

# Understanding Measurement System Analysis (MSA) also known as Gage R&R analysis for Instron® Testing Systems

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## Introduction:

Measurement system analysis (MSA), also known as a gage R&R (GRR) study, is a critical tool in understanding the capabilities of any system used to measure a part or a specimen. In the process of measuring with manually operated equipment, common sources of variation observed are: the specimen or part, the measurement device, and the operator.

Fundamentally, GRR, where the “RR” stands for “repeatability and reproducibility”, is essential to; (a) determine the total observed variability due to the gage or instrument, (b) isolate the components of variability in the system, and (c) assess if the instrument is suitable or capable for the intended application. The two “R’s” used in this study indicate if the gage/instrument is capable of recording the same observed value if we measure the same part several times under ideal conditions (repeatability) and how variation is observed when parts are measured under different conditions such as different operators and/or time periods (reproducibility).

The core question answered by this study is whether the gage or instrument is capable of distinguishing between good and bad units? The cause and effect diagram below identifies majority source of variations with a gage system or instrument.

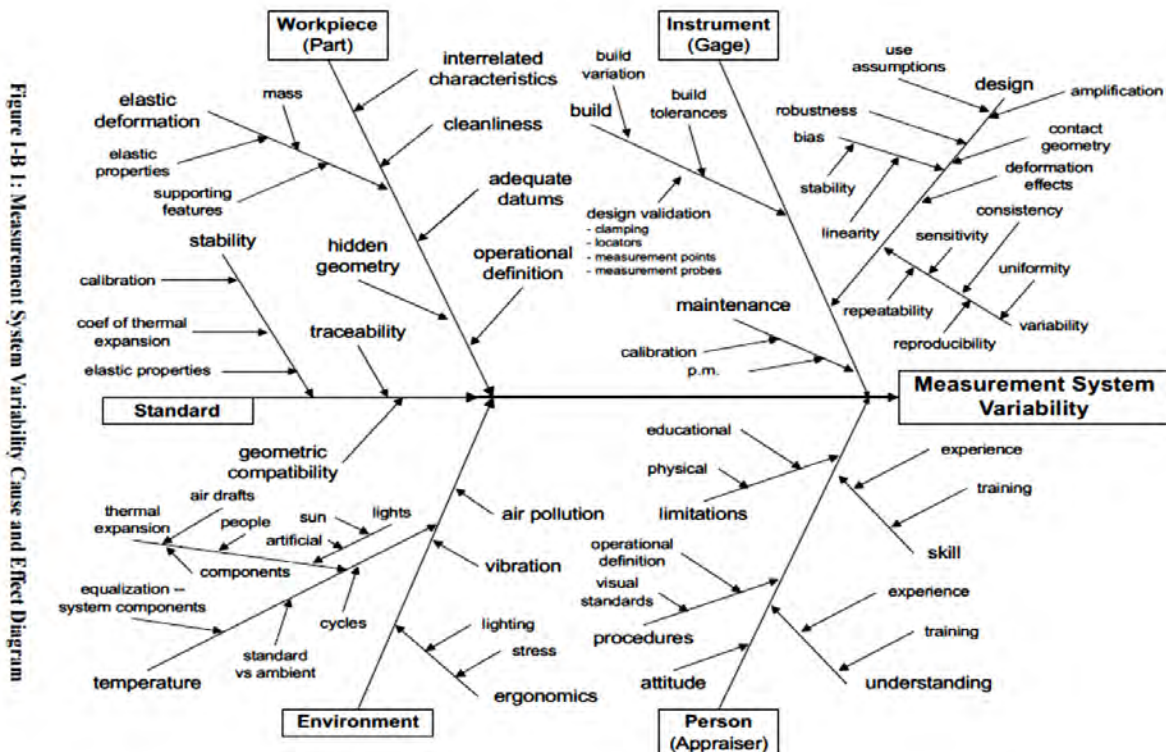


Figure 1: Cause and effect diagram (fishbone diagram) on multiple sources of variation [2]

As presented in Figure 1, there are multiple factors from various sources such as environment, operator, workpiece/part, and gage that can introduce measurement variability.

## Gage R&R Analysis:

There are two types of GRR analysis: the analysis of variance (ANOVA) method and the average and range method ( $\bar{x}$  and R).

### ANOVA Method:

The ANOVA method is a powerful technique to estimate the variability of each component or factor in the experiment while understanding the effect of each factor on the response (measurement). In a typical GRR study the user is interested in understanding the effect of factors such as the parts and/or operators. Therefore, ANOVA can be extended to apply in GRR studies to learn the sources of variation. The analysis estimates p-value (probability value) that is used to statistically determine if a factor has a significant effect on the experiment or not. If the p-value is less than 0.05 (based on 95% confidence interval) then that factor is highly significant in the study. Furthermore, the contribution of variation from each factor and the total %R&R can be estimated.

### $\bar{x}$ and R Method:

The  $\bar{x}$  and R method is an alternate method for conducting a GRR analysis. This method is used when a lower sample size is preferred for the number of trials per part per operator. A set of mathematical equations are defined to estimate %R&R, making this method easy for calculations.

The  $\bar{x}$  and R method, unlike the ANOVA method, does not have the ability to estimate interactions between parts and operators and does not estimate errors from the experiment. Therefore the ANOVA method is preferred for GRR studies with the availability of powerful statistical software packages.

Figure 2 presents a sample graphical summary from a GRR experiment conducted. All the components variations are presented in this study.

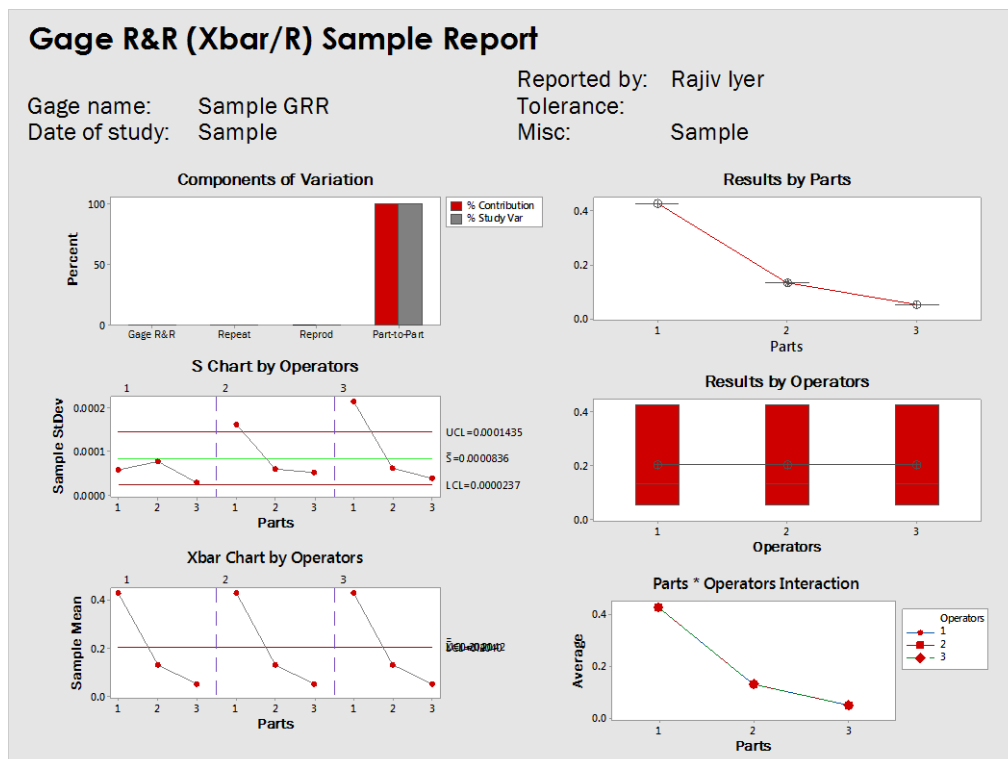


Figure 2: Gage R&R graphical results on variation contribution to the measurement by various factors [3]  
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Figure 2 shows the part-to-part as high source of variation compared to operators (reproducibility) and the gage itself. This means the majority of the variation comes from the parts used in the study, resulting in low total gage variations (%R&R). From Figure 2, one can interpret that the gage is capable of measurements.

The guidelines for GRR studies were defined originally by Automotive Industry Action Group (AIAG) back in the 1990s. An MSA reference manual was created and approved by Chrysler Motors, GM Corporation, and Ford Motors Company. The guidelines are defined for the %R&R estimates that will help determine if a gage is capable or not. They are as presented in Table 1.

Table 1: AIAG guidelines for GRR acceptance

GRR	DECISION	COMMENTS
Under 10%	Generally considered to be an acceptable measurement system.	Recommended, especially useful when trying to sort or classify parts or when tightened process control is required.
10% to 30%	May be acceptable for some applications.	Decision should be based upon, for example, importance of application measurement, cost of measurement device, and cost of rework or repair. Should be approved by the customer.
Over 30%	Considered to be unacceptable.	Every effort should be made to improve the measurement system. This condition may be addressed by the use of an appropriate measurement strategy; for example, using the average result of several reading of the same part characteristic in order to reduce final measurement variation.

## How GRR applies to Instron® Testing Systems?

Instron systems are commonly used to test properties and performance of various materials, components, and structures composed of plastics, metals, and composites, among others. Since accurate measurement is an integral part of Instron systems, it is important to understand the repeatability and reproducibility capabilities. With respect to materials testing, it is critical GRR considers a range of specimens that represent all materials that may be tested. Fundamentally, the study is designed to determine if a system has the capability to identify good parts from bad parts. Therefore, when applied to Instron systems, it is essential that the measurement intended varies significantly to identify part to part variation.

GRR can be classified into two types: non-destructive GRR and destructive GRR. Non-destructive testing is an easier approach when conducting GRR, assuming the specimens in the study do not change in physical properties that can affect the measurements over time. For example, specimens such as springs can be used in the GRR study because springs are stable under ambient conditions over time and do not change physical properties over multiple measurements. Therefore, the measurement intended for springs which is the spring stiffness should vary amongst the specimens used (ex. springs of stiffness 0.1 kN/mm, 0.5 kN/mm, and 1 kN/mm are recommended).

However, as a part of GRR experiment planning, it is recommended to use specimens that mimic the system's intended applications with a distinct difference in measurements between specimens. This will best evaluate the measurement capabilities of the Instron system under study. For example, if an application involves testing plastics, it is recommended to consider using a variety of plastic specimens such as rigid, semi-rigid, and soft plastic materials to introduce part variation for distinct measurements.



Destructive GRR studies are more rigorous when compared to non-destructive GRR because specimens are tested until they fail or break and therefore cannot be re-used in the experiment. Although rigorous, this study adds value to the measurement evaluation of Instron systems which are widely used in destructive testing applications. The fundamental concept of destructive GRR is the same, where the measurement intended to be studied should be distinctly different between the specimens used in the study. A key assumption introduced in the destructive GRR is that all the specimens obtained from one single batch are almost identical to each other.

To plan a destructive GRR experiment it is most important to consider specimens that are relevant to the system's intended application. For example, if an application involves testing metal specimens, then it is important to use metals of distinctly different strengths as part variation in the GRR planning. Since the test involves breaking metal specimens, a part can be used only once in the study and therefore when running multiple trials, it is highly recommended to consider using metals from a single batch so they are almost identical to each other. Significant variations in measurements of metals from a single batch can add bias to the study and mislead the GRR results by masking the variations of different types of metals used in the same study.

Introducing only one part among different operators is not a recommended test methodology for above GRR study. In that case, a different format of GRR study is recommended known as Type I gage study or precision to tolerance ratio (P/T ratio).

### Type I Gage Study of Precision to Tolerance Ratio (P/T Ratio)

In simple terms, a Type I gage study is used to understand the precision and accuracy of measurement system without considering other sources of variation such as operators or parts. The Type I gage study is typically used to check measurement capabilities of old or pre-installed systems or when only a single part is available. The comprehensive GRR methods detailed in previous sections are commonly used for brand new or newly installed systems.

P/T ratio is used to estimate how precise the data is to the defined tolerances or specification limits set by the user. This method is used to analyze the variation coming from the gage due to its limitations in measurements and therefore requires only one part to be measured by one operator, multiple times. P/T ratio is commonly applied to qualify a machine or instrument used in production or quality control (QC) environments.

With Instron® systems, if a user is interested in learning the GRR capabilities within 10% tolerance, then a non-destructive test can be introduced such as the spring example above, but considering only one spring and one operator to run the test and measuring stiffness multiple times. Again, a specimen that closely represents the intended application requirement is recommended for P/T analysis. P/T ratio follows the same guidelines defined by AIAG in Table 1.

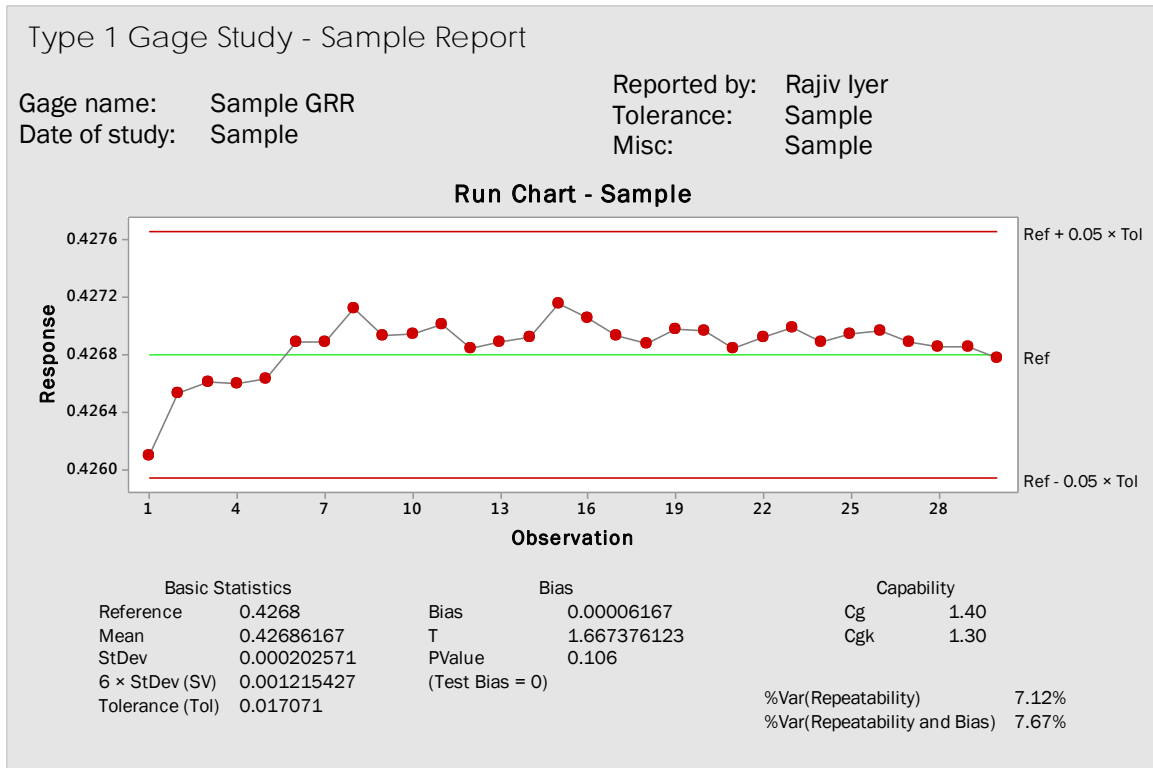


Figure 3: P/T results summary for diameter measurement of one part [3]

Figure 3 shows detailed results from a Type I gage study performed when measuring the diameter of a part. The P/T value indicated by the parameter “%Var (Repeatability)” is 7.12%. Based on guidelines from AIAG, the P/T ratio is below 10% and therefore it can be concluded that the gage is capable of measurement.

This concludes the detailed overview of the GRR studies that are important when understanding an Instron® system’s measurement capabilities.

For more information and discussions on this please contact us at [www.instron.com](http://www.instron.com).

## References

1. Montgomery, C. D., 2009, Introduction to Statistical Quality Control (6<sup>th</sup> ed.), John Wiley & Sons, USA.
2. Chrysler, Ford, and GM (2010), Measurement Systems Analysis Reference Manual (4<sup>th</sup> ed.), AIAG, Detroit, MI.
3. MINITAB 17, Statistical Software Package.