Evaluation of a Weight Measurement System in a Manufacturing Process Using Gage R&R Analysis

Oasis Rodríguez Reynoso
Master of Engineering in Manufacturing Engineering
Advisor: José A. Morales, Ph.D.
Polytechnic University of Puerto Rico
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Abstract *— Measurement systems play a role in manufacturing environments because process decisions depend on accurate and reliable data. This study evaluates the performance of a digital weighing system through a Measurement System Analysis using a Gage Repeatability and Reproducibility approach. The objective was to determine whether the system can produce consistent and reproducible measurements suitable for quality related decision making. The study involved ten parts, three operators, and three repeated measurements per part, a total of ninety observations. Statistical analysis was performed using the Analysis of Variance method to quantify repeatability, reproducibility, and total measurement variation. Results showed a total Gage R&R value of 3.97 percent, indicating that the system meets industry acceptance criteria. Variation was attributed to part-to-part differences, while the Number of Distinct Categories confirmed discrimination capability. These findings demonstrate that the measurement system is stable, reliable, and appropriate for manufacturing process control and quality assurance applications.*

Keywords *— Measurement System Analysis, Gage Repeatability and Reproducibility (Gage R&R), Manufacturing Quality, Process Control.*

INTRODUCTION

Measurement systems are fundamental components of manufacturing and quality assurance processes because operational and quality-related decisions depend on accurate and reliable data [1]. In modern manufacturing environments, critical product characteristics such as weight, dimensions, torque, and pressure must be measured consistently to ensure compliance with technical specifications and process requirements. When a measurement system has not been properly validated, part of the observed variation may originate from the measurement device or operator influence rather than actual product variation.

Measurement System Analysis (MSA) is widely used to evaluate the capability, stability, and reliability of measurement systems before their data are used for process control or product acceptance decisions [2]. Among the different MSA techniques, Gage Repeatability and Reproducibility (Gage R&R) is one of the most applied statistical methods because it separates measurement variation into repeatability and reproducibility components [2].

Repeatability refers to the variation observed when the same operator measures the same part multiple times using the same equipment under the same conditions. Reproducibility refers to the variation introduced by differences among operators performing the same measurement task [1]. Together, these components determine the overall contribution of the measurement system to total process variation.

In applications where product weight is a critical quality characteristic, reliable measurement systems are essential to ensure process stability and accurate decision-making. An inadequate weighing system may lead to incorrect conclusions regarding product conformity, unnecessary rejection of acceptable units, or the inability to detect true process changes.

The purpose of this research is to evaluate the adequacy and performance of a digital weighing system used in a manufacturing-type environment through a Gage R&R study using the Analysis of Variance method. The study aims to determine whether the measurement system produces consistent and reliable measurements suitable for manufacturing process control and quality assurance applications.

LITERATURE REVIEW

Measurement System Analysis is recognized as an essential element of statistical quality control and continuous improvement methodologies such as Lean Six Sigma. According to AIAG [2], a capable measurement system must demonstrate adequate repeatability and reproducibility before its data can be considered reliable for decision-making.

Montgomery explains that inaccurate measurement systems can distort process variation and negatively affect process capability studies, root-cause investigations, and quality control activities [1]. Because manufacturing decisions rely heavily on measurement data, organizations must ensure that their measurement systems are validated and controlled.

Gage Repeatability and Reproducibility studies are among the most widely used techniques within MSA because they quantify how much variation originates from the equipment and how much originates from operators. Previous studies have demonstrated the effectiveness of Gage R&R analysis in evaluating scales, calipers, coordinate measuring machines, and other industrial measurement devices [3].

Additionally, literature related to metrology emphasizes the importance of accuracy, precision, repeatability, calibration, and traceability in manufacturing environments [4]. Even simple measuring devices, such as digital weighing scales, require formal evaluation to ensure their suitability for process monitoring and product verification.

Measurement systems are directly related to manufacturing process capability because all process decisions are based on collected data. If a measurement system is not reliable, process capability indices such as Cp and Cpk may provide misleading conclusions regarding process performance [1]. For this reason, MSA is commonly performed before Statistical Process Control studies.

Lean Six Sigma methodologies also recognize measurement system validation as a critical requirement during the Measure phase of the DMAIC framework [5]. Organizations implementing continuous improvement programs rely on accurate measurement systems to identify root causes, quantify variation, and validate process improvements.

According to ISO 9001 and ISO 10012 standards, organizations must establish measurement management systems capable of ensuring valid and traceable results [6], [7]. This reinforces the importance of evaluating measuring devices before using their data for quality assurance activities.

Researchers have also identified operator influence as a major source of variability in industrial environments. Differences in operator experience, handling techniques, interpretation of procedures, and environmental conditions may significantly affect measurement consistency [8]. Gage R&R studies help organizations identify these sources of variation and implement corrective actions such as training, standardization, or calibration improvements.

The Analysis of Variance method is considered one of the most robust approaches for conducting Gage R&R studies because it allows the separation of repeatability, reproducibility, and interaction effects between operators and parts [1]. Compared to the Average and Range method, the ANOVA approach provides a more detailed statistical interpretation of measurement system variation.

Literature consistently supports the use of statistical methods such as Gage R&R to validate measurement systems and minimize the risk of making incorrect manufacturing decisions due to measurement errors.

METHODOLOGY

This study applied a crossed Gage Repeatability and Reproducibility experimental design to evaluate the performance of a digital weighing system used in a manufacturing-type process [2].

Materials and Equipment

The following materials and equipment were used during the study [9]:

- Digital weighing scale with 0.01 g resolution
- Ten representative parts with different weight values
- Three operators
- Data collection sheet and spreadsheet software
- Statistical analysis software

Experimental Design

The study followed a crossed experimental design in which all operators measured all parts multiple times using the same measurement device. The experimental structure included [9]:

- 10 parts
- 3 operators
- 3 repeated measurements per part
- Total measurements = 90

The order of measurements was randomized to minimize potential bias during data collection.

Data Collection Procedure

Each operator independently measured each part three times using the digital weighing system. All measurement values were recorded in a structured data collection sheet that included:

- Part identification number
- Operator identification
- Trial number
- Measured weight value

Prior to analysis, the dataset was reviewed to verify data integrity, identify transcription errors, and confirm the absence of missing values or significant outliers.

Statistical Analysis

The data collected were analyzed using the Analysis of Variance method for Gage R&R analysis [2]. The study quantified the following measurement system components:

- Equipment Variation (EV)
- Appraiser Variation (AV)
- Total Gage R&R
- Part-to-Part Variation (PV)
- Number of Distinct Categories (NDC)

Industry-accepted criteria were used to evaluate measurement system adequacy:

- Less than 10% = Acceptable
- Between 10% and 30% = Marginally acceptable
- Greater than 30% = Unacceptable

RESULTS AND DISCUSSION

This section presents the results obtained from the data collection phase of the study, which was conducted according to the defined experimental design. The objective of this stage was to ensure that the collected data were accurate, complete, and representative of typical process conditions before performing the statistical analysis. Proper data validation is essential to guarantee the reliability of the subsequent Gage Repeatability and Reproducibility (Gage R&R) evaluation.

Data Collection Results

A total of ninety measurements were collected according to the experimental design. The study included ten parts, three operators, and three repeated measurements per part. All measurements were obtained using a calibrated digital weighing scale with a resolution of 0.01 grams.

The dataset was reviewed before statistical analysis. No missing values, transcription errors, or significant outliers were identified. Therefore, the data was considered valid and appropriate for Gage R&R analysis.

The selected parts represented the expected range of variation commonly observed in the process. This allowed the study to evaluate whether the measurement system could reliably detect real differences between products.

Operators performed measurements independently to simulate realistic manufacturing conditions. The order of measurements was randomized to reduce potential bias associated with measurement sequence or operator expectation.

Gage R&R Results

This section presents the results of the Gage Repeatability and Reproducibility analysis, which was conducted to evaluate the overall performance of the measurement system. The objective of this analysis is to quantify the contribution of measurement variation to the total observed variability and determine whether the system meets established industry acceptance criteria.

The Gage Repeatability and Reproducibility analysis was performed using the Analysis of Variance method.

The Total Gage R&R value of 3.97% indicates that the measurement system is acceptable according to industry standards because the variability introduced by the measurement system is below the 10% threshold [2]. (Refer to Table 1).

The analysis also demonstrated that most of the observed variation originated from actual differences between parts rather than from measurement error. This indicates that the weighing system is capable of accurately distinguishing differences among products.

Table 1
Gage R&R Study Results

Source	% Study Variation	% Contribution	Interpretation
Total Gage R&R	3.97%	0.16%	Acceptable (< 10%)
Repeatability (EV)	3.20%	0.10%	Variation due to equipment (repeatability)
Reproducibility (AV)	2.35%	0.06%	Variation due to operators (reproducibility)
Operator	2.12%	0.04%	Differences among operators
Operator*Part	0.30%	0.01%	Interaction between operator and part
Part-to-Part	99.92%	99.84%	Actual variation among parts
Total Variation	100.00%	100.00%	Total observed variation

The contribution of the measurement system to total variation was minimal compared to the contribution generated by actual part-to-part differences. This is considered the desired condition for an effective manufacturing measurement system [2].

Repeatability and Reproducibility Analysis

Total measurement variation is further decomposed into repeatability and reproducibility components to quantify equipment variability and operator effects.

The repeatability component contributed 3.20% of the total variation, while reproducibility contributed 2.35%. These results indicate that the measurement system exhibits strong consistency during repeated measurements and minimal operator influence [2] (Refer to Figure 1).

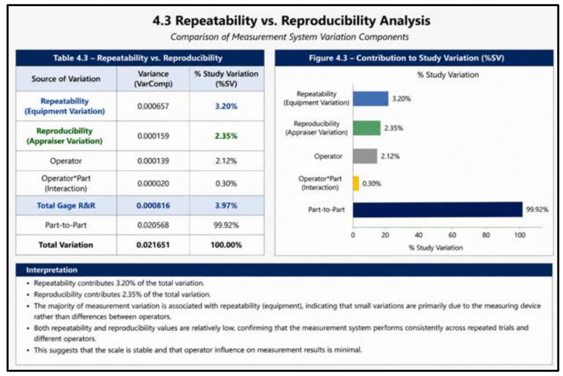

Figure 1
Repeatability vs. Reproducibility Analysis

The low reproducibility value confirms that operators performed measurements consistently across all trials, while the low repeatability value demonstrates stable equipment performance.

Repeatability is particularly important because it evaluates the inherent consistency of the measurement device itself. In this study, the low repeatability variation indicates that the weighing scale produces highly consistent readings when the same operator measures the same part multiple times.

Reproducibility evaluates the consistency among different operators. The low reproducibility obtained demonstrates that operator technique and interpretation had minimal influence on the final measurement results, consistent with accepted MSA principles [2]. This suggests that the measurement procedure is well understood and consistently applied.

The interaction between operators and parts was also minimal, indicating that no operator measured certain parts differently from others. This is an important indicator of process consistency and measurement reliability [2].

Graphical Analysis

Graphical analysis provides a comprehensive evaluation of the measurement system by assessing its stability, repeatability, and ability to detect variation across samples. These visual tools allow for the identification of patterns, consistency in measurements, and potential sources of variability, supporting a more complete interpretation of the system performance.

Graphical analysis was conducted to further evaluate measurement system behavior.

X-bar Chart

The X-bar chart showed several points outside the control limits, indicating that the system can successfully detect true variation between parts. (Refer to Figure 2).

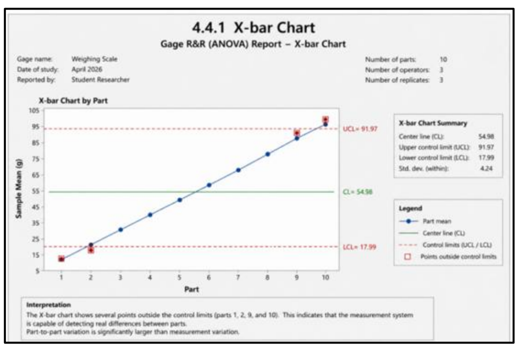

Figure 2
Gage R&R X-bar Chart

This behavior is desirable because it demonstrates that the variation among parts is significantly larger than the variation introduced by the measurement system [2]. If all points remained within the control limits, it could indicate that the measurement system lacks sufficient sensitivity to detect real differences among products.

The chart confirmed that the measurement system has adequate discrimination capability and can identify actual variation within the manufacturing process.

R Chart

The R chart demonstrated that all sample ranges were within control limits, confirming stable repeatability and measurement consistency [2]. (Refer to Figure 3).

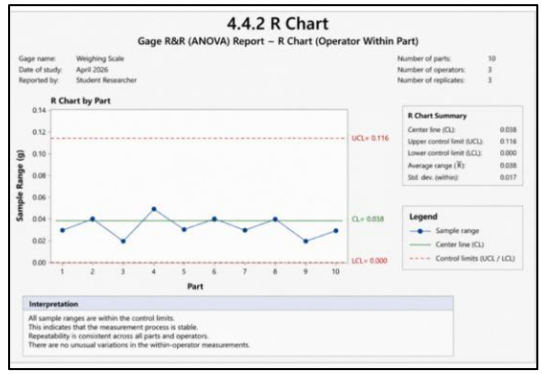

Figure 3
R Chart

Because all ranges remained under statistical control, the study confirmed that the measurement process is stable across repeated trials and operators. No abnormal variability or inconsistent measurement behavior was identified during the experiment.

The R chart also demonstrated that the weighing system produces repeatable measurements regardless of the operator performing the measurement.

Operator vs Part Interaction Plot

Further evaluation of the measurement system includes the analysis of operator interaction effects, sources of variation, and system capability. These assessments provide a comprehensive understanding of measurement behavior, variability contributions, and the system's ability to reliably distinguish differences among parts.

The interaction plot showed mostly parallel lines with minimal crossing, indicating low interaction between operators and parts. This suggests that operator-related variability is minimal.

Minimal interaction between operators and parts indicates that all operators follow a consistent measurement pattern and interpret the measurement procedure similarly. This is important because high interaction effects may indicate inconsistent techniques, unclear procedures, or operator bias [2].

The results obtained in this study confirm that operator influence on the measurement system is negligible [2]. (Refer to Figure 4).

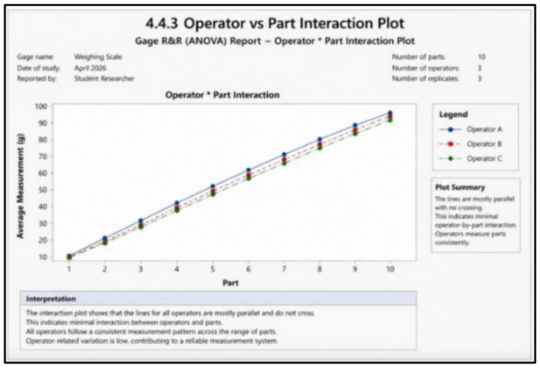

Figure 4
Operator vs Part Interaction Plot

Components of Variation

The components of variation chart confirmed that part-to-part variation represented the dominant source of variation, while measurement system variation remained minimal.

The part-to-part variation value of 99.92% demonstrates that nearly all observed variation corresponds to actual differences between parts rather than errors generated by the measurement system [2].

This confirms that the measurement system accurately reflects true product variability and can support manufacturing quality decisions [2]. (Refer to Figure 5).

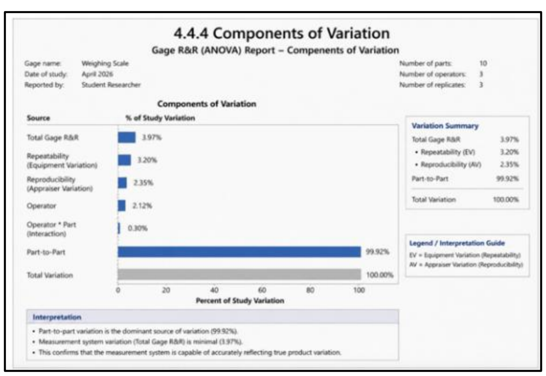

Figure 5
Components of Variation Chart

Measurement System Capability

The Number of Distinct Categories value obtained during the study was:

- NDC = 35

Because the NDC value is greater than 5, the measurement system demonstrates excellent discrimination capability. This confirms that the system can reliably differentiate between parts with different weight values.

An elevated NDC value indicates that the measurement system possesses strong sensitivity and can separate products into multiple distinct categories based on measured variation [2].

According to AIAG guidelines, systems with NDC values greater than 10 are considered excellent [2]. Therefore, the value obtained in this study demonstrates exceptional system capability. (Refer to Figure 6.

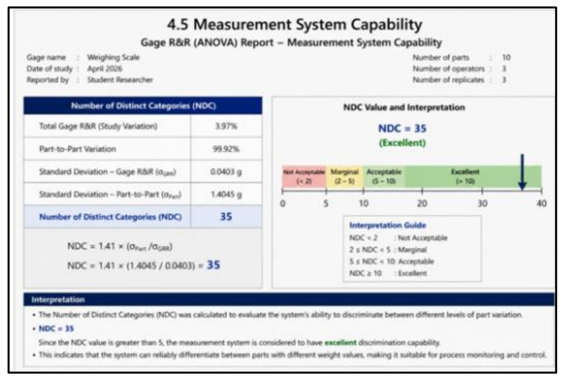

Figure 6
Measurement System Capability

Discussion

The following discussion integrates the statistical and graphical findings to evaluate the overall performance, reliability, and suitability of the measurement system within a manufacturing context. Emphasis is placed on the interpretation of variability sources, system capability, and the practical implications for process control and quality assurance.

The results of the study demonstrate that the digital weighing system satisfies the requirements for reliability and capability in manufacturing environments. The low Total Gage R&R value indicates that the measurement system contributes only a small percentage of total variation [2].

Additionally, the graphical analysis confirmed measurement stability, low operator influence, and strong discrimination capability. These findings support the suitability of the weighing system for quality control, product acceptance decisions, and process monitoring activities.

The study also reinforces the importance of validating measurement systems before relying on their data for manufacturing decision-making [2]. Even simple measurement devices require formal evaluation to ensure data integrity and process reliability.

From a manufacturing perspective, the use of an inadequate measurement system could result in false process adjustments, unnecessary product rejection, increased operational costs, and inaccurate quality reporting. Therefore, validating measurement systems contribute directly to operational efficiency and continuous improvement [5].

The results also demonstrate the value of integrating statistical quality tools into manufacturing operations. Gage R&R studies provide organizations with quantitative evidence regarding the adequacy of their measurement systems and help identify opportunities for improvement [2].

The findings obtained in this study are aligned with previous literature that emphasizes the importance of capable measurement systems for supporting Statistical Process Control and Lean Six Sigma initiatives [1], [5].

Overall, the results confirm that the weighing system is stable, reliable, and appropriate for manufacturing process control and quality assurance applications.

CONCLUSION

The purpose of this research was to evaluate the performance and adequacy of a weight-based measurement system using a Gage Repeatability and Reproducibility study.

The results demonstrated that the measurement system is acceptable for manufacturing applications because the Total Gage R&R value obtained was 3.97%, which is significantly below the accepted industry threshold of 10% [2].

The study confirmed that most observed variation originated from actual differences between parts rather than from measurement error. Additionally, both repeatability and reproducibility values were low, indicating stable equipment performance and consistent operator technique.

The Number of Distinct Categories value of 35 demonstrated excellent discrimination, confirming that the system can reliably distinguish among parts [2].

Overall, the findings indicate that the weighing system is stable, reliable, and suitable for manufacturing process control, quality assurance, and product acceptance activities. (Refer to Figure 7).

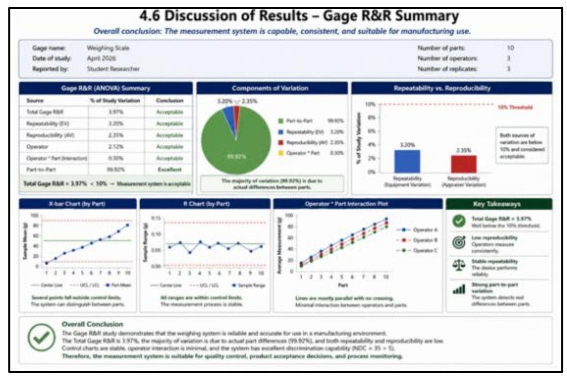

Figure 7
Gage R&R Summary

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