Management Science Letters 8 (2018) 201–216

Contents lists available at GrowingScience

Management Science Letters

homepage: www.GrowingScience.com/msl

On the fuzzy evaluation of measurement system analysis in a manufacturing and process industry environment: A comparative study

Kapil Mittal[a*], Puran Chandra Tewari[b] and Dinesh Khanduja[b]

[a]*PhD Research Scholar, National Institute of Technology, Kurukshetra, Haryana, India*
[b]*Professor, National Institute of Technology, Kurukshetra, Haryana, India*

C H R O N I C L E

Article history:
Received: November 26, 2017
Received in revised format: January 31, 2018
Accepted: March 14, 2018
Available online:
March 14, 2018

Keywords:
MSA
Automotive Industry Action Group (AIAG)
Wheeler's Method
ANOVA
Fuzzy TOPSIS

A B S T R A C T

Variation exists in all processes. There is not even a single process that is completely true. Measuring the trueness of the process is itself a process which can also imitate the process variation. Therefore, measurement system should be strong enough to wager on the trueness of the process. This paper is an attempt to indicate the true method and substantiate the use of measurement system analysis (MSA) by using it in two different environments i.e. in manufacturing as well as process industry. Also, a comparison among various analyzing techniques has been drawn for authenticating the candid method followed by an evaluation using fuzzy TOPSIS for authenticating the results of comparison. The organization's type, also, strongly influences the performance of MSA as revealed in the conclusion of the article. The results calculated by various methods and in both environments were discussed and as a result ANOVA comes out to be the best method. The application of correct MSA is highly required which ultimately results in increased organizations' performance. The study is one of its type and will motivate the researchers and industrialists to use and explore the new and efficient ways of MSA.

1. Introduction

Inaccuracies are everywhere and industries too, are not away from it. There are two types of causes for variations: assignable causes (Ex.: faulty design, improper layout, incapable machinery) and chance causes (Ex.: environmental conditions, vibrations, organizational culture). One can work on the assignable causes by finding the root cause and eliminating them but cannot remove chance causes completely. Here comes the importance of providing tolerance to every product and process. But what if the measuring instrument is providing unreal results? The consumer will be supplied with the Not Good (NG) products. This can seriously hamper the organization's reputation as the ultimate goal of customer satisfaction will go in vain.

There are mainly two types of industries: Manufacturing and Process. A manufacturer assembles along in a routine whereas a process manufacturer produces in a batch. Product manufacturing includes producing and assembling the individually produced items (Lots) in a sequence of operations against an

* Corresponding author. Tel.: +91-9896990007
E-mail address: kapilmittal007@gmail.com (K. Mittal)

doi: 10.5267/j.msl.2018.3.001

order whereas the process manufacturing includes batch or continues processes and the operations are of irreversible nature. The working environment of a process industry and manufacturing industry is entirely different. Where in the manufacturing industries, the data available is of discrete nature, in the process industry it is of continuous nature. The nature of data always has a role to play when any type of analysis has to be made out of that data. Here also, in this paper, applying the MSA under both environments was a challenge and required a depictive skill. Till now three mostly used methods of MSA available are the AIAG, Wheeler's and the ANOVA. The objective of the study was to find out the most accurate and easy to use method, which can be applicable to both types of industries. First of all, starting from the basics of MSA, here is the introduction of MSA and gauge Repeatability and Reproducibility (R&R).

1.1 Measurement System Analysis

MSA is a scientific and objective method of analyzing the validity of a measurement system. It is a systematic discipline (Jones, 2013) & a tool that quantifies equipment variation, appraiser variation & the total variation of a measurement system. To address actual process variability, the variation due to the measurement system must first be identified and separate out from the process (Göndör & Koczor, 2010). It is required to be sure that measurement system function independently and correctly 100% of time; otherwise, there is a risk of flaws in data. MSA can be and should be applied to each and every process because bad measurement system can cause to scrap good products and ship bad products. The possible types of variations and their check are as shown in Fig 1.

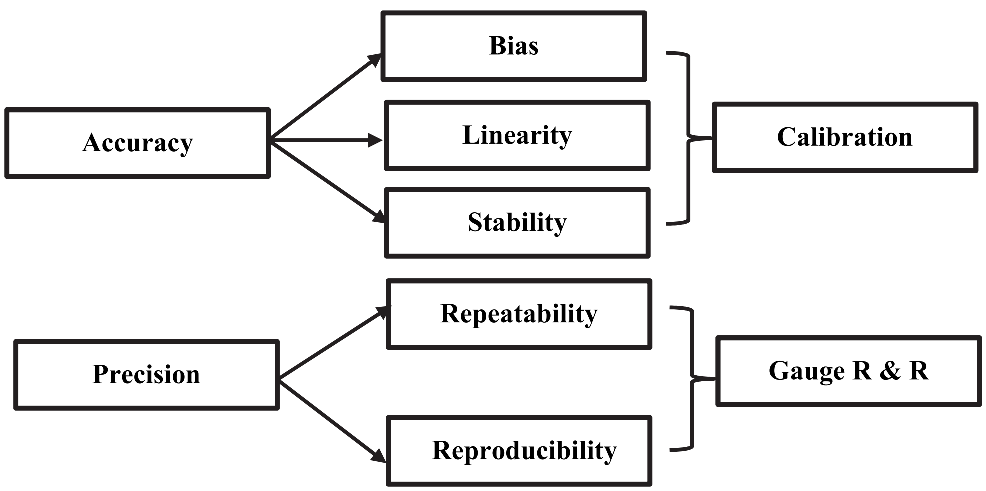

Fig. 1. Types of variations (The British Standards Institution 2008, MSA/Issue 1.3/July 2008)

1.2 Gauge Repeatability & Reproducibility Study

Gauge R&R 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 (Kaushik et al., 2012; Smith et al., 2007). The purpose of gauge R&R study is to ensure that measurement system is sound. When measuring the product of any process, there are two sources of variation: the variation of the process itself and the variation of the measurement system. The purpose of conducting the gauge R&R is to be able to distinguish the former from the latter, and to reduce the measurement system variation if it is excessive (Zanobini et al., 2016). The measurement error is one of the most important yet overlooked and misunderstood aspects of any measurement process (Hajipour et al., 2013). When implementing any statistical method that relies on data, it is important to be sure that the systems collect that data accurately and precisely & follow the real conditions (Kooshan, 2012). For measurement systems that result in quantitative measurements such as weight, concentration, or strength, it is important to determine the magnitude of any error in the resulting measurements (Dearden, 2014). Gauge repeatability and reproducibility analysis addresses the issue of precision and accuracy of measurement (Awad et al., 2009). The purpose of repeatability and reproducibility experiments is to determine the proportion of measurement variability that is due to

(1) The items or parts being measured (part-to-part variation),
(2) The operator or appraiser of the gauges (reproducibility), and
(3) Errors (unreliability's) in the measurements over several trials by the same operators of the same parts (repeatability).

In the ideal case, all variability in measurements will be due to the part-to- part variation, and only a negligible proportion of the variability will be due to operator reproducibility and trial-to-trial repeatability.

2. Different Methods of Analysis

2.1 Automotive Industries Action Group (AIAG) Method

The AIAG was founded in 1982 and publishes a no. of documents including the MSA manual, in which various steps of the analysis process are described. Also it provides some of the tables carrying the values for different constants/Correction Factors (d2, D4 and d2*) used during the calculation. Various step followed under this method are as follows:

1. Find the Average range and corresponding Upper range limit (URL). None of the ranges in the tab le should exceed this limit.

$$\mathrm{URL} = \mathrm{D_4} * \overline{\mathrm{R}}$$

   Use D_4=3.27 for 2 trials
   D_4= A Constant depends upon no. of trials or subgroups
2. Next step is to find the Repeatability or the Equipment Variation (EV).

$$\mathrm{EV} = \frac{\overline{\mathrm{R}}}{\mathrm{d_2}}$$

   Use d_2= 1.128 for 2 trials
   d_2= Bias Correction Factor for Estimating Standard Deviation
3. Next step is to find the Reproducibility or Appraiser Variation (AV)

$$\mathrm{AV} = \sqrt{\left[\frac{\mathrm{R_0}}{\mathrm{d_{2^*}}}\right]^2 - \frac{\mathrm{o}}{\mathrm{nop}}\mathrm{EV}^2}$$

   where
   R_0 is the range of the operators' averages
   d_{2^*}=1.91 for subgroup size 3
   d_{2^*}= Bias Correction Factor for estimating the range
   o is the no. of operators
   p is the no. of parts
   n is the no. of trials
4. Find the Combined Repeatability and Reproducibility (Gauge R&R) in next step using the formul a as:

$$\mathrm{GRR} = \sqrt{\mathrm{EV}^2 + \mathrm{AV}^2}$$

5. In the next step Product Variation (PV) is estimated using the formula:

$$PV = \frac{R_p}{d_{2^*}}$$

where
R_p is the range of the Part Averages
d_{2^*}=2.48 for the subgroup size 5

6. Finally, the Total Variation (TV) is estimated by using the formula:

$$TV = \sqrt{EV^2 + AV^2 + PV^2}$$

7. Find the % Equipment Variation

$$\%EV = \frac{EV}{TV} * 100$$

8. Find the % Appraiser Variation

$$\%AV = \frac{AV}{TV} * 100$$

9. Find the % Gauge Repeatability and Reproducibility

$$\%GRR = \frac{GRR}{TV} * 100$$

10. Find the % Product Variation

$$\%PV = \frac{PV}{TV} * 100$$

2.2 Wheeler's Method

This method was suggested by Donald J Wheeler in 2009 (Wheeler, 2009). The method is a modification of the AIAG method and uses proportions in place of percentage as used in AIAG method. Also the method is a corrected version of AIAG in statistical and trigonometric terms. The various constants/correction factors used are same as used in the previous section. Various step followed under this method are as follows:

1 Find the Average range and corresponding Upper control limit**.** None of the ranges in the Table should exceed this limit.

$$URL = D_4 * \bar{R}$$

2 Find the Repeatability variance component ($\hat{\sigma}_{pe}^2$) using formula as:

$$\hat{\sigma}_{pe}^2 = \left[\frac{\bar{R}}{d_2}\right]^2$$

3 Find the Reproducibility variance component ($\hat{\sigma}_o^2$) using formula as:

$$\hat{\sigma}_o^2 = \left\{\left[\frac{R_o}{d_2^*}\right]^2 - \frac{o}{nop}\hat{\sigma}_{pe}^2\right\}$$

4 Find the Combined Repeatability and Reproducibility Variance Component ($\hat{\sigma}_e^2$)

$$\hat{\sigma}_e^2 = \hat{\sigma}_{pe}^2 + \hat{\sigma}_o^2$$

5 Find the Product Variance Component ($\hat{\sigma}_p^2$)

$$\hat{\sigma}_p^2 = \left[\frac{R_p}{d_2^*}\right]^2$$

6 Find the Total Variance Component ($\widehat{\sigma}_x^2$) by adding 4 and 5.

$$\widehat{\sigma}_x^2 = \widehat{\sigma}_p^2 + \widehat{\sigma}_e^2$$

7 Find the Repeatability Proportion

$$\text{Repeatability Proportion} = \frac{\widehat{\sigma}_{pe}^2}{\widehat{\sigma}_x^2}$$

8 Find the Reproducibility Proportion

$$\text{Reproducibility Proportion} = \frac{\widehat{\sigma}_o^2}{\widehat{\sigma}_x^2}$$

9 Find the Combined Repeatability and Reproducibility Proportion

$$\text{Combined R \& R proportion} = \frac{\widehat{\sigma}_e^2}{\widehat{\sigma}_x^2}$$

10 Find the Intraclass Correlation Coefficient

$$\text{Intraclass correlation coefficient} = \frac{\widehat{\sigma}_p^2}{\widehat{\sigma}_x^2}$$

2.3 MSA by Analysis of Variance (ANOVA) Calculation by Minitab software

Apart from the two methods describe above, MSA can also be done by ANOVA. ANOVA stands for analysis of variation. It is an experimental design technique that looks at no. of variables at a time. ANOVA offer statistics on interactions between samples and appraisers. With an ANOVA, we can vary the number of samples, appraisers, trials, and even the number of measurement devices to get a more accurate picture of the variation in the measurement system. It allows us to get an accurate estimate of variances. It is used to help regulate which of the variables under study have a statistically noteworthy influence on the process output. Calculations using ANOVA are more complex than those with other techniques. Therefore, it is best to use a computer with DOE software for the calculations. A standard 2-factor ANOVA format is used for examining measurement systems. Factor A is used to designate the parts or samples. Factor B represents the appraisers. The number of levels for each factor is a function of the number of samples and the number of appraisers. Following are the terms that are calculated theoretically. Direct results can be calculated easily by using a software.

1. Mean Square Values
   Mean square values are calculations of variance. The variance is the standard deviation squared. Mean square values are calculated for the Parts (MS_{Parts}), Appraisers ($MS_{Appraisers}$), the Parts x Appraisers Interaction (MS_{PxA}), the Error (MS_{Error}), and a "Pooled" term MS_{Pool}, if appropriate.
2. PxA Interaction
   Evaluation is made for significance of the Parts x Appraisers Interaction using the F-test. If this interaction is significant, we will need to investigate the reasons for it.

$$F_{P*A\ Interaction} = \frac{\text{MS}_{P*A\ Interaction}}{\text{MS}_{Error}}$$

   If it is not significant, we will assume it is really part of the experimental error and pool the P*A Interaction value in with the Error Value. Here we are taking the example of P*A not significant.
3. Repeatability
   Repeatability is determined by pooling the MS_{Error} and MS_{PxA}.

$$EV = \sqrt{MS_{P*A}}$$

$$MS_{P*A} = \frac{SS_{Error} \pm SS_{P*A\ Interaction}}{df_{Error} \pm df_{P*A\ Interaction}}$$

4. Reproducibility

The Reproducibility is determined by the $MS_{Appraisers}$ with a correction term to account for confounding from the instrument variation.

$$AV = \sqrt{\frac{MS_{Appraiser} - MS_{P*A}}{a * r}}$$

where a= number of parts
r= number of trials

5. Part Variation
Part variation is determined by:

$$PV = \sqrt{\frac{MS_{Part} - MS_{P*A}}{x * r}}$$

where x=number of operators
r= number of trials

6. Gauge R&R
The R&R is simply:

$$GRR = \sqrt{EV^2 + AV^2}$$

7. Total Variation
Total variation is determined by:

$$TV = \sqrt{EV^2 + AV^2 + PV^2}$$

8. % Equipment Variation

$$\%EV = \frac{EV}{TV} * 100$$

9. % Appraiser Variation

$$\%AV = \frac{AV}{TV} * 100$$

10. % Gauge Repeatability and Reproducibility

$$\%GRR = \frac{GRR}{TV} * 100$$

11. % Product Variation

$$\%PV = \frac{PV}{TV} * 100$$

Minitab software was used in the study and following simple steps were followed in determining the required values:

Open Minitab ➡ Stat ➡ Quality Tools ➡ Gauge Study ➡ Gauge R & R Study Crossed

3 Case Study

In determining the credibility of measurement system, two different environments were chosen. In first case, a study from a manufacturing industry and in second case, a study from a process industry, is taken. Every organization wants to improve the quality of its product and aim to reduce process variability and waste (defects/nonconformities), ultimately improve business performances.

3.1 Manufacturing Industry

Table 1
Data Collection Sheet (Manufacturing Industry)

MSA Data Collection and Calculation Sheet (Manufacturing Industry)						
Appraisers	Trails	Parts				
		1	2	3	4	5
A	1	80.02	85.33	90.02	102.15	108.24
	2	82.18	87.03	93.45	104.04	110.36
Average		81.10	86.18	91.74	103.10	109.30
Range		2.16	1.70	3.43	1.89	2.12
$\overline{Xa}$				94.28		
$\overline{Ra}$				2.26		
Appraisers	Trails	Parts				
		1	2	3	4	5
B	1	81.02	86.12	92.02	101.04	107.02
	2	82.03	88.01	91.46	102.90	107.85
Average		81.53	87.07	91.74	101.97	107.44
Range		1.01	1.89	0.56	1.86	0.83
$\overline{Xb}$				93.95		
$\overline{Rb}$		1.23				
Appraisers	Trails	Parts				
		1	2	3	4	5
C	1	81.11	86.30	96.04	102.12	109.25
	2	82.20	85.26	97.95	105.84	110.05
Average		81.66	85.78	97.00	103.98	109.65
Range		1.09	1.04	1.91	3.72	0.80
$\overline{Xc}$				95.61		
$\overline{Rc}$		1.71				
Part Avg $\overline{Xp}$		81.43	86.34	93.49	103.02	108.80
Rp		27.368				
$\overline{\overline{R}}$		1.73				
$\overline{\overline{x}}$		94.61				
UCL$\overline{r}$		5.67				
LCL$\overline{r}$		0				
Ro		1.665				

First of all, a manufacturing industry is taken into consideration. The industry is having a turnover of INR 4.5 Crores and hence comes under the category of small scale industry (SSI). It is manufacturing sheet metal parts of varying thickness. These sheet metal parts are being supplied to large manufacturing units who further use these parts in manufacturing various other important parts of automobiles. So thickness is very critical factor which is being measured by a Vernier Calliper. Although many advance and accurate instruments can be used for measuring sheet thickness but Vernier calliper was being used as the resources of the industry were limited. Also, in such SSIs, due to not much management support, less importance is given to these type of work (MSA) and are often regarded as non-productive work.

Five parts of different thickness were taken to analyse whether the measurement system is correct or not. Table 1 shows the actual readings of those five parts taken randomly by three different appraisers. All dimensions are in mm. Parts were coded so as to avoid the interference among the operators and to obtain exact results. The table 1 also includes various direct values {X-bar, R-bar, Upper Critical limit (UCL), Lower Critical Limit (LCL) etc.} calculated by using simple statistics. Now by using the values from table 1, 10 different terms (Repeatability, Reproducibility, Part Variation, Total variation and their proportions) were calculated by using the three different methods described under section 2 in detail. The comparison of the readings is shown in Table 2. The comparison showed a different picture as results were surprising. The most widely used AIAG method was giving false interpretations.

Table 2
Comparison Sheet of Various MSA Methods (Manufacturing Industry)

Measurement System Analysis of a Vernier Calliper in a Manufacturing Industry					
Sr. No	**Terms**		**AIAG**	**Wheeler's Method**	**ANOVA**
1	Equipment Variation (Repeatability)	EV	1.600	2.560	1.967
2	Appraiser Variation (Reproducibility)	AV	0.660	0.435	1.583
3	Gauge Repeatability & Reproducibility	GRR	1.720	2.995	3.550
4	Part Variation	PV	11.030	121.660	128.520
5	Total Variation	TV	11.160	124.650	132.070
6	% or Proportionate Equipment Variation of Total Variation	%EV	14.300	2.100	1.490
7	% or Proportionate Appraiser Variation of Total Variation	%AV	5.800	0.300	1.020
8	% or Proportionate Gauge R & R Variation of Total Variation	%GRR	15.400	2.400	2.690
9	% or Proportionate Total Variation of Total Variation	%PV	98.800	97.500	97.310
10	% or Proportionate Part Variation of Total Variation	%TV=%GRR+ %PV	114.200	100.000	100.000

Two-Way ANOVA Table with Interaction (Manufacturing Industry) Gauge R&R

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)
Total Gage R&R	1.8841	11.3049	16.39
Repeatability	1.4024	8.4143	12.20
Reproducibility	1.2583	7.5498	10.95

Fig. 2. ANOVA Calculation by Minitab (Manufacturing Industry)

Fig. 2 and Fig. 3 shows the results of gauge R&R study using ANOVA. It indicates high part to part variation than repeatability, reproducibility and gauge r & r. The Fig. 2 shows number of distinct categories (NDC) as 8 which is greater than 5 means the system is capable of discriminating the parts. Total gauge R & R % study variation comes out to be 16.39 % which is less than 30.00% which indicate that measurement system is OK.

3.2 Process Industry

Secondly a process industry is taken into consideration for more elaboration of the MSA. The industry is a paper manufacturing plant having various sections. General equipment used to measure the flow of fluids in one of the pipe sections is a flow meter. The process industry presents a different scenario as compared to manufacturing industry because conducting a MSA on a flow meter and so on to the real values is a tricky situation. As the process industry is having continuous processes so the problem is one has to dismantle the flow meter from its position and replace it with another one so that work doesn't get halted. But the industry has to adhere to the work loss in changing the flow meter and again reassembling it when checked. In this case also, the checking will be done on the assumed values not on the real. The solution to the problem also comes out to be tricky one. In place of dismantling the flow meter, for such situations, another measuring device of tested accuracy and characteristics was put in series to the original instrument before Gauge R&R study so that analysis can be done on the real values.

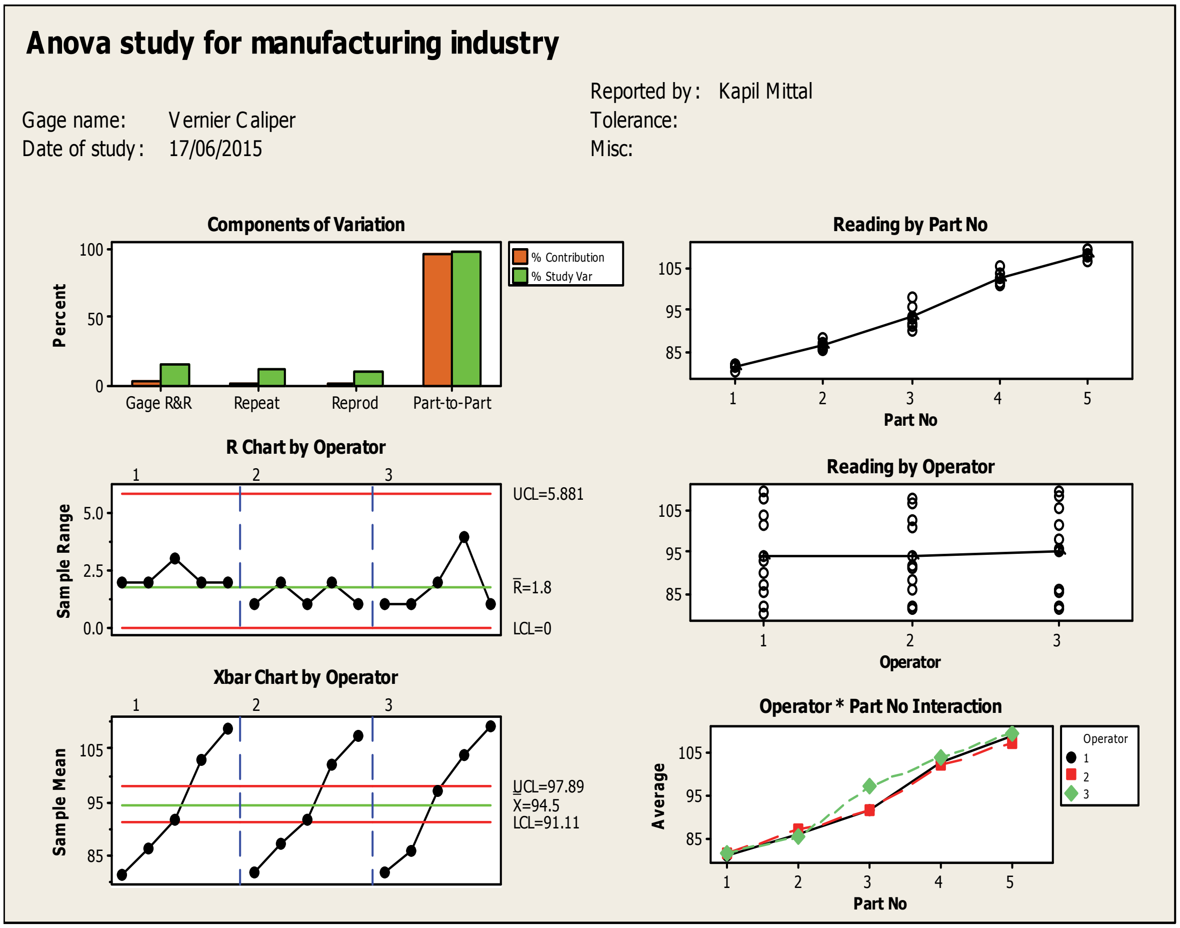

Fig. 3. Components of Variation (Manufacturing Industry)

Table 3 shows the actual readings (m^3/s) at varying flow rate taken by three different appraisers at random. The device is an analog type of instrument; hence the readings are in whole numbers. Arrangement was made to avoid the interference among the operators and to obtain exact results. The table also includes various direct values calculated by using simple statistics. Now, similar to the earlier process in previous case study of manufacturing industry, by using the values from table 3, 10 different terms were calculated by using the three different methods. The comparison of the results is shown in Table 4. Fig. 4 and Fig. 5 show the components of variation drew using the ANOVA by Minitab. It indicates high part to part variation than repeatability, reproducibility and gauge r & r. The Fig. 4 shows number of distinct categories (NDC) as 10 which is greater than 5 means the system is capable of discriminating the parts.

Table 3
Data Collection Sheet (Process Industry)

MSA Data Collection and Calculation Sheet (Process Industry)						
Appraisers	Trails	Parts				
		1	2	3	4	5
A	1	34	45	51	64	74
	2	36	46	54	66	72
Average		35	46	53	65	73
Range		2	1	3	2	2
$\overline{Xa}$		54.20				
$\overline{Ra}$		2.00				
Appraisers	Trails	Parts				
		1	2	3	4	5
B	1	33	44	52	62	73
	2	37	47	53	61	75
Average		35	46	53	62	74
Range		4	3	1	1	2
$\overline{Xb}$		53.70				
$\overline{Rb}$		2.20				
Appraisers	Trails	Parts				
		1	2	3	4	5
C	1	36	42	56	67	76
	2	35	42	53	65	72
Average		36	42	55	66	74
Range		1	0	3	2	4
$\overline{Xc}$		54.40				
$\overline{Rc}$		2.00				
Part Avg $\overline{Xp}$		35.17	44.33	53.17	64.17	73.67
Rp		38.5				
$\overline{\overline{R}}$		2.067				
$\overline{\overline{X}}$		54.10				
UCL$\overline{r}$		6.758				
LCL$\overline{r}$		0				
Ro		0.700				

Table 4
Comparison Sheet of Various MSA Methods

Measurement System Analysis of a Flow Meter in a Process Industry					
Sr. No	**Terms**		**AIAG**	**Wheeler's**	**ANOVA**
1	Equipment Variation (Repeatability)	EV	1.832	3.356	2.767
2	Appraiser Variation (Reproducibility)	AV	Error	-0.200	1.308
3	Gauge Repeatability & Reproducibility	GRR	Error	3.156	4.075
4	Part Variation	PV	15.540	241.490	233.830
5	Total Variation	TV	Error	244.640	237.900
6	% or Proportionate Equipment Variation of Total Variation	%EV	Not Determined	0.014	1.160
7	% or Proportionate Appraiser Variation of Total Variation	%AV	Not Determined	Not Determined	0.550
8	% or Proportionate Gauge R & R Variation of Total Variation	%GRR	Not Determined	1.300	1.710
9	% or Proportionate Total Variation of Total Variation	%PV	Not Determined	98.700	98.290
10	% or Proportionate Part Variation of Total Variation	%TV=%GRR+%PV	Not Determined	100.000	100.000

Two-Way ANOVA Table with Interaction (Process Industry) Gauge R&R

		Study Var	%Study Var
Source	StdDev (SD)	(6 * SD)	(%SV)
Total Gage R&R	2.0187	12.1120	13.09
Repeatability	1.6633	9.9800	10.78
Reproducibility	1.1438	6.8629	7.42

Fig. 4. ANOVA Calculation by Minitab (Process Industry)

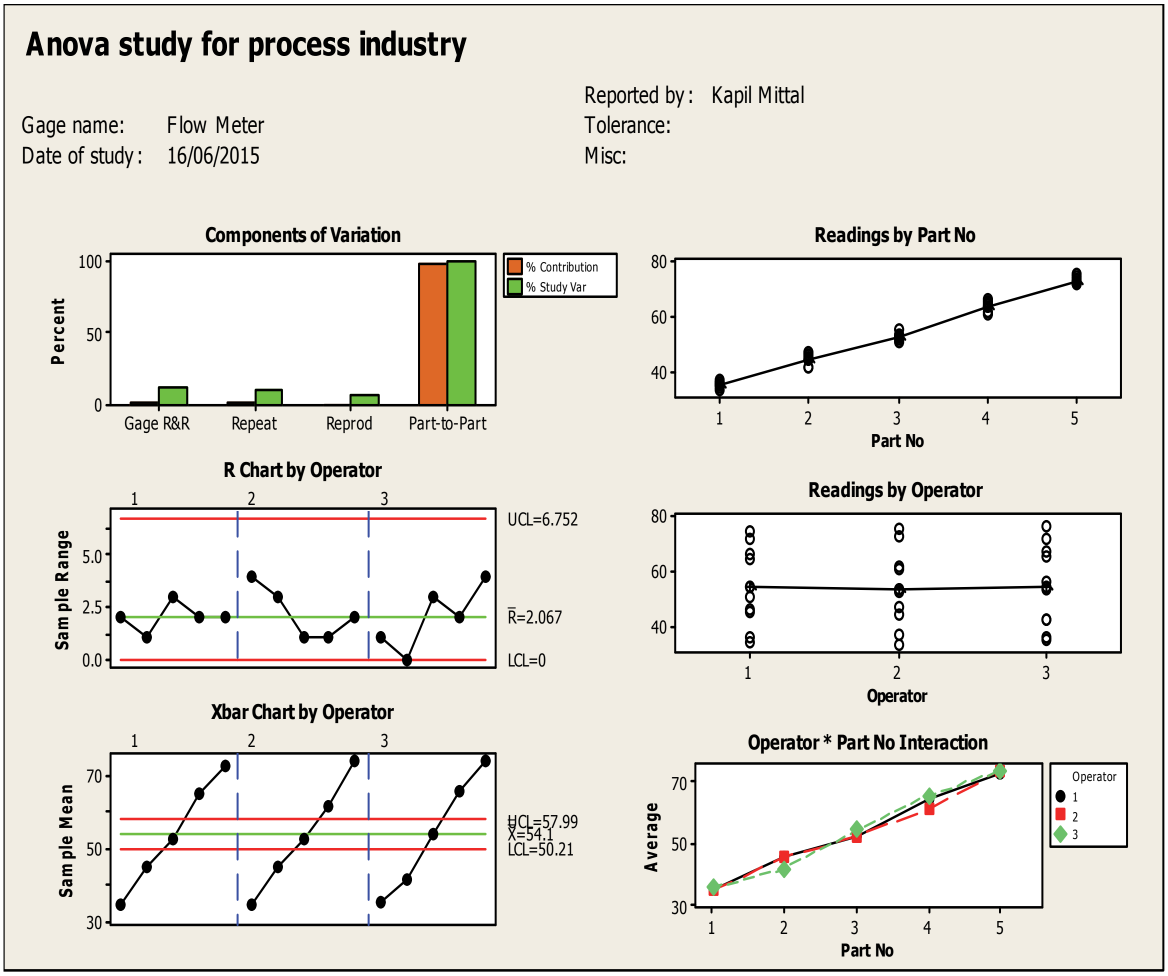

Fig. 5. Components of Variation (Manufacturing Industry)

4. Fuzzy Evaluation

In the next step it was decided to run an evaluation test on the basis of comparison results carried out in Table 2 and Table 4 for manufacturing and process industries respectively. As the present case is similar to decision making under uncertainty with the availability of various dependent parameters, a suitable multiple attribute decision making (MADM) with fuzzy logic approach could be used (Mittal, Tewari, & Khanduja, 2017a). Various MADM approaches such as TOPSIS (Technique for order preference by similarity to ideal solution) (Chen, 2000; Hwang et al., 1993; Mittal et al., 2016; Rathi et al., 2015), VIKOR (VlseKriterijumskaOptimisacija I KompromisnoResenje) (Liu et al., 2012; Opricovic & Tzeng, 2004; Yadollahi Farsi et al., 2012), AHP (Mittal et al., 2017b; Saaty, 1990) and SAW (simple additive weighting) (Chen & Klein, 1997) etc. are available but in this case study TOPSIS was selected as it was best suited for similar case scenarios.

4.1 Fuzzy TOPSIS Methodology

This section explains the steps involved in the particular fuzzy TOPSIS approach. It includes the following steps:

Step 1: Calculation of weights
In the first step weightage (Wj) of each parameter is calculated. The formula for weight calculation is as follows:

$$W_j = \frac{P_j}{\sum_{j=1}^{n} P_j}$$

As the present case is of evaluation of result, weightage of each parameter is taken as equal.

***Step 2**:* Define linguistic variables, membership function and corresponding fuzzy numbers.
A set of fuzzy numbers is necessary to compare the alternatives for each parameter.

Step 3: Construction of decision matrix
Let *p* be the parameters and *q* be the alternatives for *k* number of decision makers/team members in the proposed model. The aggregated fuzzy rating for C_j criterion is represented as $x_{ijk}= \{x_{ijk1}, x_{ijk2}, x_{ijk3}, x_{ijk4}\}$. For i = 1,2,…. *p; j* =1,2,…. *q* and k = 1,2,….*k*, x_{ijk} are calculated as (Kahraman et al., 2010; Kwong & Bai, 2003):

$$\begin{Bmatrix} x_{ij1} = min_k\{b_{ijk1}\} \\ x_{ij2} = \frac{1}{k}\sum b_{ijk2} \\ x_{ij3} = \frac{1}{k}\sum b_{ijk3} \\ x_{ij4} = min_k\{b_{ijk4}\} \end{Bmatrix}$$

Thus the obtained decision matrix *(Z)* is shown as:

$$Z = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1p} \\ x_{21} & x_{22} & \cdots & x_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ x_{q1} & x_{q2} & \cdots & x_{qp} \end{bmatrix}$$

Step 4: Defuzzification

Defuzzification is a technique of translating the fuzzy output to crisp value in fuzzy logic. The input for the technique is the aggregate set and the output is a single number. Following equation lead to the crisp values:

$$f_{ij} = \mathrm{Defuzz}(\mathrm{x_{ij}}) = \frac{\int \mu(x).x\,dx}{\int \mu(x).dx} A = \pi r^2$$

$$= \frac{\int_{x_{ij1}}^{x_{ij2}} \left(\frac{x - x_{ij1}}{x_{ij2} - x_{ij1}}\right).x\,dx + \int_{x_{ij2}}^{x_{ij3}} x\,dx + \int_{x_{ij3}}^{x_{ij4}} \left(\frac{x_{ij4} - x}{x_{ij4} - x_{ij3}}\right).x\,dx}{\int_{x_{ij1}}^{x_{ij2}} (\frac{x - x_{ij1}}{x_{ij2} - x_{ij1}})\,dx + \int_{x_{ij2}}^{x_{ij3}} dx + \int_{x_{ij3}}^{x_{ij4}} (\frac{x_{ij4} - x}{x_{ij4} - x_{ij3}})dx}$$

$$= \frac{-x_{ij1}x_{ij2} + x_{ij3}x_{ij4} + \left(\frac{1}{3}\right)(x_{ij4} - x_{ij3})^2 + \left(\frac{1}{3}\right)(x_{ij2} - x_{ij1})^2}{-x_{ij1} - x_{ij2} + x_{ij3} + x_{ij4}}$$

Step 5: Normalization

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{i=1}^{m} (f_{ij})^2}}; \forall_j$$

Step 6: Calculation of weighted normalized decision matrix:

$$V_{ij} = [r_{ij}]_{m*n} * [W_j]_{n*m}^{diagonal}$$

Step 7: Calculate of positive ideal and negative ideal solution (Sadjadi & Sadi-Nezhad, 2017)
The positive ideal solution V_j^+ and negative ideal solution V_j^- are as given below:

$$V_j^+ = \{(\max V_{ij}, j\epsilon J_1), (\min V_{ij}, j\epsilon J_2), i = 1,2,3 \dots \dots \dots m\}, \forall_j$$

$$V_j^- = \{(\min V_{ij}, j\epsilon J_1), (\max V_{ij}, j\epsilon J_2), i = 1,2,3 \dots \dots \dots m\}, \forall_j$$

Where J1 and J2 represents higher best and lower best criteria respectively.

Step 8: Calculation of distance +id and −id from the positive ideal solution and negative ideal solution respectively

$$d_i^+ = \left[\sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^+\right)^2}\right], i = 1,2,3 \dots \dots \dots . m$$

$$d_i^+ = \left[\sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^-\right)^2}\right], i = 1,2,3 \dots \dots \dots . m$$

Step 9: Calculation of TOPSIS rank index:

$$C_i^+ = \frac{d_i^-}{d_i^- + d_i^+}$$

Ranking of alternatives with highest rank index C_i^+ at the top is performed.

Table 5 shows the available parameters on which the selection depends along with their corresponding brief details.

Table 5
Various Parameters with their Brief Description

Sr. No.	Parameters	Abbreviation	Detail
1	Equipment Variation	EV	Variation due to equipment in use
2	Appraiser Variation	AV	Variation due to persons handling the process
3	Gauge R & R	GRR	Variation due to inability of measurement system
4	Part Variation	PV	Variation in different parts produced by process
5	Total Variation	TV	Sum of all three types of variations

In fuzzy logic linguistic variables are used which aids in converting the qualitative values of a parameter to numerical values known as crisp values. Table 6 shows the description of linguistic variables along with their abbreviations and corresponding fuzzy numbers. Table 7 shows the denotation of various alternatives i.e. AIAG, Wheeler Method and Anova with linguistic variables corresponding to the values calcuated in table 2 & 4 for manufacturing & process industries respectively.

Table 6
Linguistic Variable along with Corresponding Fuzzy Numbers

Linguistic Variable	Abbreviation	Fuzzy number
Exceptionally High (EH)	EH	(0.8,0.9,1.0,1.0)
Very high (VH)	VH	(0.7, 0.8, 0.8, 0.9)
High (H)	H	(0.5, 0.6, 0.7, 0.8)
Above average (AA)	AA	(0.4, 0.5, 0.5, 0.6)
Average (A)	A	(0.2, 0.3, 0.4, 0.5)
Very low (VL)	VL	(0.1, 0.2, 0.2, 0.3)
Extremely low	EL	(0, 0, 0.1, 0.2)

Table 7

Fuzzy Denotation of Table 2 & 4

	Manufacturing					Process				
Alternatives	**EV**	**AV**	**GRR**	**PV**	**TV**	**EV**	**AV**	**GRR**	**PV**	**TV**
AIAG	A	AA	AA	VL	VL	A	EL	EL	VL	EL
Wheeler's Method	VH	A	H	VH	VH	VH	VL	VH	EH	EH
ANOVA	AA	H	EH	EH	EH	AA	EH	EH	VH	VH

Crisp values are calculated by the equation described in step 4. Table 8 shows the corresponding crisp values of manufacturing and process industries.

Table 8

Crisp Value for Manufacturing & Process Industries

	Crisp Values (Manufacturing)					Crisp Values (Process)				
Alternatives	**EV**	**AV**	**GRR**	**PV**	**TV**	**EV**	**AV**	**GRR**	**PV**	**TV**
AIAG	0.367	0.533	0.533	0.233	0.233	0.367	0.078	0.078	0.233	0.078
Wheeler's Method	0.833	0.367	0.667	0.833	0.833	0.833	0.233	0.833	0.944	0.944
ANOVA	0.533	0.667	0.944	0.944	0.944	0.533	0.944	0.548	0.833	0.833

After applying various steps described in step 5 to 9 final TOPSIS ranks are shown in Table 9. It is now evident that ANOVA attains the top ranks for both manufacturing and process industries studies.

Table 9

TOPSIS Ranks for Manufacturing and Process Industries

Alternatives	**Manufacturing**		**Process**	
	Ci+	**TOPSIS Rank**	**Ci+**	**TOPSIS Rank**
AIAG	0.156	3	0.000	3
Wheeler's Method	0.663	2	0.632	2
ANOVA	0.764	1	0.751	1

5. Results & Discussions

It is visible from the comparison drawn between the three methods i.e. AIAG, Wheeler’s method and ANOVA, that the readings are different. Concentrate on the last term % or Proportionate Total Variation of the Total Variation which in case of AIAG is 114.20% (Manufacturing) & Not Determined (Process) and in case of Wheeler’s method and ANOVA is 100%. The % EV and %AV do not add up to %GRR and %GRR and %PV do not add up to 100% because they are not proportions. They are instead trigonometric functions and trigonometric functions do not satisfy the conditions needed for a set of ratios to be interpreted as proportions. This implies that values do not infer the correct information about the source of variation.

Also one can see the difference in case of part variation. In AIAG study it is mere 11.03 (Manufacturing) & 15.54 (Process) which is almost acceptable but in case of Wheeler and ANOVA the values are beyond acceptance. If these values are based on the adequacy of the measurement process, there is a high risk that one can make a bad decision about the process.

In AIAG method the variance of estimates and sum of individual proportions are not equal, in contrast Wheeler’s & ANOVA both method suggested the variance of estimates and the sum of individual proportions are equal to the total variation. Also it is visible from the tables that sometimes, as in case of process industry, the estimate of the variances cannot be made by using AIAG method while the correct estimate can be made by using ANOVA method.

In the end, evaluation performed by fuzzy TOPSIS provided a concrete solution that ANOVA is the best suited method for analysing the measurement system in both manufacturing and process industries.

The evaluation procedure using fuzzy MADM approach is a tested and frequently used method for evaluation in cases where various dependent variables are available.

Recently more people are beginning to prefer the ANOVA method for conducting Gauge R&R studies. The ANOVA method includes the interaction between the operators (or appraisers) and the parts. ANOVA breaks down the variance into four components: parts, operators, interaction between parts and operators and the repeatability error due to the measurement system (or gauge) itself. The interaction seldom is often insignificant and has little, if any, impact on the results. The ANOVA method, however, allows estimating the variance of the components. If one bases the % of total variation on the variance, instead of the standard deviation, can get very different results. One more disadvantage of ANOVA is that the use of software is necessary in case of a medium skilled user, as the statistics involved in the manual version is very lengthy and tedious talk that required a definite skill. But this can be taken as granted in favour of ANOVA that software is easily available and hence a certain advantage over other methods where one has to do the calculations.

6. Conclusion

If an organization is facing repeated quality issues, MSA is an important step that should be performed to check and confirm the current quality status of an organization, before going for a quality management technique. This paper depicts a comparative study of applying MSA by three different techniques and under two different environments. The application of MSA in a continuous system is also described, which generally proves to be tricky situation for such analysis. As it is evident from the application of three methods of MSA i.e. the AIAG, the Wheeler's and the ANOVA under the manufacturing and process environment that the ANOVA method has comes out to be the best one which can be used for any type of industry and can withheld any type of data. Evaluation by fuzzy TOPSIS also put a stamp on the results. The objective, here, was to rank the best and accurate technique for MSA and it can be seen that AIAG and Wheeler method have a certain limit to the type of data. The AIAG method does not provide the right information as explained above and can lead to the wrong interpretation and in Wheeler's method; one has to do the lots of calculation work which is not feasible in today's time bound industrial culture. Also with the availability of the computers as well as the software in the industry, definitely the ANOVA is the need of the hour.

References

Awad, M., Erdmann, T. P., Shanshal, Y., & Barth, B. (2009). A Measurement System Analysis Approach for Hard-to-Repeat Events. *Quality Engineering*, *21*(3), 300–305.

Chen, C. (2000). Extensions of the TOPSIS for group decision-making under fuzzy environment. *Fuzzy Sets and Systems*, *114*(1), 1–9.

Chen, C., & Klein, C. (1997). An efficient approach to solving fuzzy MADM problems. *Fuzzy Sets and Systems*, *88*(1), 51–67.

Dearden, H. T. (2014). Comparison Alarms for Detection of Measurement Faults. *Measurement and Control*, *47*(9), 273–275.

Göndör, V., & Koczor, Z. (2010). Improvement of the Measurement System Analysis Using Experimental Design. *Obuda University E-Bulletin*, *1*(1), 35–42.

Hajipour, V., Kazemi, A., & Mousavi, S. M. (2013). A fuzzy expert system to increase accuracy and precision in measurement system analysis. *Measurement*, *46*(8), 2770–2780.

Hwang, C.-L., Lai, Y.-J., & Liu, T.-Y. (1993). A new approach for multiple objective decision making. *Computers & Operations Research*, *20*(8), 889–899.

Jones, B. E. (2013). Measurement: Past, Present and Future: Part 1 Measurement History and Fundamentals. *Measurement and Control*, *46*(4), 108–114.

Kahraman, C., Beskese, A., & Kaya, I. (2010). Selection among ERP outsourcing alternatives using a fuzzy multi-criteria decision making methodology. *International Journal of Production Research*, *48*(2), 547–566.

Kaushik, P., Khanduja, D., Mittal, K., & Jaglan, P. (2012). A case study: Application of Six Sigma methodology in a small and medium-sized manufacturing enterprise. *The TQM Journal*, *24*(1), 4–16.

Kooshan, F. (2012). Implementation of Measurement System Analysis System (MSA): In the Piston Ring Company " Case Study ." *International Journal of Science and Technoligy*, *2*(10), 749–761.

Kwong, C., & Bai, H. (2003). Determining the importance weights for the customer requirements in QFD using a fuzzy AHP with an extent analysis approach. *Iie Transactions*, *35*, 619–626.

Liu, H., Liu, L., Liu, N., & Mao, L. (2012). Risk evaluation in failure mode and effects analysis with extended VIKOR method under fuzzy environment. *Expert Systems with Applications*, *39*(17), 12926–12934.

Mittal, K., Tewari, P. C., & Khanduja, D. (2017a). On the Right Approach to Selecting a Quality Improvement Project in Manufacturing Industries. *Operation Research and Decisions*, *27*(1), 105–124.

Mittal, K., Tewari, P. C., & Khanduja, D. (2017b). Productivity improvement under manufacturing environment using Shainin system and fuzzy analytical hierarchy process: a case study. *The International Journal of Advanced Manufacturing Technology*, 92(1-4), 407-421.

Mittal, K., Tewari, P. C., Khanduja, D., & Kaushik, P. (2016). Application of Fuzzy TOPSIS MADM approach in ranking & underlining the problems of plywood industry in India. *Cogent Engineering*, *3*, 1–11.

Opricovic, S., & Tzeng, G.-H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research*, *156*(2), 445–455.

Rathi, R., Khanduja, D., & Sharma, S. K. (2015). Six Sigma Project selection using fuzzy TOPSIS decision making approach. *Management Science Letters*, *5*, 447–456.

Saaty, T. (1990). How to make a decision: the analytic hierarchy process. *European Journal of Operational Research*, *48*(1), 9–26.

Sadjadi, S & Sadi-Nezhad, S. (2017). Ranking Canadian oil and gas projects using TOPSIS. *Journal of Project Management*, 2(3), 87-92.

Smith, M. R. R. D., McCrary, S. W., & Callahan, R. N. (2007). Gauge repeatability and reproducibility studies and measurement system analysis: A multimethod exploration of the state of practice. *Journal Of Industrial Technology*, *23*(1), 1–12.

Wheeler, D. J. (2009). An Honest Gauge R&R Study. *ASQ/ASA Fall Technical Conference*, (189), 1–19.

Yadollahi Farsi, J., SiahkaliMoradi, J., & Jamali, B. (2012). Which product would be chosen? A fuzzy VIKOR method for evaluation and selection of products in terms of customers' point of view; Case study: Iranian cell phone market. *Decision Science Letters*, *1*(1), 23–32.

Zanobini, A., Sereni, B., Catelani, M., & Ciani, L. (2016). Repeatability and Reproducibility techniques for the analysis of measurement systems. *Measurement*, *86*, 125–132.