Measurement System Analysis

Become Future Fit

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You will learn

Role of Measurement Variation

Types of Measurement System Analysis

Level of Difficulty

Medium

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Measurement System Analysis

Considered as a tool relevant only to manufacturing

Quick Check:

- Is there any data collection happening?
- Is the source providing you correct data?
- Is anyone handling the data causing variation?
- Is there an agreement on the definition of the data?

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At times, automated Data Source, can be a Curse!

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$$\sigma^2_{Observed\ Process} = \sigma^2_{Actual\ Process} + \sigma^2_{Measurement\ System}$$

$$\sigma^2_{Measurement\ System} = \sigma^2_{Repeatability} + \sigma^2_{Reproducibility}$$

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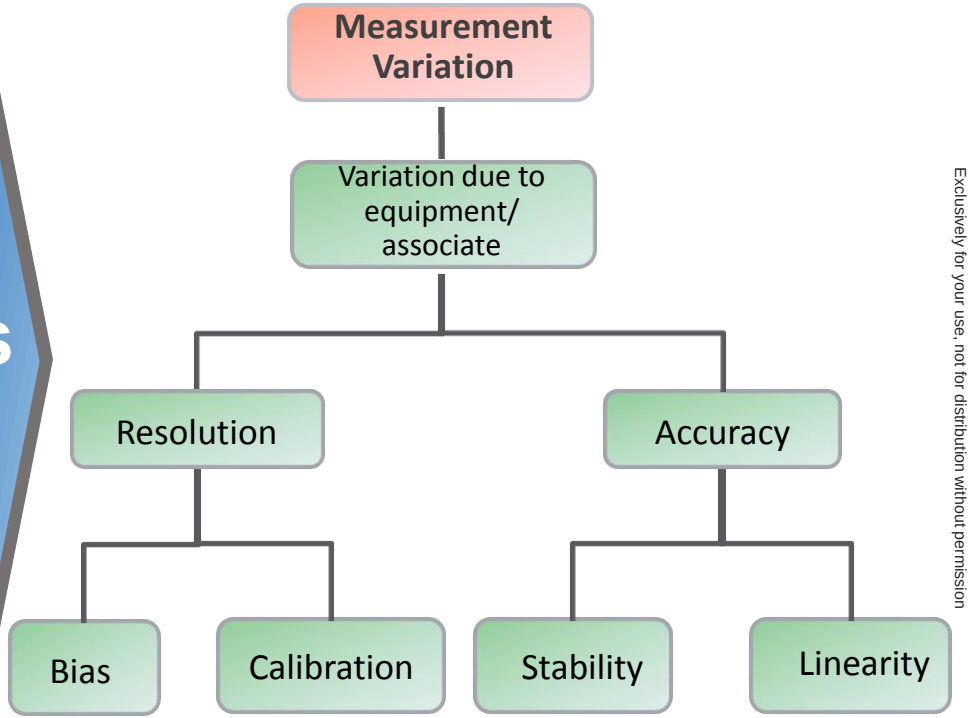
Measurement Attributes



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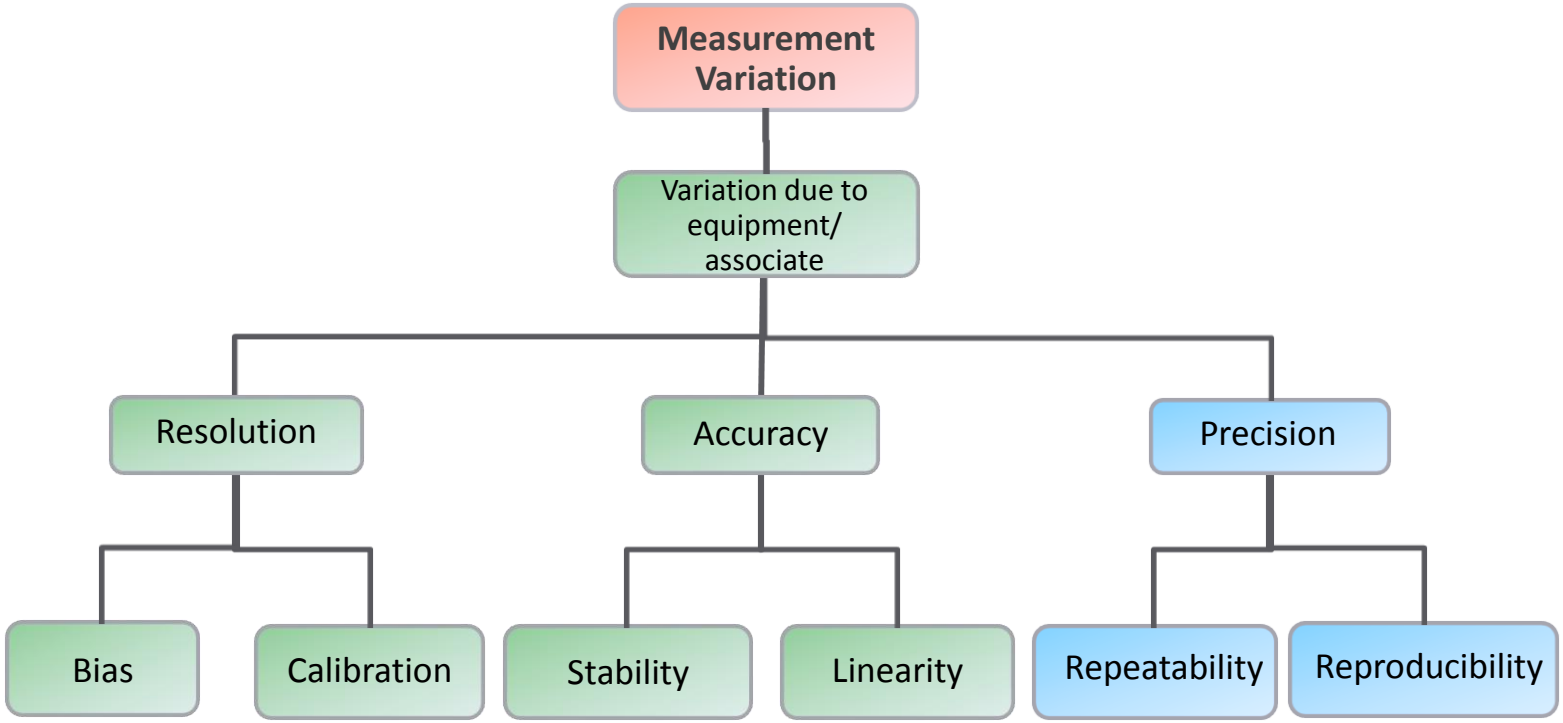
Measurement Attributes



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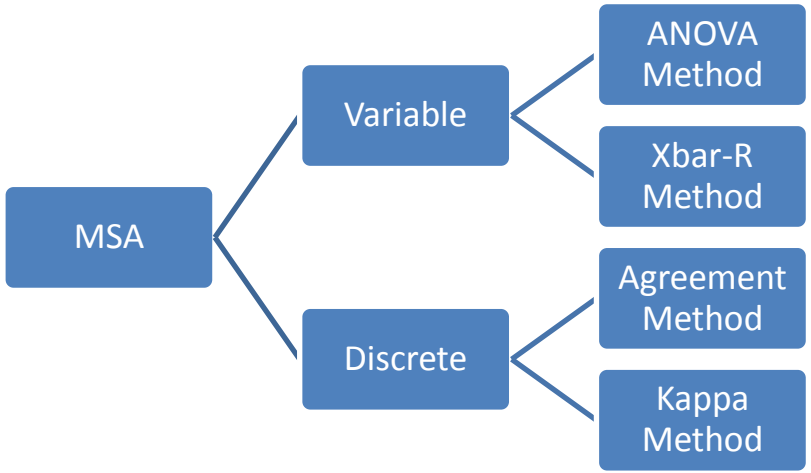
Types of MSA



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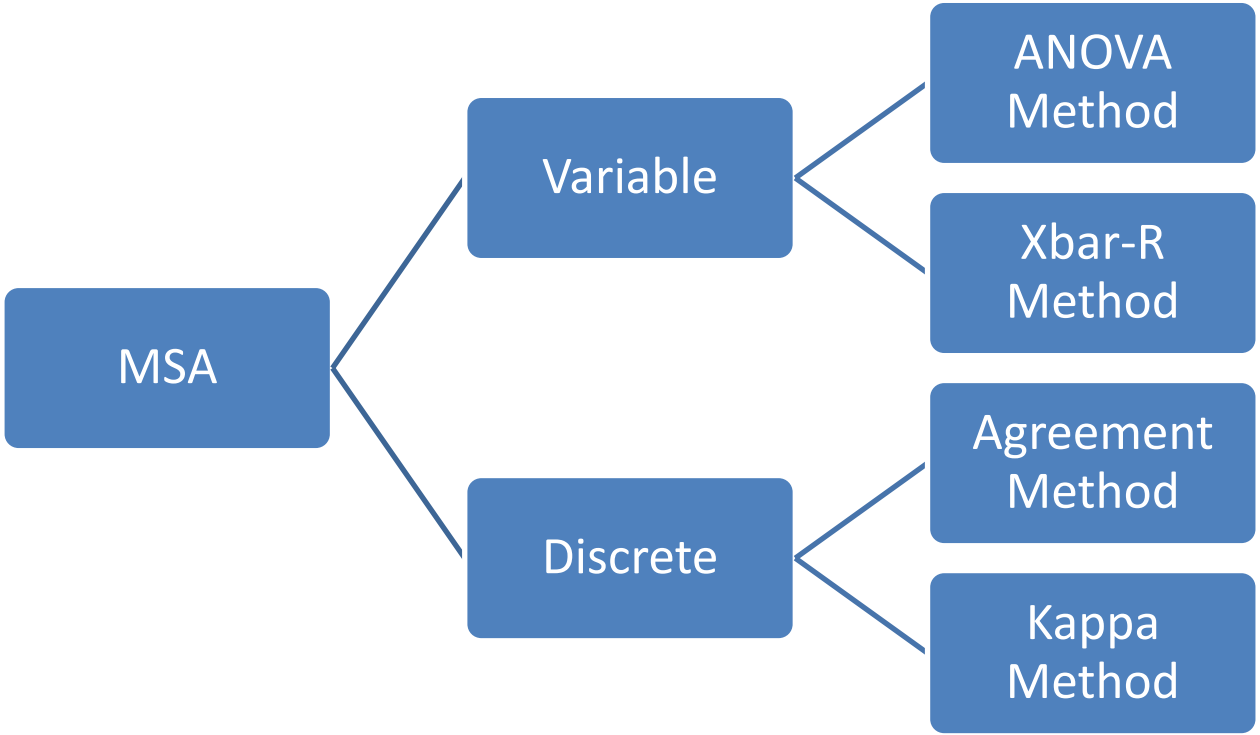
Types of MSA



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Variable MSA Overview

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You will learn

Understand Variable MSA (ANOVA method) in detail

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Level of Difficulty

High

Measurement of Weight

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- There are field complaints about variation in weight of packets of fruit drink. Currently fruit drink packets are filled by automated machines and manually sampled by 3 Quality Control personnel using weighing gages. They are the gatekeepers for quality.
- In order to ensure that the measurement system which consist of the weighing gage, samples, appraiser & environment, all are consistent & produce precise measurement, a continuous GR&R is performed.
- Process tolerance is 800 gms and 900 gms
- 10 samples are collected & given to 3 appraisers at different points in time for measurement. In the same manner, there are 2 trials performed.

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Continuous MSA

- Wrong data measurement means wrong data & so wrong decisions
- Validates the overall effectiveness of people in using a measurement system, as well as precision of measurement system
- Upkeeping quality standards

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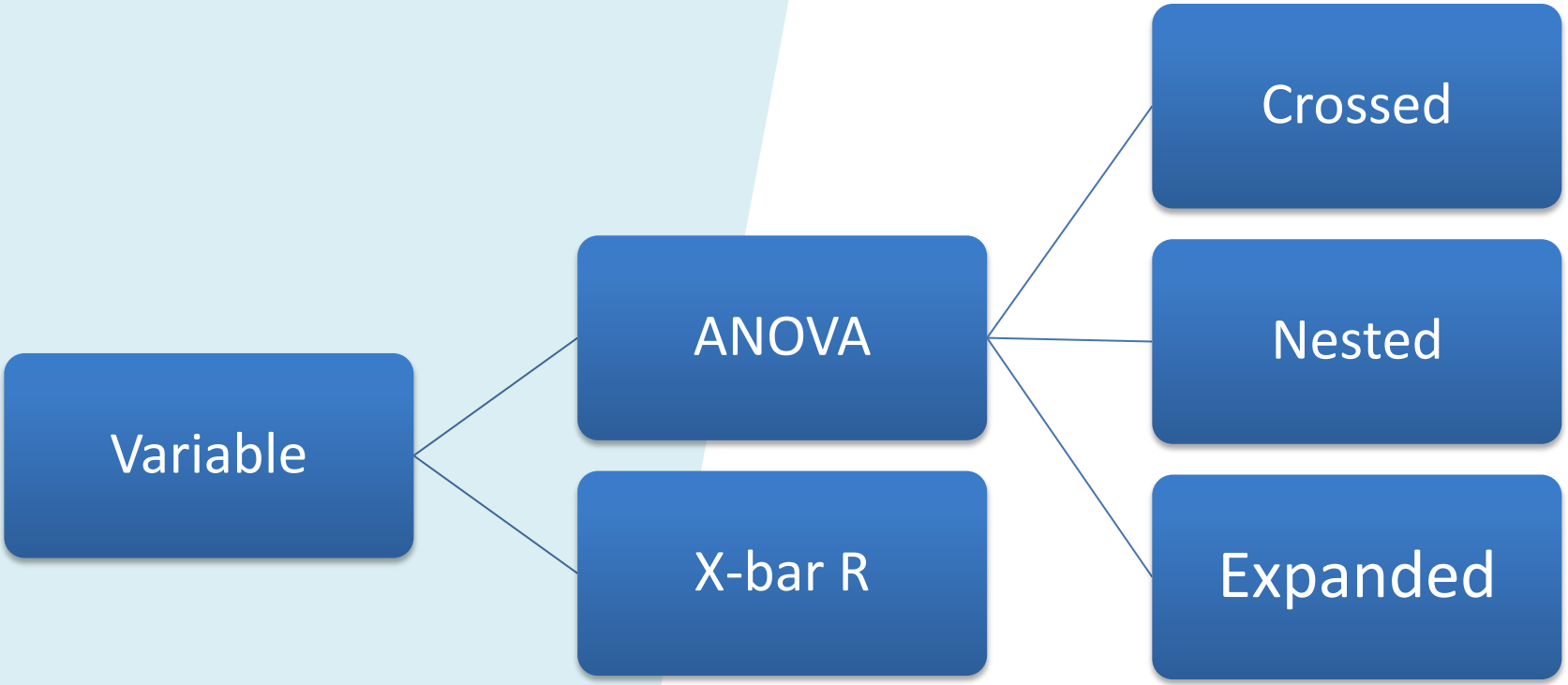
Variable MSA



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Xbar-R Gage R&R

- Measures variation between measurements of an operator to assess repeatability
- Cannot calculate Operator-Part variation

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ANOVA Gage R&R

- Uses ANOVA method to study the components of variance
- Estimates of variance are more accurate than Xbar-R method

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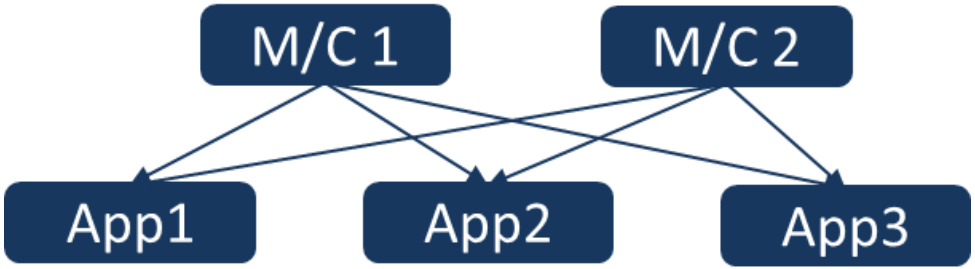
- Each appraiser measures a given part more than once.
- Used to study the contribution of total measurement variation to process variation
- Two factors involved in the study (Machine and Appraiser)



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- Each appraiser measures a given part only once.
- Scenarios involving destructive testing or Machines in different locations.
- Two factors involved in the study (Machine and Appraiser)

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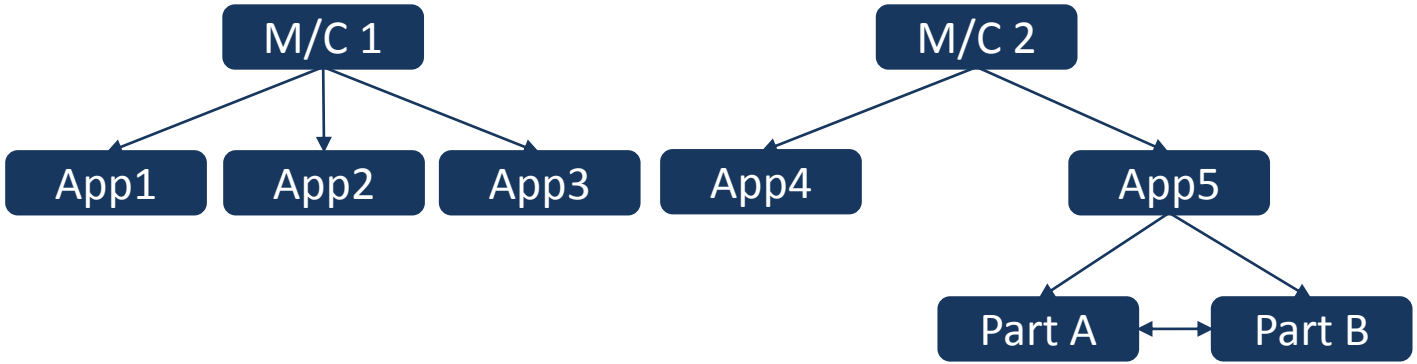

- Design is unbalanced (we don't have equal trials)
- Factors involved in greater than 2 (for example mating parts measurement)

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Understanding Variable MSA terms

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You will learn

Understand the various terms used in

Variable ANOVA GRR

Level of Difficulty

High

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P/TV Ratio

- Addresses the percentage of observed process variation taken up by measurement error
- Is the best estimate of the effect of measurement systems on the validity of process improvement studies
- Includes both repeatability & reproducibility
- **Target for %GR&R < 30%**

$$\%GR\&R = \frac{\sigma_{MS}}{\sigma_{Observed\,Total\,Variation}} x\,100$$

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- Gives contribution of measurement system variability to overall variability
- Also referred to as %TV

- **Best Case: < 1 %.**
- **Marginal Values: Between 1-9 %**
- **Non-acceptable Values: > 9%**

$$\%\text{Contribution} = \frac{\sigma^2 \text{MS}}{\sigma^2 \text{Total}}$$

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- Precision directly proportional to measurement system variation
- Usually taken as 6 times the variation (but traditionally 5.15 times – 99%)

$$P = 6 \times \sqrt{\sigma^2_{MS}}$$

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- Precision to Tolerance Ratio (P/T)
- Addresses the percentage of tolerance taken up by measurement error
- Includes both repeatability and reproducibility

- **Best case: 10% Acceptable: 30%**

$$P/T = \frac{6 * \sigma_{MS}}{Tolerance}$$

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No. of Distinct Categories

- A measure of the resolution
- Number of distinct categories within the process data that a measurement system can discern
- **Best case: > 4**
- **Acceptable: 3 - 4**

$$No.\ of\ Distinct\ Categories = \frac{\sigma_{Parts}}{\sigma^2_{MS}} \times \sqrt{2}$$

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Performing Variable MSA

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How to perform ANOVA Variable GRR

and interpret the results?

Level of Difficulty

High

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Procedure

- Parts should cover the entire specification range
- Appraisers should be involved daily measurement
- Randomize the order
- Retain the parts/documents even after measurement

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Procedure

Setting up Experiment

Worksheet in Minitab

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Procedure

Collect the data

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Procedure

Running the ANOVA analysis in Minitab

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Minitab Session Output Screen

Gage R&R Study - ANOVA Method

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	9	0.0843958	0.0093773	339.872	0.000
Appraiser	2	0.0003670	0.0001835	6.651	0.007
Part * Appraiser	18	0.0004966	0.0000276	0.840	0.645
Repeatability	30	0.0009855	0.0000328		
Total	59	0.0862450			

α to remove interaction term = 0.05

Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
Part	9	0.0843958	0.0093773	303.691	0.000
Appraiser	2	0.0003670	0.0001835	5.943	0.005
Repeatability	48	0.0014821	0.0000309		
Total	59	0.0862450			

Gage R&R

Variance Components

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0000385	2.41
Repeatability	0.0000309	1.93
Reproducibility	0.0000076	0.48
Appraiser	0.0000076	0.48
Part-To-Part	0.0015577	97.59
Total Variation	0.0015962	100.00

Process tolerance = 0.1

P is the probability that the associated source is not a statistically significant cause of total variation

Here, Part & Appraiser are significant contributors

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Gage R&R Study - ANOVA Method

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	9	0.0843958	0.0093773	339.872	0.000
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Part-To-Part	0.0015577	97.59
Total Variation	0.0015962	100.00

Process tolerance = 0.1

$$\frac{\sigma^2_{MS}}{\sigma^2_{Total}} \%$$

% Contribution should be less than 1% for the Gage to be acceptable

In this case, as % Contribution is 2.4%, the gage is provisionally acceptable

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Gage Evaluation

%GR&R

P/T

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.0062056	0.037234	15.53	37.23
Repeatability	0.0055568	0.033341	13.91	33.34
Reproducibility	0.0027626	0.016576	6.91	16.58
Appraiser	0.0027626	0.016576	6.91	16.58
Part-To-Part	0.0394682	0.236809	98.79	236.81
Total Variation	0.0399531	0.239719	100.00	239.72

%GR&R & P/T should be less than 10% for the Gage to be acceptable

In this case, though the %GR&R is provisionally acceptable, the P/T ratio is higher than 30 %. Hence this gage is not acceptable

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Process tolerance = 0.1

Gage Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.0062056	0.037234	15.53	37.23
Repeatability	0.0055568	0.033341	13.91	33.34
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Appraiser	0.0027626	0.016576	6.91	16.58
Part-To-Part	0.0394682	0.236809	98.79	236.81
Total Variation	0.0399531	0.239719	100.00	239.72

Number of Distinct Categories = 8

No of Distinct Categories

No. of distinct categories should be greater than 4 for the Gage to be acceptable

In this case, this gage is acceptable

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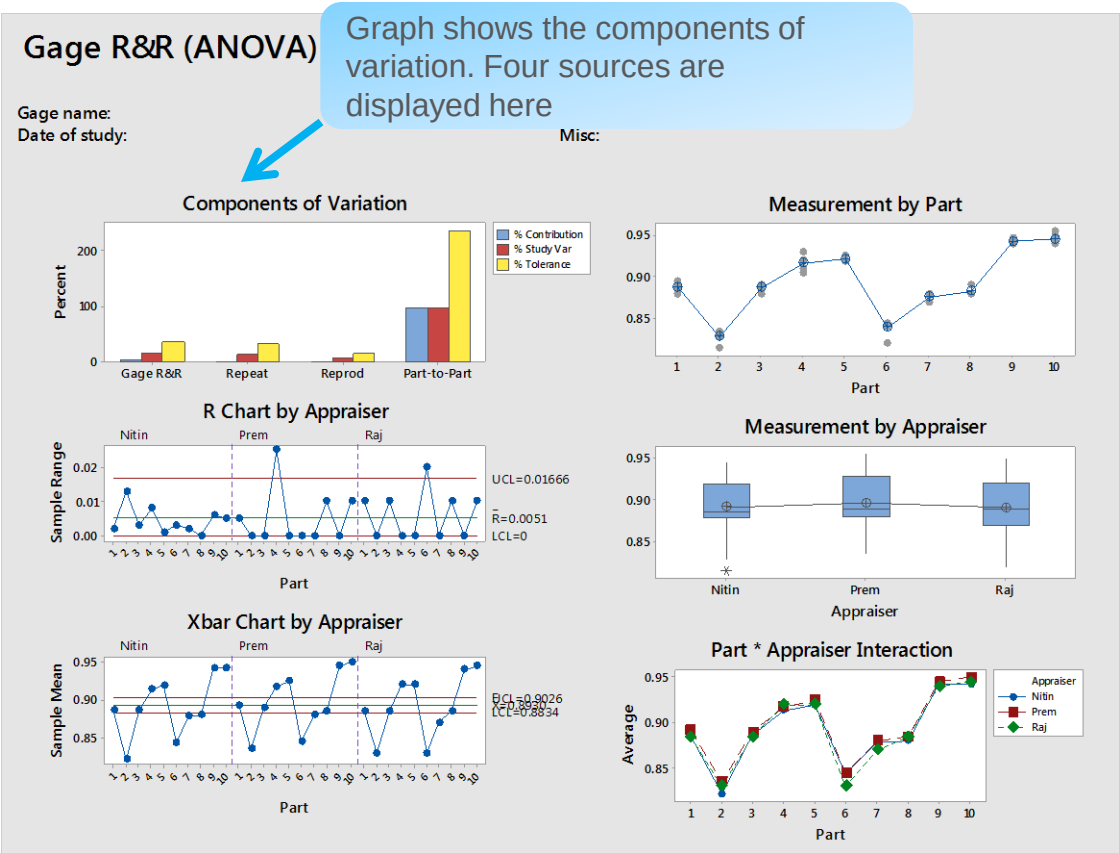
Graph shows the components of variation. Four sources are displayed here



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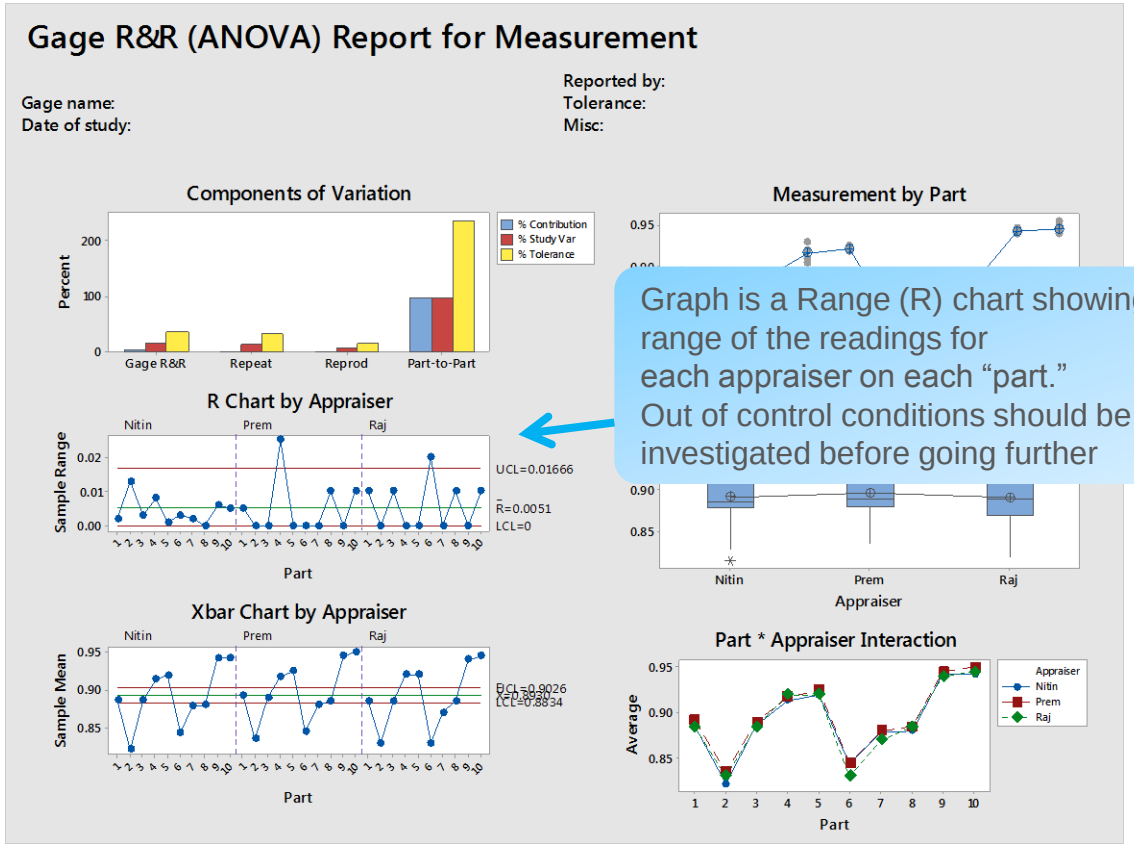

Graph is a Range (R) chart showing the range of the readings for each appraiser on each “part.” Out of control conditions should be investigated before going further

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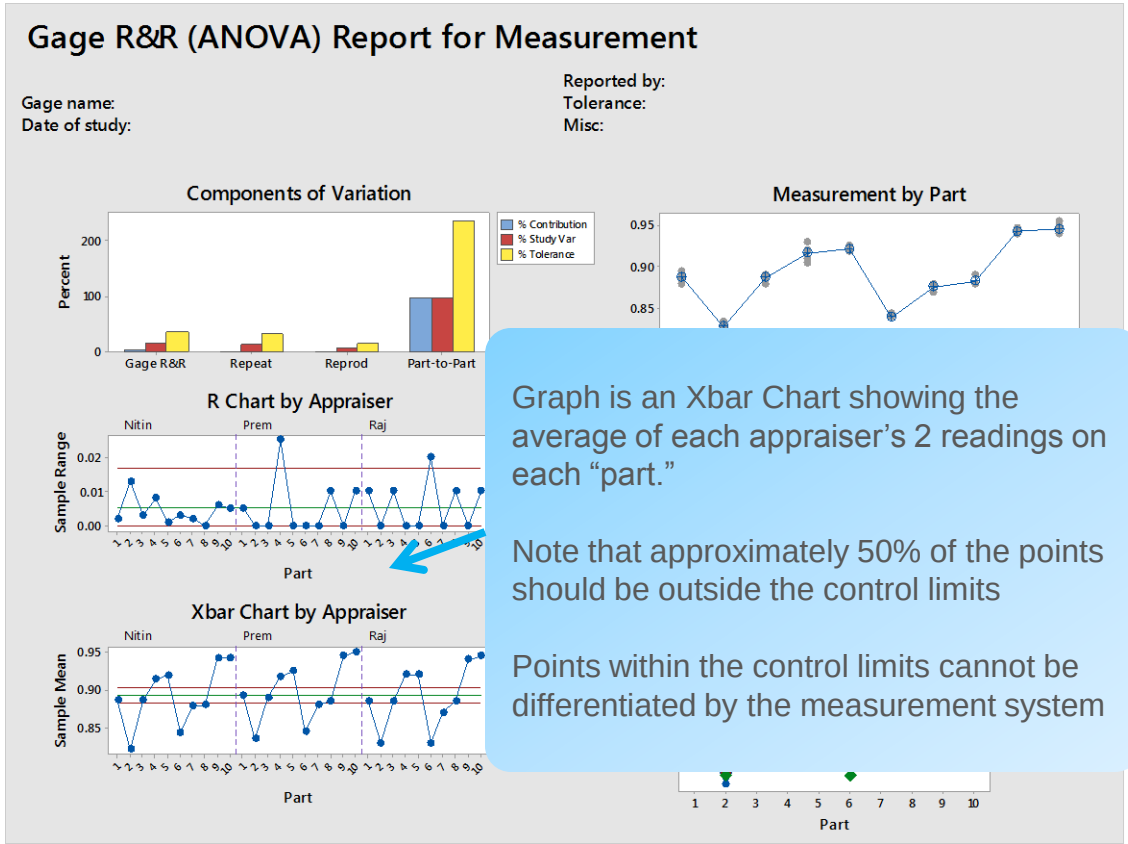

Graph is an Xbar Chart showing the average of each appraiser's 2 readings on each "part."

Note that approximately 50% of the points should be outside the control limits

Points within the control limits cannot be differentiated by the measurement system

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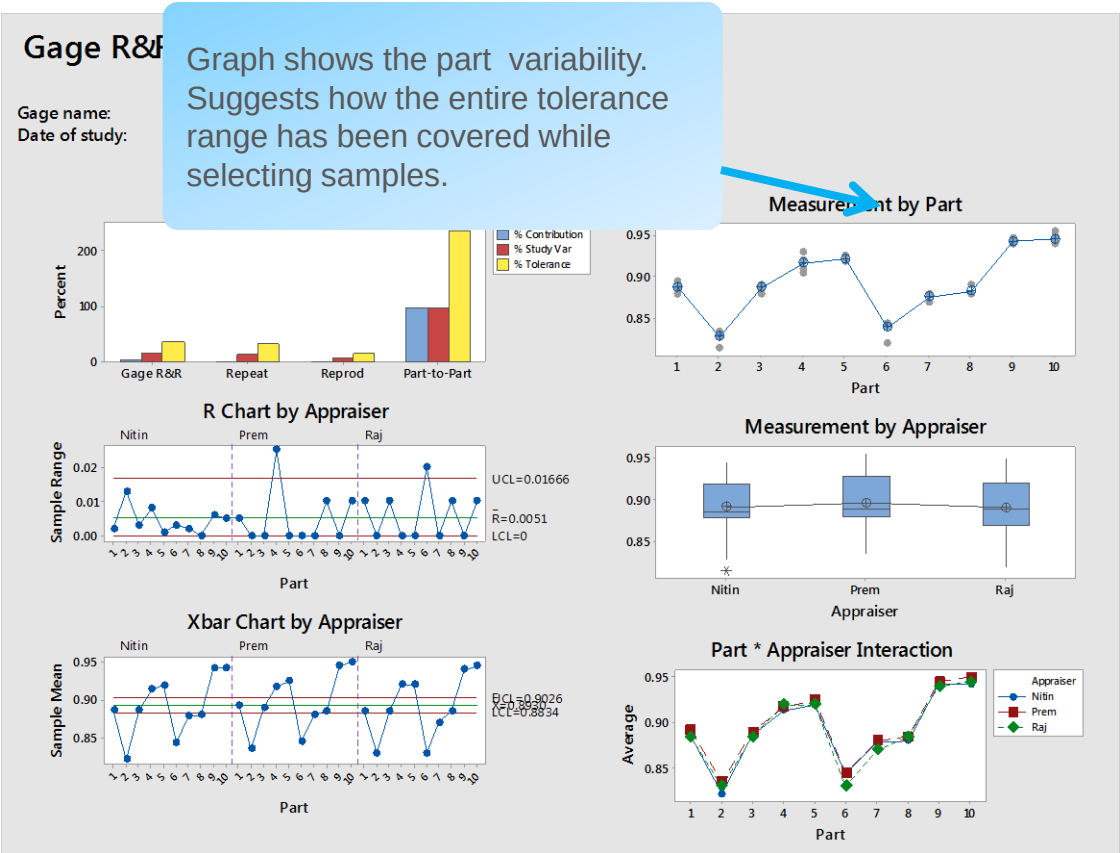
Graph shows the part variability. Suggests how the entire tolerance range has been covered while selecting samples.



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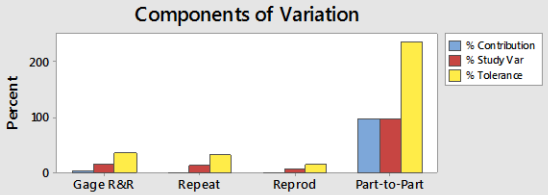
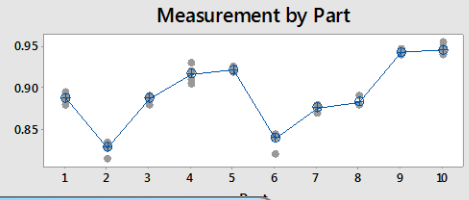
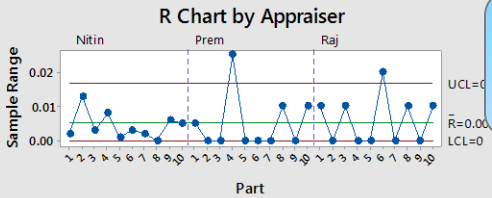
Gage R&R (ANOVA) Report for Measurement

Gage name:
Date of study:

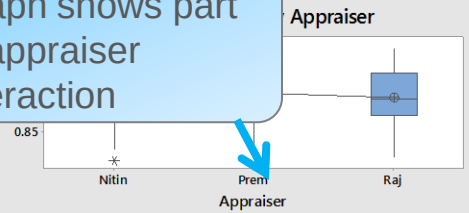
Reported by:
Tolerance:
Misc:

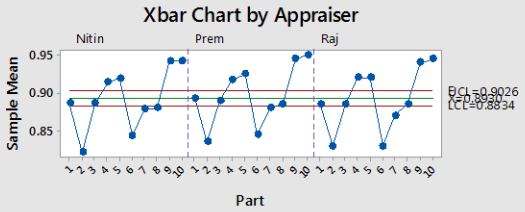


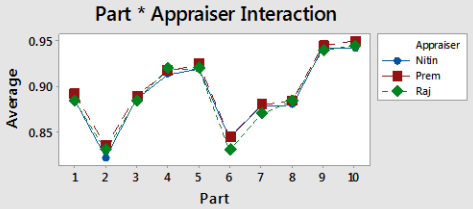


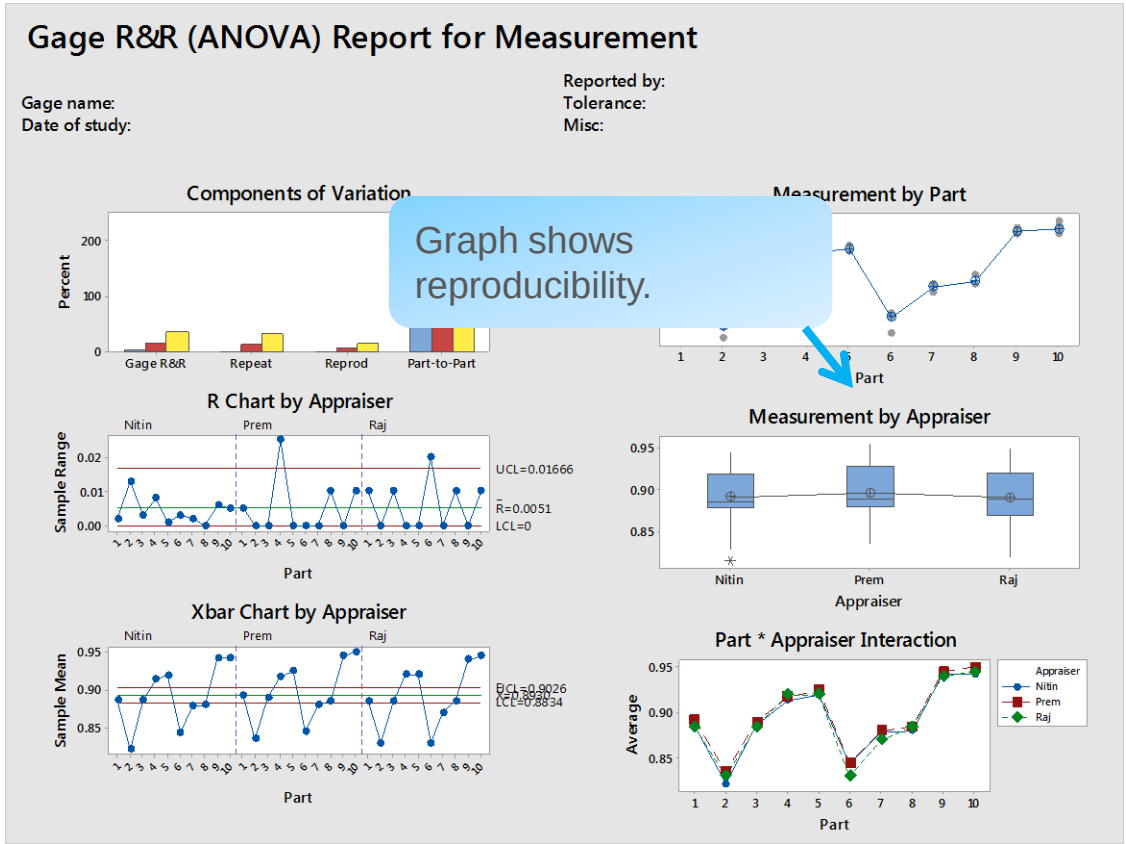


Graph shows part to appraiser interaction









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R&R improvement strategy

1. If a gage is deemed incapable for its application:
    - Team must review design of gage to improve intended application and ability to measure critical steps correctly
2. If recalibration is required – recalibration steps should be followed
3. If Equipment Variation is large compared to Appraiser Variation:
    - Instrument needs maintenance – gage should be redesigned
    - Location for gaging needs improvement
    - Excessive within-part variation
4. If Appraiser Variation is large compared to Equipment Variation:
    - Inadequate training on gage
    - Calibrations are not effective
    - Fixture may be needed to help use the gage more correctly

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Discrete MSA – Agreements & Kappa

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You will learn

Learn to perform discrete MSA using

Agreement & Kappa Method

Level of Difficulty

High

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Transactions are received and grouped as ‘complete’ or ‘incomplete’ based on the details it contains to process it.

A team of reviewers usually classify them and forward it to respective teams. If done incorrectly, the processing teams would face delivery & capacity issues.

Two reviewers are put through Discrete GRR Evaluation.

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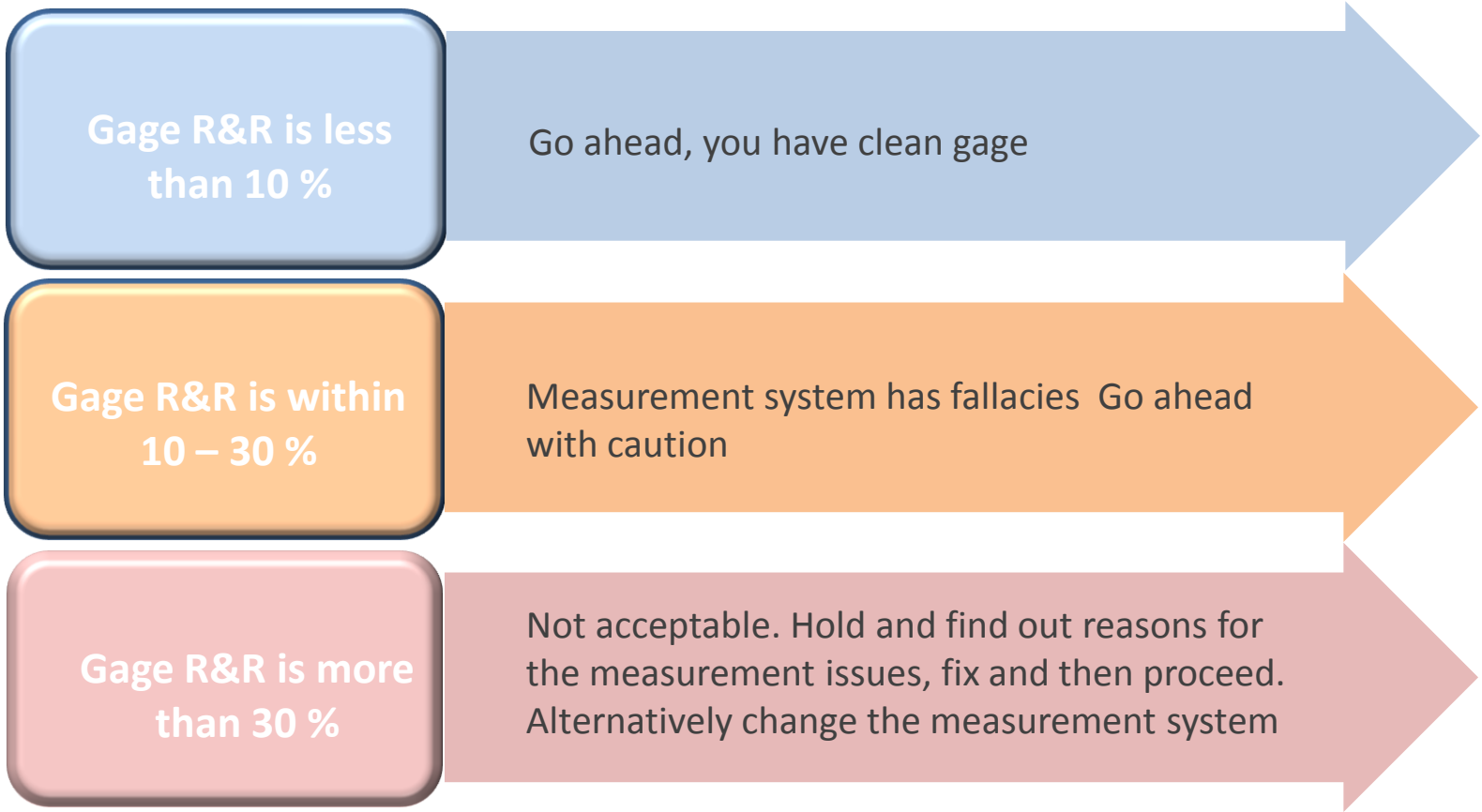
Criteria for Discrete MSA



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Transactions are grouped received and grouped into 3 buckets (High, Medium and Low) based on the time it would take to process it.

A team of reviewers usually classify them and forward it to respective teams. If done incorrectly, the processing teams would face delivery & capacity issues.

Two reviewers are put through Discrete GRR Evaluation.

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Cohen's Kappa

Canopus Business Management Group

- Kappa Coefficient measures the agreement between the evaluations of two appraisers when both are rating the same object.
- It is the ratio of the proportion of times that the appraisers agree (corrected for chance agreement) to the maximum proportion of times that the appraisers could agree (corrected for chance agreement).

- **(Cohen's) kappa Computation :**

$$kappa = \frac{p_o - p_e}{1 - p_e}$$

Actual Agreement p_o = the sum of the observed proportions in the diagonal cells

Chance Agreement p_e = the sum of the expected proportion in the diagonal cells

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Kappa Interpretation

Kappa values range from –1 to +1.

Kappa Value	Interpretation
= 1.00	Indicates perfect agreement
> 0.75	Indicates good to excellent agreement
< 0.4	Indicates poor agreement
= 0.00	Indicates no agreement

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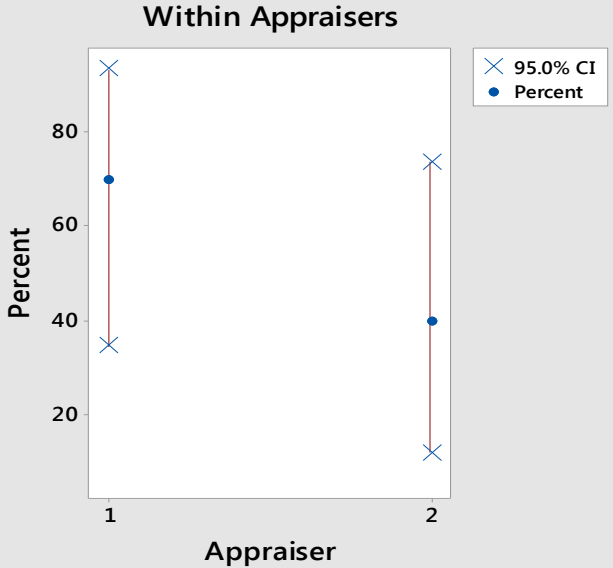
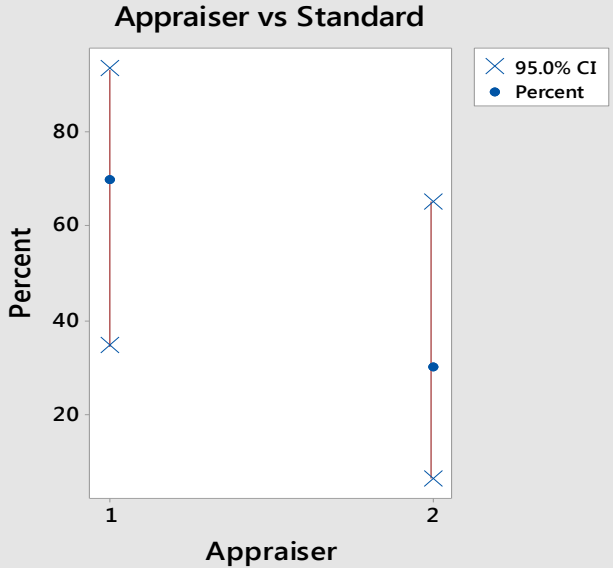
Assessment Agreement

Date of study:
Reported by:
Name of product:
Misc:





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Within Appraisers

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
1	10	7	70.00	(34.75, 93.33)
2	10	4	40.00	(12.16, 73.76)

 # Matched: Appraiser agrees with him/herself across trials.

Cohen's Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
1	High	0.545455	0.281672	1.93649	0.0264
	Low	0.545455	0.281672	1.93649	0.0264
	Medium	0.583333	0.316228	1.84466	0.0325
	Overall	0.558824	0.207139	2.69782	0.0035
2	High	0.200000	0.289828	0.69007	0.2451
	Low	-0.086957	0.308665	-0.28172	0.6109
	Medium	0.285714	0.221313	1.29099	0.0984
	Overall	0.130435	0.195572	0.66694	0.2524

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Each Appraiser vs Standard

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
1	10	7	70.00	(34.75, 93.33)
2	10	3	30.00	(6.67, 65.25)

 # Matched: Appraiser's assessment across trials agrees with the known standard.

Cohen's Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
1	High	0.759725	0.216996	3.50110	0.0002
	Low	0.542334	0.216996	2.49928	0.0062
	Medium	0.791667	0.223607	3.54044	0.0002
	Overall	0.696970	0.156582	4.45115	0.0000
2	High	0.123810	0.214476	0.57726	0.2819
	Low	0.435818	0.220949	1.97248	0.0243
	Medium	0.434524	0.192989	2.25154	0.0122
	Overall	0.334651	0.148880	2.24778	0.0123

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Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
10	2	20.00	(2.52, 55.61)

 # Matched: All appraisers' assessments agree with each other.

Cohen's Kappa Statistics

You must have two appraisers and single trial per appraiser to compute kappa.

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All Appraisers vs Standard

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
10	2	20.00	(2.52, 55.61)

 # Matched: All appraisers' assessments agree with the known standard.

Cohen's Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
High	0.441767	0.152551	2.89587	0.0019
Low	0.489076	0.154843	3.15852	0.0008
Medium	0.613095	0.147686	4.15134	0.0000
Overall	0.515810	0.108032	4.77463	0.0000

Attribute Agreement Analysis

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