SMEs Perception towards Adoption of Measurement System Analysis Strategy: A Case Study in Pump Manufacturing Industry

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Abstract. Every industry from large scale to small scale is nowadays seeking for their continuous improvement. It is necessary to compare the performance of the measurement processes with the standard systems. In a typical scenario, one of the two processes represents an attempt to improve the other process, and one must determine if the attempt has been successful. Since repeatability and reproducibility (R&R) studies are often used to determine the adequacy of each measurement process separately, it is suitable to compare the results of these studies to determine if there is any difference in the variability of the two processes. In this paper, we consider R&R studies with two factors of parts and operators. We consider situations where the operator factor can be either random or fixed. Each operator makes repeated measurements on each part in a sample of process output and the different operators are used for each measurement process and the parts used for measurements are the same. A ratio commonly used to determine the adequacy of a single measurement process is used to compare the variability of the two measurement processes. Two statistical tests a result for differences in their ratio depends on their confidence intervals are proposed and compared using computer simulation. Finally, our study enables delegates to assess the performance of new and existing measurement systems.

Keywords: Measurement System Analysis (MSA), Analysis of Variance (ANOVA), Small Medium Enterprises (SMEs), Precision to Tolerance Ratio (PTR).

1. INTRODUCTION

Nowadays, every production industry faces difficult competition due to their increased customer demand [1]. Every production industry has to actively perform their improvement to satisfy the customers. In our study, quality is one of the important factors, not only for our research; generally for the entire production unit it plays a major role. This paper presenting a case study of measurement system analysis applied in small and medium scale pump industry [2]. Measurement system analysis is a system which plays a major role in lean six sigma. This measurement system is different from the traditional approach; consist of the measurement method, measurement process, measured part and the measurement environment [3]. Sources of variations in measurement are one of the main sources of variation in quality. In production industries, quality problems are solved by identifying and correcting inaccurate data and measurement process. The ability to make right decisions depends on the availability of measurement process. In our research, we consider Gage R&R studies with two main factors one is parts and the other is operators [4]. Each operator makes the repeated measurements on each part in the samples and also three different operators are used for each measurement process and the parts to be measured is the same component. Outcome of the results of simulation are used to provide the recommendations for the effective instruments. Measurement system analysis is recommended to fulfil the requirements of the client and also it is used to ensure that company owns an acceptable measurement system [5].

2. MEASUREMENT SYSTEM ANALYSIS

Measurement system analysis (MSA) is a scientific tools used to determine the amount of total variations from the measurement system [6]. The purpose of the measurement system analysis is to qualify a measurement system for quantifying its precision, accuracy and its stability. MSA is a quality improvement initiative which has the ability to assess the measurement system and to detect the differences in process variables.
Generally measurements are used to guide a decision, which follows whether the measurement errors are made by the instrument or equipment or by the operators [7]. The level of variations attributed to the operator or parts and the operator has the ability to measure each individual part is experienced during the measure phases and is presented in Figure 1. Total variations of measurement system analysis and its causes are classified into two types and they are process and measurement variations. In this study, the focus is mainly on the measurement variation and also, the variations obtained due to the process.

![Figure 1. Total Measurement Variations](image)

2.1 Bias

The difference between the average value of all measurements and true value is called as bias.

2.2 Stability

Stability is the capacity of a measurement system to produce the same values over time when measuring the same sample. It statistically monitors the state of measurement system over a period of time and shows the variations in the readings obtained due to wear and tear as it gets into their use.

2.3 Linearity

Linearity is the difference in bias values over the range of instrument capability. The difference in the accuracy values of a gage through the expected operating range of the gage. It may be classified as a good linearity and bad linearity.

2.4 Repeatability

Repeatability is the variation in measurements obtained with measurement instrument when used several times by same appraiser while measuring the identical characteristics on the same part. It also states that when repeated measurements are made of same conditions such as same operator, same units, same setup and same environmental conditions.

2.5 Reproducibility

Reproducibility is the variations in the average of measurement made by the different operators using the same measuring instrument on the same identical part. It is caused by the measurement made by the appraisers.

3. GAGE R&R

In MSA gage R&R plays a major role and it is the combined estimate of measurement system of repeatability and reproducibility [8]. This paper based on R&R analysis by using Analysis of Variance [ANOVA] method. In ANOVA method we could separate the repeatability and reproducibility interprets easily. In the Gage R&R, generally there are two to three operators are involved to measure the process outputs [9]. In our study, we utilize 3 operators to participate and they were to measure 10 parts randomly and 3 trials taken by each operator.
This paper is based on gage R&R analysis to know Precision to Tolerance (P/T ratio) and Analysis of Variance (ANOVA) method using Minitab software. According to the Automotive Industry Action Group (AIAG) standard [10], the least count of the measuring instrument should be 1/10th of the tolerance. AIAG standard says that precision to tolerance ratio is below 10% (acceptable), average between 10% to 30% ratio is (conditionally acceptable) and if it is above 30 % (not acceptable). Table 1 shows the AIAG standard tolerance assumption criteria.

Table 1. AIAG Standard Tolerance Assumption Criteria

| Classification | Criteria       |
|----------------|----------------|
|                | Accepted       | Caution | Rejected |
| %contribution  | <1%            | 1-10%   | >10%     |
| %Tolerance     | <10%           | 10-30%  | >30%     |
| NDC            | >10            | 4-9     | < 4      |

4. EXISTING CASE STUDY

A measurement system of gage R & R study was done in small and medium scale pump industry [11]. The manufacturing industry produces the monoblock pumps, submersible pumps, etc. Here we concentrate on the single section of monoblock pump and process studies are made and data’s are collected. The data were collected from 3 operators; they measured 10 parts (outer diameter of stamping). Each part was measured 3 times at different interval of times, and finally there were 90 readings were collected, which has shown in the table (II, III and IV). Here we take the stamping component shown in Figure 2 is taken for our measurement and the measured dimensions of the parts to be 105mm within the tolerance of ± 0.9 mm.

Figure 2. Stamping Component and calibration made on Vernier calliper with least count 0.05 mm

4.1 Beginning of the Project

According to the Automotive Industry Action Group (AIAG) standards, for measurement process requires three operators measuring 10 items in three times at different intervals. All inspections had to be measured under conditions of the same instrument, with same setup at the same environmental condition, and the sample items had the same characteristics [12]. Each operator is measuring the each sample item three times in random sequence. For evaluating the repeatability of the measurement system, here the operator was for measuring is the same person.
Figure 3. Gage R&R Methodology of Reading

The above Figure 3 shows the gage R&R methodology [13], that how the three appraisers are taking the measurement reading for the 10 sample parts without knowing each other’s result. After all this data’s are collected, then the measurement data would be entered in software (worksheet made) program and analyzed using excel software. All the mathematical calculation using respective formulas are in the worksheet and finally, the results would be assessing the capability of the measurement system.

4.2 Readings before MSA System

The initial measurements were obtained by the operators with a Vernier calliper (Least Count=0.05mm). The values are in the Table 2 for operator A, Table 3 for operator B and Table 4 for the operator C.

Table 2. Data Collected From Operator A

| PART  | TRIAL 1 | TRIAL 2 | TRIAL 3 |
|-------|---------|---------|---------|
| 1     | 105.20  | 105.10  | 105.20  |
| 2     | 105.30  | 105.20  | 105.30  |
| 3     | 105.50  | 105.50  | 105.40  |
| 4     | 105.50  | 105.50  | 105.50  |
| 5     | 105.50  | 105.60  | 105.60  |
| 6     | 105.80  | 105.70  | 105.70  |
| 7     | 105.90  | 105.80  | 105.90  |
| 8     | 105.90  | 105.80  | 105.80  |
| 9     | 105.90  | 105.80  | 105.80  |
| 10    | 105.70  | 105.60  | 105.70  |

Table 3. Data Collected From Operator B

| PART  | TRIAL 1 | TRIAL 2 | TRIAL 3 |
|-------|---------|---------|---------|
| 1     | 105.10  | 105.00  | 105.10  |
| 2     | 105.30  | 105.20  | 105.30  |
| 3     | 105.40  | 105.50  | 105.50  |
| 4     | 105.40  | 105.60  | 105.60  |
| 5     | 105.60  | 105.60  | 105.60  |
| 6     | 105.70  | 105.80  | 105.70  |
| 7     | 105.70  | 105.80  | 105.70  |
| 8     | 105.90  | 105.80  | 105.90  |
| 9     | 105.90  | 105.80  | 105.90  |
| 10    | 105.80  | 105.60  | 105.60  |
Table 4. Data Collected From Operator C

| PART 1 | TRIAL 1   | TRIAL 2   | TRIAL 3   |
|--------|-----------|-----------|-----------|
| TRAIL 1| 105.00    | 105.00    | 105.10    |
| TRAIL 2| 105.30    | 105.30    | 105.30    |
| TRAIL 3| 105.50    | 105.50    | 105.50    |
| TRAIL 4| 105.60    | 105.60    | 105.60    |
| TRAIL 5| 105.80    | 105.80    | 105.80    |
| TRAIL 6| 105.90    | 105.90    | 105.90    |
| TRAIL 7| 105.90    | 105.90    | 105.90    |
| TRAIL 8| 105.60    | 105.60    | 105.60    |

The readings are made by the three different operators and the individual readings are noted separately on the Tables 2, 3 and 4 respectively. Total 90 readings were obtained from the measurement system and these readings were made at different interval time [14]. One thing is should be kept, that while measuring the parts, it should be randomly picked and the appraiser does not remains the existing reading. This data’s were used by the mathematical formulas to find the average, ranges and precision to tolerance ratio (P/T Ratio). This all values are obtained by mathematical symbols or framing formulas in the worksheets were by directly uploading the data’s and obtain the values of the final reading. Table 5 shows the Gage R&R Study of reading using the vernier calliper with 0.05 mm least count.

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Table 5. MSA- Gage R&R study for Vernier caliper (Least Count 0.05 mm)

The primary purpose of this worksheet methodology is the graphical approach to determine whether the measurement process is adequate to measure the manufacturing process variations. From the worksheet, we have formulated the table with mathematical signs and by entering the iteration values, it just evaluate and give the final gage results. This table is simple and easier compared to the mathematical formulas by applying and finding the results for each and every iteration.
From the result, the ranges and the average values are not within the control limits by using the vernier calliper with least count of 0.1mm and precision to tolerance ratio (P/T ratio) is 30% where the system is conditionally accepted and need some improvements according to the AIAG standard reference manual. Therefore, the system clearly identifies the reason for the lack of control in process variability [15]. This problem can be remedied, by changing the system which has the ability to detect the variation within the parameters by increasing the discrimination of measurements in the gage R&R [16].

4.3 ANOVA Method

MINITAB is one of the statistical software, reliable and easy to use and it has been used by many successful companies for their deployment of quality control functions. In MINITAB software by using ANOVA method, we can evaluate the repeatability and reproducibility of the measurement system [17]. Analysis of the variance (ANOVA) is a statistical method that tests the contribution of control factors and interactive effects between the different factors. To conduct MSA [18], for our test, there are 3 operators to participate and to measure 10 parts randomly and 3 trials taken by each operator. While doing this, we must ensure that the parts are given to the appraisers in a random order which they do not remember their earlier result. They also should not see other appraisers measuring the parts. Once the measurements are completed, the data is analysed using the Minitab software.

The gage R & R study (crossed) can be made for each operator [19], measured each part by using Minitab software is analysed. Result of the collected data illustrated in figure 5 would be interpreted in the form of percentage of contribution [20]. If this percentage of contribution is below 10% the system would be acceptable. If the contribution is in the range of 10% to 30%, the measurement systems seem to be conditionally acceptable depending on the application, cost of gage and cost of repairs, etc. If it is beyond 30%, the measurement system was no fit for the system and need some improvements. Here, our study works affirms that the current measuring system could not produce the precise and accurate data. The graphical results shows that the part to part variation of the percentage contribution are higher in the current system and the appraisers are measuring the system of range and average values are not within the control limits. From the results, it clearly shows the remedial actions to be made for further improvement of product variations among the appraisers and the process. The Figure 4 shows the graphical results of calibration of vernier calliper with least count of 0.05 mm as the standard measuring instrument.

Figure 4. Graphical results for vernier calliper (least count=0.05 mm)
4.4 Gage R&R Study- ANOVA Method: Initial Data Results

By the outcome of the ANOVA results, we could clearly see the variations and the percentage of contributions are higher. Here, the numbers of distinct categories (NDC) are not up to the acceptable condition. NDC indicate the number of groups within the process data that the measurement system concern. According to the AIAG standard assumptions, the NDC should be more than 10 is good and acceptable system. If it is between 4 to 9 categories, the group seems to be some good and bad and further some measures to be made. If NDC is < 4 it is useless for certain decision making. According to our existing measuring system, using the vernier calliper instrument with least count 0.1mm here the number of distinct categories is 6 and the results obtained in the current measuring system clearly shows further improvements should be made for quality system. Figure 5 shows the Gage R&R study for the two way ANOVA method [21].

Figure 5. Gage R&R study – Two way ANOVA Method

5. OUTCOME OF THE PROJECT

This problem can be remedied, by changing the system which has the ability to detect the variation within the parameters by increasing the discrimination of measurements. The decision of replacing the vernier calliper (least count=0.05 mm) with a vernier calliper (least count=0.02 mm). This measurement system will have adequate discrimination due to apparent resolution of vernier with 0.02 mm least count. With this small relative measurement the average ranges are seems to be within the control limits and process variations are reduced. The measurements made by the vernier calliper (least count=0.02 mm) with gage Repeatability and reproducibility [22] study are shown in Tables 6, 7 and 8 respectively.

Table 6. Data Collected From Operator A

|        | TRIAL 1 | TRIAL 2 | TRIAL 3 |
|--------|---------|---------|---------|
| PART 1 | 105.00  | 105.00  | 105.10  |
| PART 2 | 105.25  | 105.30  | 105.28  |
| PART 3 | 105.40  | 105.42  | 105.40  |
| PART 4 | 105.45  | 105.48  | 105.50  |
| PART 5 | 105.58  | 105.56  | 105.56  |
| PART 6 | 105.72  | 105.73  | 105.74  |
| PART 7 | 105.79  | 105.80  | 105.78  |
| PART 8 | 105.85  | 105.85  | 105.85  |
| PART 9 | 105.88  | 105.89  | 105.90  |
| PART10 | 105.58  | 105.60  | 105.59  |
Table 7. Data Collected From Operator B

| PART  | TRIAL 1 | TRIAL 2 | TRIAL 3 |
|-------|---------|---------|---------|
| 1     | 105.10  | 105.00  | 105.10  |
| 2     | 105.30  | 105.30  | 105.30  |
| 3     | 105.42  | 105.40  | 105.43  |
| 4     | 105.50  | 105.48  | 105.50  |
| 5     | 105.55  | 105.55  | 105.55  |
| 6     | 105.42  | 105.40  | 105.43  |
| 7     | 105.73  | 105.74  | 105.74  |
| 8     | 105.80  | 105.80  | 105.78  |
| 9     | 105.80  | 105.85  | 105.85  |
| 10    | 105.59  | 105.59  | 105.59  |

Table 8. Data Collected From Operator C

| PART  | TRIAL 1 | TRIAL 2 | TRIAL 3 |
|-------|---------|---------|---------|
| 1     | 105.00  | 105.00  | 105.10  |
| 2     | 105.25  | 105.30  | 105.30  |
| 3     | 105.43  | 105.45  | 105.45  |
| 4     | 105.50  | 105.50  | 105.50  |
| 5     | 105.55  | 105.56  | 105.56  |
| 6     | 105.74  | 105.74  | 105.74  |
| 7     | 105.80  | 105.80  | 105.80  |
| 8     | 105.85  | 105.85  | 105.85  |
| 9     | 105.90  | 105.90  | 105.90  |
| 10    | 105.59  | 105.60  | 105.59  |

After suggested measuring instrument with Vernier calliper least count (0.02 mm) again 90 readings are made by the three different operators and the individual readings are noted separately on the table (VI, VII and VIII). These readings were entered in the worksheet we designed and the values are obtained from the measurement system. This data’s were used by the mathematical formulas to find the average, ranges and precision to tolerance ratio (P/T Ratio). Table 9 shows the Gage R&R Study of reading using the vernier calliper with 0.02 mm least count.

Table 9. MSA- Gage R&R study for Vernier caliper (Least Count 0.02 mm)

| Sample | Parts | Operator | Instrument: Vernier caliper | Specification: 0.02mm | USL: 105.9 mm | LSL: 105 mm | X Bar | R Bar | Diff.among operators (R diff) | sigma (o) reproducibility, n=3 operators | sigma (o) reproducibility, n=3 operators | sigma gage (o)2 | Precision Tolerance ratio (P/T) |
|--------|-------|----------|-----------------------------|------------------------|-----------------|-------------|-------|-------|----------------------------|---------------------------------|---------------------------------|----------------|-----------------------------|
| 1      | 1     | Operator A | 22.08.2014  | 205.00 | 205.00 | 205.00 | 205.00 | 0.3   | 205.00 | 205.00 | 205.00 | 0.3 | 0.02467 |
| 2      | 2     | Operator B | 22.08.2014  | 205.25 | 205.30 | 205.30 | 205.30 | 0.3   | 205.30 | 205.30 | 205.30 | 0.3 | 0.01333 |
| 3      | 3     | Operator C | 22.08.2014  | 205.50 | 205.50 | 205.50 | 205.50 | 0.3   | 205.50 | 205.50 | 205.50 | 0.3 | 0.01437 |
| 4      | 4     | Operator D | 22.08.2014  | 205.74 | 205.74 | 205.74 | 205.74 | 0.3   | 205.74 | 205.74 | 205.74 | 0.3 | 0.00777 |
| 5      | 5     | Operator E | 22.08.2014  | 205.99 | 205.99 | 205.99 | 205.99 | 0.3   | 205.99 | 205.99 | 205.99 | 0.3 | 0.00027 |
| 6      | 6     | Operator F | 22.08.2014  | 206.23 | 206.23 | 206.23 | 206.23 | 0.3   | 206.23 | 206.23 | 206.23 | 0.3 | 0.010893 |

Here, the MSA is excellent. As P/T ratio=10%, this is because the instrument with 0.02 mm least count used as per the standard.
5.1 ANOVA Method for Improved Results

The use of ANOVA method is to conform and provide further insight to the data. Although the values can be calculated manually, most of them will prefer computer program to generate the results. This method will provide information concerning the causes of measurement system or gage variation, if the repeatability is large compared to the reproducibility the instruments need some maintenance, or the gage need to be redesigned etc. At the other hand, if the reproducibility is large compared to repeatability then the appraisers needs to be better trained to use and read gage instrument [23]. Using Minitab software, graphical results for the measured data from vernier calliper (least count=0.02 mm) are shown in the Figure 6. The graphical results clearly shows the components of variations are within the limits and the appraisers are measuring the system of range and average values are within the control limits. The measurement of parts variation is rectified by the improved systems [24]. The result shows, the remedial suggestion makes an excellent quality improvement in their process.

![Figure 6. Graphical Results for Vernier Caliper (Least Count=0.02 mm)](image)

5.2 Gage R&R Study - ANOVA Method: Improved Data Results

The Suggested measuring instrument results shows the excellent performance in MSA. The results are obtained by Minitab gage R&R (crossed) analysis using the ANOVA method [25]. The output in Figure 7 shows, that the percent of operator assessment is 0.043 meaning that the instrument using with the least count of 0.02 mm gives a minimal difference in agreeing the measurement. Also, the number of distinct categories is equal to 17, where by the AIAG standard reference manual, if NDC is > 10, then the system is excellent and acceptable.

![Figure 7. Gage R&R study – Two way ANOVA Method Improved Results](image)
6. INTERPRETING THE RESULTS

Minitab uses the two way analysis of Variance (ANOVA) procedure to calculate the variance in the components, and it uses the components to estimate the % variation due to the measuring system. These % variations are appearing in the gage R&R table [25]. The % contribution is based on the estimates of the variance components and each value in the varComp is divided by the total variation and multiplied by 100.

%Study Var for gage R&R = (0.12966/1.59419) * 100 ≈ 8.13%.

By comparing the measurement system variation with the % tolerance, then Minitab calculates % tolerance compare with the measurement system variation to specification. From the Minitab, it multiplies the resulting proportion by 100 and reports it as the percent Tolerance.

% Tolerance for gage R&R is (0.12966/8) * 100= 14.41%.

The %Study Var results indicate that the measurement system should be less than 10% of the overall variation in this study.

Total Gage R&R, %Study Var = 8.13

The number of distinct categories represents how many separate groups of parts the system can distinguish. If the number <4 , the system cannot discriminate between parts, if the number is 4 to 9 then the parts can be divided into two groups(pass/fail). According to AIAG standard the system is acceptable when the number of distinct categories >10. In this case, the number of distinct parts= 17. Here the system is Excellent and acceptable. From the graphical representation, we understand that the most variations are generated by part to part.

7. CONCLUSION

In our study, the measurement system comparison is made before and after the suggested improvement. A result clearly shows that the suggested measurement system analysis is excellent and acceptable after replacing the existing instrument of vernier calliper with least count 0.02mm. The purpose of doing the measurement system analysis is to identify and to reduce the measurement variation in a system. In this study the suggested measuring instrument of (vernier calliper with LC=0.02mm) contributes very little to overall variations as noticed in data representation and in graphical representation using ANOVA in Minitab software. Results show the percentage of contribution of Gage R&R would be acceptable according to AIAG standard. Variations are mostly obtained from the parts, not from instruments, operators, nor methods. With this study, the Company knew that its measurement system was giving accurate and precise information and hence the measurement systems could be acceptable and reliable. If the measurement systems are not satisfactory, operators can know what the cause of problem and this system helps the operators to determine which function should be fixed to improve the measurement system. Any modern companies of SMES [18], in future would go for quality audit systems [20] such as lean six sigma, ISO [21], Agile or TQM implementation [22] etc., this system plays a basic key factor to entering into the process.

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