MEASUREMENT SYSTEMS ANALYSIS AND A STUDY OF ANOVA METHOD

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Abstract

Instruments and measurement systems form the base of any process improvement strategies. The much widely used QC tools like SPC depends on sample data taken from processes to track process variation which in turn depends on measuring system itself. The purpose of Measurement System Analysis is to qualify a measurement system for use by quantifying its accuracy, precision, and stability and to minimize their contribution in process variation through inherent tools such as ANOVA. The purpose of this paper is to outline MSA and study ANOVA method through a real-time shop floor experiment.

Keywords: *SPC, Accuracy, Precision, Stability, QC, ANOVA*

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1. INTRODUCTION TO MSA

Various shops use measurement to produce data to prepare various control charts x-bar, R charts, X-MR charts, np, p or c charts.

Now these charts are only as accurate as the measured data i.e. People and tools engaged in SPC process, similar is the case with DOE methods or acceptance sampling, or inspection methods.

MSA(measurement systems analysis) is a tool to clarify these doubts regarding reliability of measuring systems by qualifying these systems by calculating error if any like accuracy , precision, stability in them so that their contribution in overall variation can either be accounted for or minimized.

2. TYPES OF MEASUREMENT SYSTEM VARIATIONS

Measurement system variations can be laid out as follows:

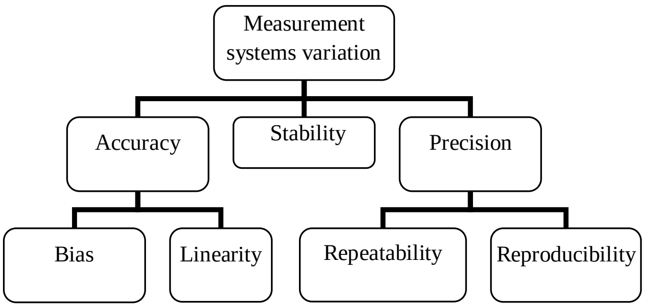


Fig 2.

2.1 Accuracy

It denotes how close instrument's average value is to true value (i.e. it represents the closeness of observed value to the true value).

Concept of accuracy incorporates concept of bias, And both require pre knowing of true value.

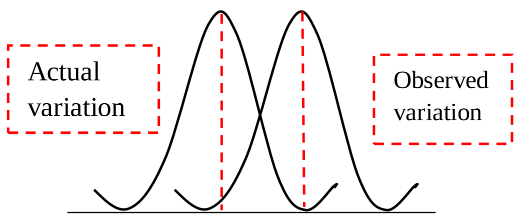


Fig 2.1

2.2 Bias

In measurement or sampling situation, bias is "the difference between a population mean of measurement and true value". Bias leads to an under or over estimate of true value.

Measurement bias is mainly due to faulty measuring device or procedures and it doesn't disappear away by increasing samples.

Sampling bias occurs mainly due to under representative sampling of target data pool and cannot be decreased by increased sampling either.

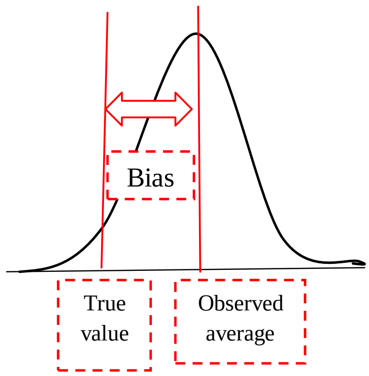


Fig 2.2

2.3 Precision

It refers to degree of closeness between repeated measurements taken from the same system in unchanged conditions.

It is the opposite of variance/ variability and unlike bias its magnitude only depends on observed (measured) value and is independent of true value.

If a system has precision error it creates spread error in result of measurements.

2.4 Stability

Stability refers to degree of measure to which system can produce same mean over extended periods of time with no variation using the same gauge and appraiser to repeatedly measure the same part.
In SPC It can be determined using control charts (X bar and R chart), given the appraiser measure the same way as others over an extended period of time meaning absence of "special cause" variation.

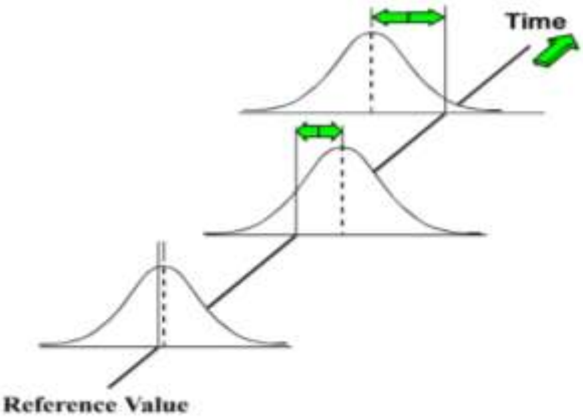
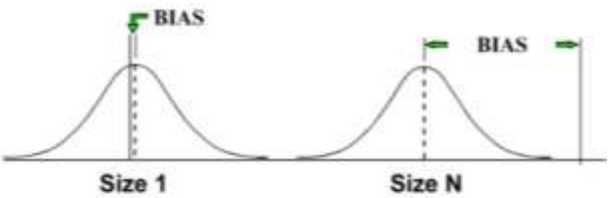


Fig 2.4 Stability/ Alias -Drift 1

2.5 Linearity

It is the measure of consistency of bias over range of measuring device.
for e.g. if a measuring scale is biased by 1 mm when measuring 10 cm but is off by 3 mm when measuring 40 cm , it means the scale bias is non- linear.



2.6 Repeatability

It refers to the variation in measurements obtained when one measuring instrument is used several times by an appraiser while measuring identical characteristics of the same part.

The trials must be successive under fixed and defined conditions. It is often Referred to as EV (equipment variation), instrument capability or within system variation.

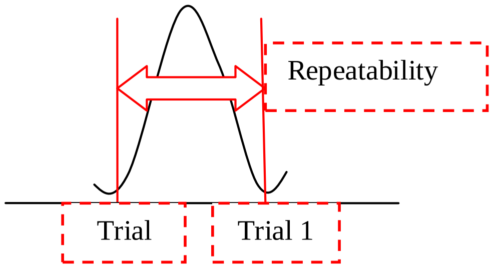


Fig 2.6

2.7 Reproducibility

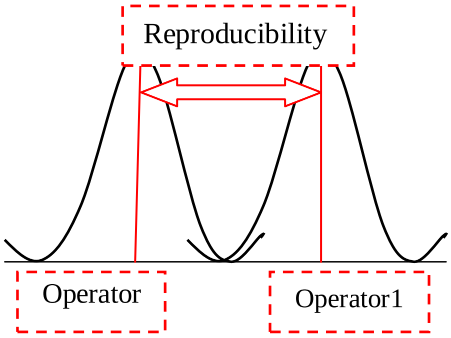
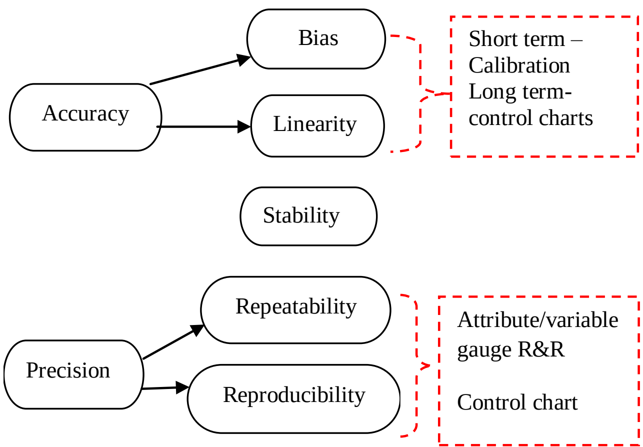


Fig 2.7

It is the difference in mean of measurements made by different appraiser using same instrument, while measuring identical characterestics of same part.
Referred to as AV (appraiser variation) or between system variation.

3. The above measurement system variations can be analyzed and minimized by following methods.



3.1 Calibration

Calibration can be defined as activity of checking accuracy of an instrument of any type by comparing to a standard which may also include adjustment of the instrument to bring it in alignment with the standard.

This process can also be extended across operating range of the gauge for its Gauge linearity study.

3.2 Gauge R&R

Gauge R&R is means of assessing the repeatability and reproducibility of a measurement systems.
Depending on the characteristics of the Data it is classified into

1. Variable gauge R&R
2. Attribute gauge R&R

Variable Gauge R&R can be calculated by using 3 methods:
1. Range method
2. Average and range method(X-bar and R)
3. ANOVA method

ANOVA (analysis of variance) method

ANOVA developed by Ronald fisher in 1918 is an extremely important tool used in statistics to test mathematical hypothesis by analyzing variation between different data sets.

In context of MSA, ANOVA is most widely used as it takes into account operator to part interaction which the other methods don't.
It is also preferred for its flexibility and accuracy if appropriate computer program is available.

Due to these advantages we will be focusing on ANOVA method, and its study through an experiment done on Minitab.

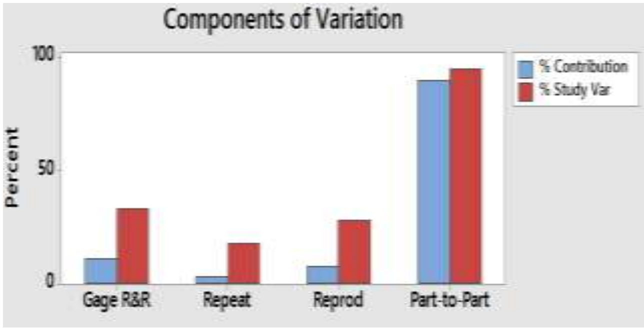
Perquisites for the experiment:

- Minimum of 2 operators although 3 or 4 are recommended
- At least 10 parts should be chosen to represent entire spectrum of manufacturing variation (it may be acceptable to use fewer parts in some special cases)
- Same characteristics of each part should be measured 2 or 3 times in random order.
- Operators should not be aware of previous results when measuring the same part.

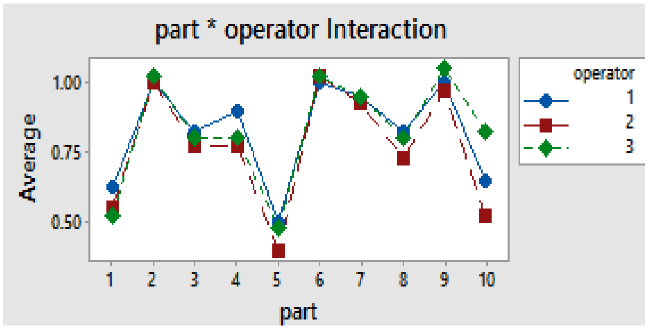
Following is the data taken by 3 operators while measuring side profile curvature of fly wheel housing for Gauge R&R study.

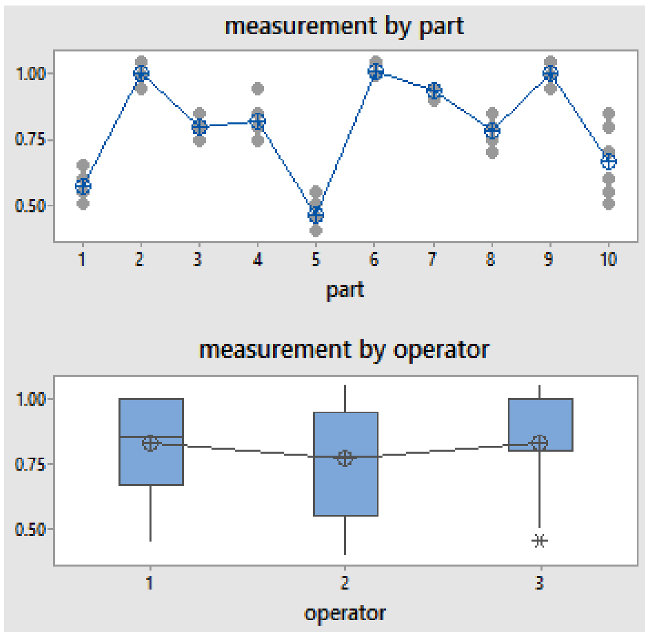
part	Operator 1	Operator 2	Operator 3
1	0.65	0.55	0.50
1	0.60	0.55	0.55
2	1.00	1.05	1.05
2	1.00	0.95	1.00
3	0.85	0.80	0.80
3	0.80	0.75	0.80
4	0.85	0.80	0.80
4	0.95	0.75	0.80
5	0.55	0.40	0.45
5	0.45	0.40	0.50
6	1.00	1.00	1.00
6	1.00	1.05	1.05
7	0.95	0.95	0.95
7	0.95	0.90	0.95
8	0.85	0.75	0.80
8	0.80	0.70	0.80
9	1.00	1.00	1.05
9	1.00	0.95	1.05
10	0.60	0.55	0.85
10	0.70	0.50	0.80

After we analyze above data in Minitab we get following results



Component of variation 1





Measurement by parts- repeatability
Measurement by operator- reproducibility

Two-Way ANOVA Table with Interaction

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Source          DF     SS         MS      p
Part             9  2.05871  0.228745 0.000
Operator         2  0.04800  0.024000 0.033
part*operator   18  0.10367  0.005759 0.000
Repeatability   30  0.03875  0.001292
Total           59  2.24913
```

As P<0.05 so all terms are significant

Gage R&R

```
                                    %Contribution
Source                  VarComp     (of VarComp)
Total Gage R&R        0.0044375            10.67
Repeatability         0.0012917             3.10
Reproducibility       0.0031458             7.56
   Operator           0.0009120             2.19
  Operator*part       0.0022338             5.37
Part-To-Part          0.0371644            89.33
Total Variation       0.0416019           100.00
```

Estimate of variance for each source

```
 Source               StdDev(SD)  (6 × SD)     σR-R
Total Gage R&R         0.066615    0.39969
Repeatability          0.035940    0.21564
Reproducibility        0.056088    0.33653
  Operator             0.030200    0.18120
  Operator*part        0.047263    0.28358
Part-To-Part           0.192781    1.15668
Total Variation        0.203965    1.22379
```

Interpreting the results:

As stated earlier our target has to be to keep measurement system variation (Gauge R&R) as small as possible in total variation.

(σ_T) = total variation (σ_0) = reproducibility

(σ_e)= repeatability $(\sigma_{p\text{-}p})$ = part to part variation

$(\sigma_T) = (\sigma_0) + (\sigma_e) + (\sigma_{p\text{-}p})$

To calculate the % of process tolerance taken up by the measurement system variation, represented by 6x St Deviation of gauge **($\sigma_{R\text{-}R}$)** this is known as %precision/tolerance or %P/T.

$$\%P/T = 100\% \times \frac{6\,\sigma_{R\text{-}R}}{\text{Process tolerance}}$$

% P/T (6 $\sigma_{R\text{-}R}$ /Process Tolerance)	Acceptability of gauge
0 - 10%	Very Good (Six Sigma Gauge)
10 - 30%	May be Acceptable
>30%	Probably Not acceptable

Improving the measuring system

Gauge incapable

Repeatability (Gauge):

- Take multiple measurements and use average(short term fix)
- Mistake proofing (e.g. provision of tooling to hold part during measurement).

Reproducibility (operator):

- Use 1 operator (short term fix during improvement only)
- Have several operators measure the part and take the average (short term fix)
- Ensure consistency (training, SOPs, WIS..)
- Mistake proofing (e.g. provision of tooling to hold part during measurement)
- Calibrations on the gauge dial may not be clear.

Reproducibility Operator x Part Interaction:

- Identify cause of interaction and then as Operator try to minimize or eradicate it.

CONCLUSION

MSA forms an integral part of 6-sigma methodology and is demanded by nearly all of the certification standards.
It is often under taught in industry and done for the sake of requirements which is not the right approach considering the effect a non-qualified measurement system can have on the subsequent processes.
ANOVA method as discussed above can calculate the contribution of measurement system in overall process variation allowing us to take steps to minimize it.

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BIOGRAPHIES

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