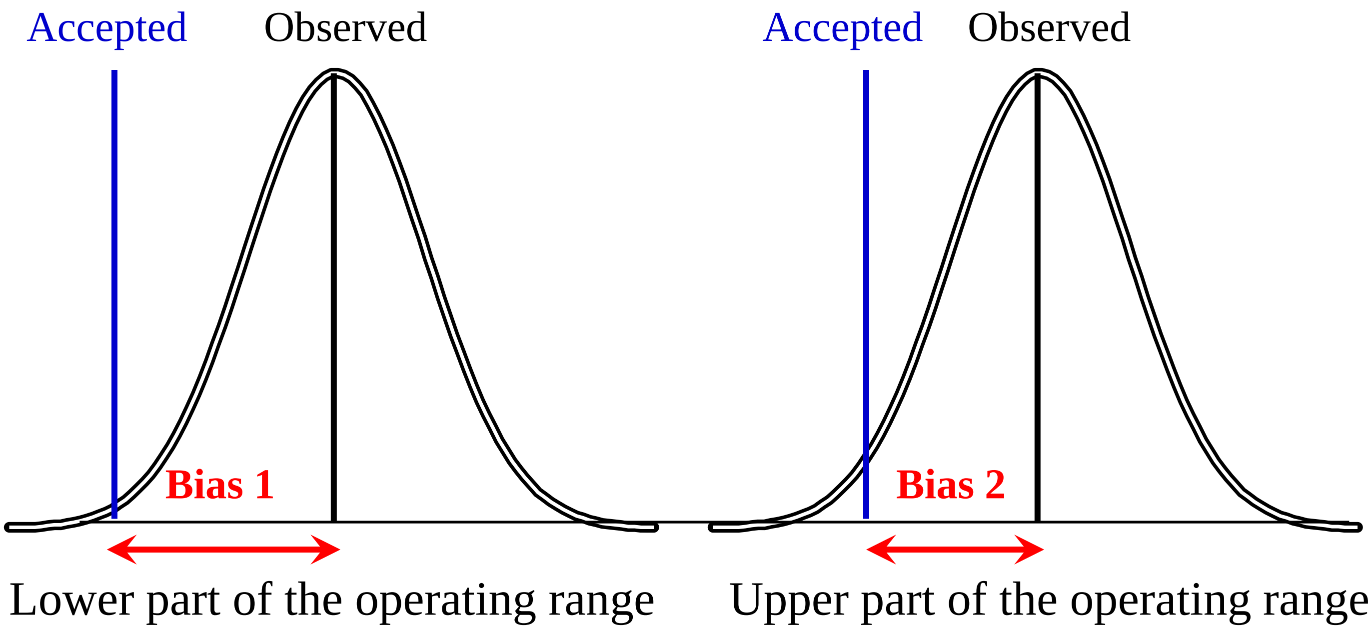
- Measurement System Analysis

Common Causes for Excessive Instability:

- Calibration interval too long.
- Inadequate maintenance or support of equipment.
- Wear or ageing in instrument, equipment or fixture.
- Poor quality or worn equipment, fixture or instrument.
- Error in reference value.
- Incorrect or inadequate method being used.
- Cleanliness and environmental issues.

Linearity:

- Evaluates the linear change in bias over the expected operating range of the measuring device.



Common causes for Non-Linearity:

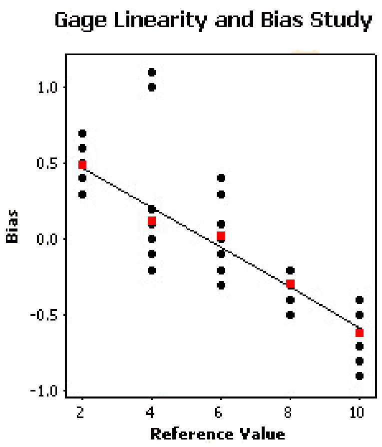
- Instrument out of calibration.
- Poor quality or worn equipment, fixture or instrument.
- Inadequate maintenance or support of equipment.
- Error in reference in one or more of the reference values.
- Incorrect or inadequate method being used.
- Wrong gauge, or made wrong dimension.
- Gauge or part distortion varies with part size.
- Cleanliness and environmental issues.

- Measurement System Analysis

Gauge Linearity and Bias Study:

- Evaluates the accuracy of a measurement system by comparing measurements made by the measurement tool to a set of known reference values.

- **A good measurement system shows:**
  - Little bias.
  - No signs of linearity.
  - Stability overtime.



- Measurement System Analysis

Gage Linearity and Bias Study:

- If there were zero bias, the reference value would be within the confidence intervals.
- 'P' is the probability that we don't have bias.
- If 'P' value is less than 0.05, we can be 95% confident that we have a significant bias.

Gage Linearity

Predictor	Coef	SE Coef	P
Constant	0.18208	0.03150	0.000
Slope	-0.004125	0.004749	0.389

S	0.104040	R-Sq	1.3%
Linearity	0.018562	%Linearity	0.4

Gage Bias

Reference	Bias	%Bias	P
Average	0.157333	3.5	0.000
2	0.170833	3.8	0.000
4	0.158333	3.5	0.000
6	0.171667	3.8	0.000
8	0.154167	3.4	0.004
10	0.131667	2.9	0.001

Is the Level of Bias Not Acceptable?

- Calibrate the measurement system.
- Investigate the common causes for bias.
- Develop, improve and communicate operational definitions.
- Develop, improve and communicate procedures for use of measurement system.
- Train users.
- Use visual standards.
- Limit the allowable operating range of a gauge.

- Measurement System Analysis

Attribute Agreement Analysis:

- Allows for the study of within auditor variation "repeatability" and between appraiser variation "reproducibility".
- It allows to examine the responses from multiple operators as they look at several scenarios multiple times.
- It also allows comparison with a known standard.
- **Used to evaluate:**
  - The individual consistency.
  - The individual accuracy to standard.
- For example, we can rate the quality of operators responding to customers.

Product quality
1. Pass
2. Fail

Rating scale
1. Poor
2. Fair
3. Good
4. Very Good
5. Excellent

- Measurement System Analysis

Example:

Sample	STD	Oper1	Oper1	Oper1	Oper2	Oper2	Oper2	%
1	Fail	Fail	Fail	Pass	Fail	Fail	Fail	83.3
2	Pass	Pass	Pass	Fail	Pass	Pass	Pass	83.3
3	Pass	Pass	Pass	Fail	Fail	Fail	Fail	33.3
4	Fail	Pass	Pass	Pass	Pass	Pass	Pass	0
5	Pass	Pass	Pass	Pass	Pass	Pass	Pass	100
6	Pass	Pass	Pass	Pass	Pass	Pass	Pass	100
7	Fail	Fail	Fail	Fail	Fail	Fail	Fail	100
8	Pass	Pass	Pass	Fail	Pass	Pass	Pass	83.3
9	Pass	Pass	Fail	Pass	Pass	Pass	Pass	83.3
10	Fail	Pass	Pass	Fail	Pass	Pass	Pass	16.3

- Measurement System Analysis

- **Kappa** statistic is a statistical measure for assessing the reliability of agreement for attribute data.
- Kappa ranges from -1 to +1.
- The higher the value of Kappa, the stronger the agreement.
- Perfect agreement (Kappa = 1).
- When Kappa equals to zero, this means that the agreement is the same as would be expected by chance.

- Measurement System Analysis

Our Goal is to Find Out:

- Appraisers agree with themselves.
- Appraisers agree with each other.
- Appraisers agree with the standard.

Within Appraisers

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95 % CI
Brenda	9	9	100.00	(71.69, 100.00)
Erin	9	8	88.89	(51.75, 99.72)
Karen	9	9	100.00	(71.69, 100.00)
Michael	9	9	100.00	(71.69, 100.00)
Robert	9	9	100.00	(71.69, 100.00)

Matched: Appraiser agrees with him/herself across trials.

Between Appraisers

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
Low	0.807692	0.0496904	16.2545	0.0000
Medium	0.542114	0.0496904	10.9098	0.0000
High	0.745455	0.0496904	15.0020	0.0000
Overall	0.697648	0.0352628	19.7842	0.0000

All Appraisers vs Standard

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
Low	0.871429	0.105409	8.2671	0.0000
Medium	0.721239	0.105409	6.8423	0.0000
High	0.835554	0.105409	7.9268	0.0000
Overall	0.811071	0.074950	10.8216	0.0000

Visual Defect Measurement Systems: