# Measurement System Scrutiny using Gage R&R: Case Study

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**Abstract –** *DMAIC process is to be performed in a part manufacturing and machining industry viz. (AMT Pvt. Ltd.). MSA (Measurement System Analysis) is a crucial pilot step to check the reliability of the measurement System before the DMAIC process for ensuring the accuracy and reliability of the measurements to be taken amid the process. Gage R&R study, a part of MSA is a statistical method that is used to determine the amount of variation present in the measurement system emerging from the measurement device and operator. The goal of this research paper is to scrutinize the ability of the measurement system of the industry to yield repetitive and reproducible measurement results within permissible limits by GRR study. Crossed Gage R&R Study method which takes into account the operator*part variation is implemented. Minitab software is used for performing Crossed GRR Study and data interpretation. With the part-to-part variation being 98.73% it can be interpreted that Appraiser Variation and Equipment Variation combined contributes a negligible amount of 1.26% of the total variation. Moreover, the operators are skilled enough to take consistent repetitive measurements of multiple parts with minor room for correction. Thus, as confirmed by both the Gage R&R table and graphs, it can be concluded that the Measurement System of the industry is capable of differentiating the parts based on the individual part measurement and it is safe to perform the DMAIC process.*

***Key Words***: **MSA (Measurement System Analysis), Gage R&R Study, Part-to-part Variation.**

## 1. INTRODUCTION

Component manufacturing industries produce parts on a large scale. In this continuous manufacturing process, errors are an inevitable part. Hence, the industry always attempts to keep these errors within permissible limits so that the parts rejected are as less as possible. To check these errors, a measuring system is used. Every part goes through the measuring system under which it must be checked for errors to ensure that these errors don't get carried towards the end-users.

DMAIC methodology is used for part quality or process quality improvement in the industry. This process includes dynamic data collection which is primarily based on part dimensional measurements. AMT Pvt. Ltd. as a production-based company with 2 major verticals, wherein one is dedicated to producing machined components and the other one is wherein it has its own manufactured products. The company is known for its precision in machined products with tolerance in micrometers. Recently the one of the major industry machined parts are facing rejections and thus DMAIC process needs to be implemented for rectifying the possible errors in the part machining process. To interpret the part dimensions which are in micrometer, the Measurement System used in the industry must be completely free from variations or randomizations and simultaneously should be accurate enough to work within the calibrated limits to determine the variation in data collected during the DMAIC process.

MSA is a set of techniques that allows us to assess the reliability, repeatability, accuracy of the Measurement System. It is a set of experiments that mainly focuses on identifying the variation and takes into account the process of obtaining data and the instruments. It evaluates the test process, measuring equipment and the overall process of obtaining measurements to ensure the reliability of data used for analysis and to understand the effects and to take the decisions related to the same. The gauge study proves which part of the Measurement System is contributing the most to the instability of the measurements. Measurement Systems have variation from three major sources: The component, the operator taking measurements, and the device used. In a good measurement system, one must expect to calculate almost completely the variation in the products only. If the operators and devices create most of the variation, it shows that the system is not valid. Hence Measurement System Analysis takes into all the critical parameters like linearity, bias, stability, and GRR studies which help in determining the performance of the Measurement System. This research focuses on performing the GRR study on the industry's measurement system.

## 2. METHODOLOGY

Problem of variation in part dimensional measurement is identified in the industry. Research is done on examining and learning the process required for the determining the variation introduced in the part by the act of measuring. Study objectives are decided. Type of improvement technique to be implemented is selected. Data required for the selected technique is collected. Then the collected data is fed to Minitab software.

The results generated form Minitab software are interpreted to determine the amount of variation in the Measurement System. If there is a room for improvement in the Measuring System or the operators, solution and proper guidelines are recommended. Conclusion is given on the capability of the Measurement System if it qualifies for use.

## 3. LITERATURE REVIEW

**A. Jain (2017)** Applied measurement system analysis in a pump company and performed various studies to calculate the variation in the measurement system. The various studies were performed includes Bias, Linearity, GRR and Attribute R&R. The data was collected by using Vernier Caliper, Micrometer Dial Gauge and Air Gauge; analysis is done to validate whether it shows Bias, Linearity, GRR, Attribute R&R. Improvements were done to achieve acceptable performance from the measurement system.

**R. Bhakhri, and D.R. Belokar (2017)** Implemented Gauge R&R in engine spare parts manufacturing industry. The motive of the study to reduce the rejection rates and cost of poor quality of manufactured parts. DMAIC framework was used for the study. Minitab software was used to determine Repeatability & Reproducibility, Part-to-Part variation and Total variation.

**M. Sharma, S.P. Sahini, and S. Sharma (2019)** Conducted a study on the analysis of burst strength test equipment. He implemented the Crossed Gauge R&R (ANOVA) method. The overall aim of this research was to evaluate the effectiveness of Crossed Gauge R&R in quantifying measurement error. Thus, evidence formation from the Crossed Gauge R&R study combined with the manufacturing and measurement process served in distinguishing and excluding the root causes for measurement variation. This research thus proved useful as it stressed the effectiveness of Crossed Gauge R&R.

**A.M. Kazerouni (2009)** Published a paper on Decision Making based on ANOVA method. The aim of this research was to work out the need and assurance of in depth development in analyzing measurement systems, particularly with the utilization of Repeatability and Reproducibility Gages to improve physical measurements. This paper focuses on MSA as a comprehensive collection of tools for measurement, acceptance and data or errors analysis which consists of topics such as Statistical Process Control (SPC), capability analysis and GR&R. Thus, referring this paper helped strongly in the decision-making process considering all different forms of ANOVA method.

## 4. GAGE R&R STUDY

MSA is one of the pilot stages performed for quality improvement techniques.

Gage Repeatability & Reproducibility (Gage R&R): Gage Repeatability and Reproducibility (Gage R&R) is a methodology used to define the amount of variation present in the measurement data due to the measurement system. Gage R & R then compare measurement variation obtained to the total variability observed then defining the capability of the measurement system.

Types of Gage R &R:

1. Nested Gage R&R analysis: Nested Gage R&R nested analysis is used for evaluating repeatability and reproducibility of the measurement system where each operator measures one part once. Nested R&R evaluation is done using the ANOVA method.

2. Crossed Gage R&R analysis: Crossed Gage R&R crossed is the most commonly used method for evaluating repeatability and reproducibility of the measurement system where multiple operators measure multiple parts multiple times. It can be done with two approaches: one is ANOVA and the other is the method of mean averages and ranges.

3. Expanded Gage R&R analysis- Expanded Gage R&R is used when multiple factors affecting the measurement system are to be evaluated. Besides usual factors, the operator and the object, some other factors are taken into account. R&R evaluation is done using the ANOVA method.

How to Perform a Gage Repeatability & Reproducibility (Gage R&R):

There are definite techniques for completing a Gage R & R study. The two widely accepted methods for calculating Gage Repeatability and Reproducibility are as follows:

- The Average and Range Method
- The ANOVA (Analysis of Variance) Method

ANOVA Analysis

Method for Gage R&R analysis: The ANOVA (Analysis of Variance) Method.

ANOVA method provides an additional test for the possibility of an interaction between the operators and the parts. Therefore, the results obtained by the ANOVA method are more accurate as compared to the average and range method. ANOVA gage R&R measures the amount of variability induced in measurements by the measurement system itself and associates it to the total variability inspected to ascertain the viability of the measurement system.

Repeatability and Reproducibility Error (R&R), Appraiser variation (EV)/ Repeatability Error, Equipment Variation (EV)/ Reproducibility Error, Total Variation (TV) and Part-To-Part Variation are the sources of variation to be taken into account.

## 5. DATA COLLECTION


**Figure-1: Support latch**

In order to ensure the performance of the measurement system in accordance with the operators, hole of 32mm (32H7 Tolerance[+0.025 to -0.000]) Inner Diameter of 'Support latch' is chosen on the basis of its importance and part mass production by the industry. The study has been conducted with 10 such parts with 3 operators taking 3 measurements of each part during the data collection process.

**Table -5.1: MINITAB DATASHEET OF INNER DIAMETER OF SUPPORT LATCH FOR GAGE R&R STUDY (IN MILLIMETERS)**

| SR. NO. | PART | OPERATOR | MEASUREMENT |
|---|---|---|---|
| 1 | 1 | Yogesh | 32.008 |
| 2 | 1 | Yogesh | 32.009 |
| 3 | 1 | Yogesh | 32.009 |
| 4 | 2 | Yogesh | 32.028 |
| 5 | 2 | Yogesh | 32.029 |
| 6 | 2 | Yogesh | 32.028 |
| 7 | 3 | Yogesh | 32.020 |
| 8 | 3 | Yogesh | 32.021 |
| 9 | 3 | Yogesh | 32.021 |
| 10 | 4 | Yogesh | 32.016 |
| 11 | 4 | Yogesh | 32.015 |
| 12 | 4 | Yogesh | 32.016 |
| 13 | 5 | Yogesh | 32.013 |
| 14 | 5 | Yogesh | 32.014 |
| 15 | 5 | Yogesh | 32.014 |
| 16 | 6 | Yogesh | 32.022 |
| 17 | 6 | Yogesh | 32.023 |
| 18 | 6 | Yogesh | 32.022 |
| 19 | 7 | Yogesh | 32.012 |
| 20 | 7 | Yogesh | 32.013 |
| 21 | 7 | Yogesh | 32.012 |
| 22 | 8 | Yogesh | 32.019 |
| 23 | 8 | Yogesh | 32.020 |
| 24 | 8 | Yogesh | 32.020 |
| 25 | 9 | Yogesh | 32.015 |
| 26 | 9 | Yogesh | 32.016 |
| 27 | 9 | Yogesh | 32.015 |
| 28 | 10 | Yogesh | 32.010 |
| 29 | 10 | Yogesh | 32.009 |
| 30 | 10 | Yogesh | 32.010 |
| 31 | 1 | Deepak | 32.008 |
| 32 | 1 | Deepak | 32.009 |
| 33 | 1 | Deepak | 32.008 |
| 34 | 2 | Deepak | 32.027 |
| 35 | 2 | Deepak | 32.028 |
| 36 | 2 | Deepak | 32.028 |
| 37 | 3 | Deepak | 32.020 |
| 38 | 3 | Deepak | 32.021 |
| 39 | 3 | Deepak | 32.021 |
| 40 | 4 | Deepak | 32.016 |
| 41 | 4 | Deepak | 32.015 |
| 42 | 4 | Deepak | 32.015 |
| 43 | 5 | Deepak | 32.012 |
| 44 | 5 | Deepak | 32.013 |
| 45 | 5 | Deepak | 32.014 |
| 46 | 6 | Deepak | 32.023 |
| 47 | 6 | Deepak | 32.022 |
| 48 | 6 | Deepak | 32.022 |
| 49 | 7 | Deepak | 32.013 |
| 50 | 7 | Deepak | 32.013 |
| 51 | 7 | Deepak | 32.012 |
| 52 | 8 | Deepak | 32.020 |
| 53 | 8 | Deepak | 32.021 |
| 54 | 8 | Deepak | 32.020 |
| 55 | 9 | Deepak | 32.016 |
| 56 | 9 | Deepak | 32.015 |
| 57 | 9 | Deepak | 32.015 |

| | | | |
|---|---|---|---|
| 58 | 10 | Deepak | 32.010 |
| 59 | 10 | Deepak | 32.009 |
| 60 | 10 | Deepak | 32.010 |
| 61 | 1 | Harish | 32.008 |
| 62 | 1 | Harish | 32.008 |
| 63 | 1 | Harish | 32.009 |
| 64 | 2 | Harish | 32.027 |
| 65 | 2 | Harish | 32.028 |
| 66 | 2 | Harish | 32.028 |
| 67 | 3 | Harish | 32.019 |
| 68 | 3 | Harish | 32.020 |
| 69 | 3 | Harish | 32.020 |
| 70 | 4 | Harish | 32.016 |
| 71 | 4 | Harish | 32.015 |
| 72 | 4 | Harish | 32.013 |
| 73 | 5 | Harish | 32.013 |
| 74 | 5 | Harish | 32.014 |
| 75 | 5 | Harish | 32.013 |
| 76 | 6 | Harish | 32.022 |
| 77 | 6 | Harish | 32.022 |
| 78 | 6 | Harish | 32.023 |
| 79 | 7 | Harish | 32.014 |
| 80 | 7 | Harish | 32.012 |
| 81 | 7 | Harish | 32.014 |
| 82 | 8 | Harish | 32.019 |
| 83 | 8 | Harish | 32.020 |
| 84 | 8 | Harish | 32.020 |
| 85 | 9 | Harish | 32.015 |
| 86 | 9 | Harish | 32.016 |
| 87 | 9 | Harish | 32.016 |
| 88 | 10 | Harish | 32.010 |
| 89 | 10 | Harish | 32.008 |
| 90 | 10 | Harish | 32.009 |

## 4. ANALYTICAL GAGE R&R ANOVA REPORT FOR MEASUREMENT

| Source | VarComp | 95% CI | %Contribution (of VarComp) | 95% CI |
|---|---|---|---|---|
| Total Gage R&R | 0.0000005 | (0.000, 0.000) | 1.263 | (0.372, 3.523) |
| Repeatability | 0.0000005 | (0.000, 0.000) | 1.256 | (0.370, 2.827) |
| Reproducibility | 0.0000000 | (0.000, 0.000) | 0.007 | (0.000, 1.834) |
| Operator | 0.0000000 | (0.000, 0.000) | 0.007 | (0.000, 1.834) |
| Part-To-Part | 0.0000367 | (0.000, 0.000) | 98.737 | (96.477, 99.628) |
| Total Variation | 0.0000372 | (0.000, 0.000) | 100.000 | |

Process tolerance = 0.025

**Figure-2: Variance Components Table**

| Source | StdDev (SD) | 95% CI | Study Var (6 × SD) | 95% CI | %Study Var (%SV) |
|---|---|---|---|---|---|
| Total Gage R&R | 0.0006856 | (0.001, 0.001) | 0.0041138 | (0.004, 0.007) | 11.238 |
| Repeatability | 0.0006838 | (0.001, 0.001) | 0.0041025 | (0.004, 0.005) | 11.208 |
| Reproducibility | 0.0000506 | (0.000, 0.001) | 0.0003038 | (0.000, 0.005) | 0.830 |
| Operator | 0.0000506 | (0.000, 0.001) | 0.0003038 | (0.000, 0.005) | 0.830 |
| Part-To-Part | 0.0060622 | (0.004, 0.011) | 0.0363729 | (0.025, 0.066) | 99.366 |
| Total Variation | 0.0061008 | (0.004, 0.011) | 0.0366048 | (0.025, 0.067) | 100.000 |

**Figure-3: Gage Evaluation Table 1**

| Source | 95% CI | %Tolerance (SV/Toler) | 95% CI |
|---|---|---|---|
| Total Gage R&R | (6.103, 18.770) | 16.455 | (14.306, 26.208) |
| Repeatability | (6.083, 16.813) | 16.410 | (14.190, 19.460) |
| Reproducibility | (0.000, 13.543) | 1.215 | (0.000, 20.090) |
| Operator | (0.000, 13.543) | 1.215 | (0.000, 20.090) |
| Part-To-Part | (98.223, 99.814) | 145.492 | (99.993, 265.741) |
| Total Variation | | 146.419 | (101.340, 266.255) |

Number of Distinct Categories = 12
95% CI = (7.40053, 23.1302)

**Figure-4: Gage Evaluation Table 2**

## 5. GRAPHICAL GAGE R&R ANOVA REPORT FOR MEASUREMENT

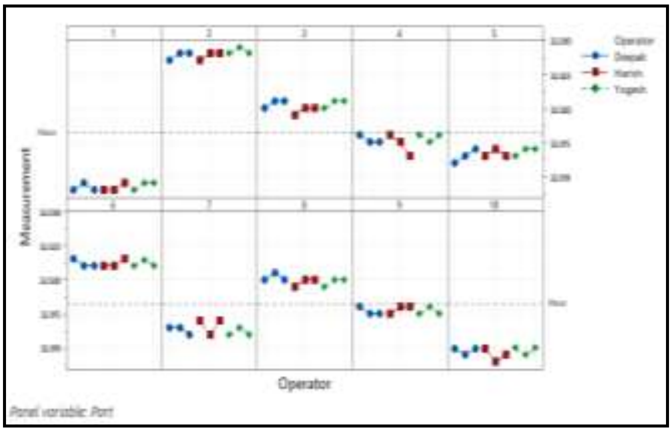


**Chart -1: Gage Run Chart of Measurement by Part, Operator**

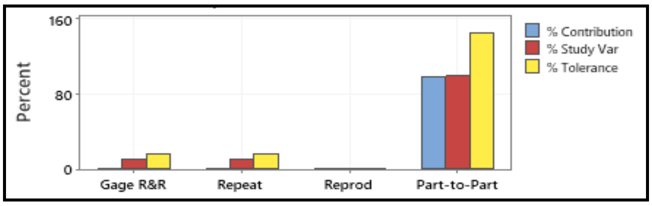


**Chart -2: Components of Variation**

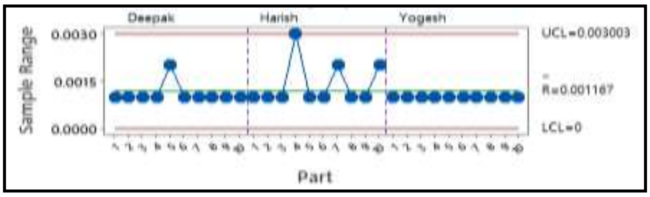


**Chart -3: R Chart by Operator**

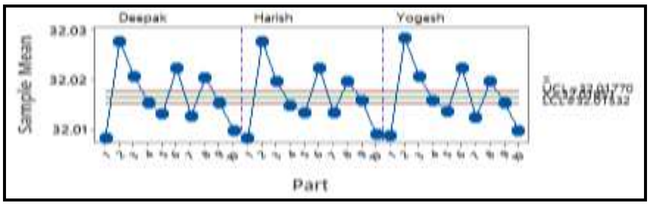


**Chart -4: X-Bar Chart by Operator**

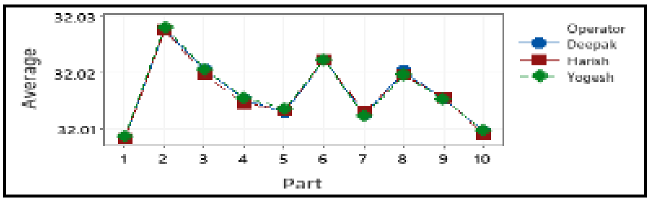


**Chart -5: Part*Operator Interaction**

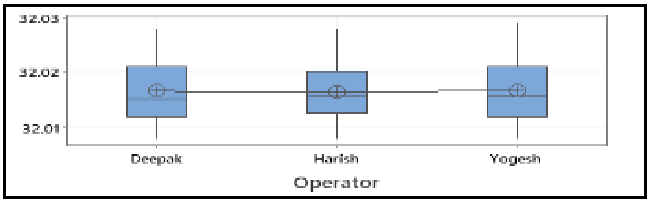


**Chart -6: Measurement by Operator**

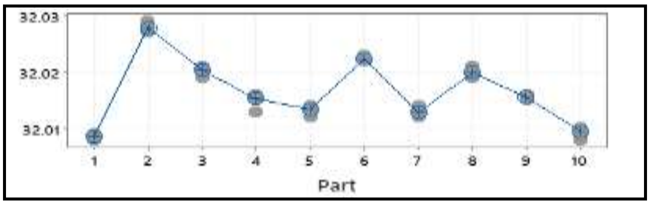


**Chart -7: Measurement by Part**

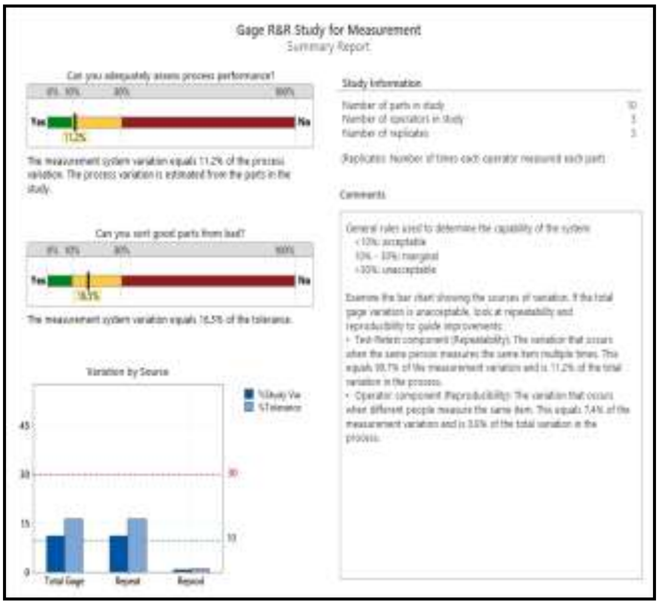


**Figure-5: Summary Report**

## 6. CONCLUSION

The following can be concluded from 'ANALYTICAL GAGE R&R ANOVA REPORT FOR MEASUREMENT'. (Gage Studies for Continuous Data [PDF], 2010) In the Variance Components table, 98.737% of the total variation is because of the difference between parts. As %contribution for the part to part is high, the measurement system can precisely differentiate between parts. Variation in 'Repeatability' of an operator is the major contributor in %Total Gage R&R percentage and thus can be lowered down by increasing concentration of the operator to take multiple readings of the same part.

The %Study Var results indicate that the measurement system accounts for 11.238% of the overall variation in this study, which is very close to 10% and slight performance improvements in the system can rectify the value to <10% of the overall variation. %Tolerance of the value of 16.45% of total variation compares measurement system variation to specifications. As the value is more than 10% there is a bit scope for improvement in the part machining process. The value of the number of distinct categories is equal to 12 which makes the system acceptable (Automotive Industry Action Group [AIAG]) and it can distinguish between parts.

From 'GRAPHICAL GAGE R&R ANOVA REPORT FOR MEASUREMENT' following can be concluded. In Gage Run Chart of Measurement by Part, the Operator indicates that all the operators have good repeatability over all the measurements. Also, the differences in the measurements between operators for the same part are small.

In the Components of Variation chart, it can be rendered that the largest component of variation is part-to-part variation. Since the part number 2 is out of tolerance limit, the hiked up %tolerance measure in part-to-part variation can be observed. R-Chart by operator depicts the consistency of the 3 operators in the measuring part and all the points fall within the control limits. From the X-bar chart, it can be interpreted that all the operators follow the same measuring pattern and part-to-part variation is much greater than measurement system variation.

The virtually identical operator lines Part*Operator plot indicates that the operators are measuring the parts similarly. The horizontal line along X-axis in Measurement by operator plot shows that the measurements and variability are consistent among operators, with little room for improvement in the case of Harish (operator 2). The Measurement by part plot indicates the clear differences between the parts and enough variation in averages.

Thus, Equipment Variation (repeatability variation) which is the main contributing factor in the variation can be reduced by training selective operators like Harish (operator 2) to take accurate and precise repetitive measurements of the same feature of a part. From the above interpretation, it can be concluded that the Measurement System of the industry is capable of differentiating the parts based on the individual part measurement and contributes very little to the overall variation, as confirmed by both the Gage R&R table and graphs.

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https://www.amtplindia.com/

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