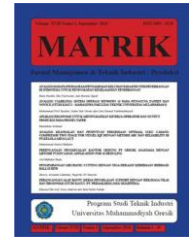




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Reliability Analysis of Door trim Measurement System Using Measurement System Analysis at PT. XYZ

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ABSTRACT

This research is motivated by the importance of the reliability of measurement systems in maintaining product quality in the automotive manufacturing industry. Inconsistencies in measurement results, especially in door trim components, can have an impact on product quality decisions. The purpose of this Study is to evaluate the reliability of the measurement system using the Measurement System Analysis (MSA) method. The method used is a quantitative approach with Gage Repeatability and Reproducibility (Gage R&R), bias, linearity, and stability testing on 10-part measurement data by three appraisers. The results showed that the Gage R&R Value was 6.90% (good), with the largest contribution of variation coming from part-to-part at 93.10%. In addition, the results of the bias and linearity tests showed no significant deviations, and the stability test showed a stable measurement process. Thus, the measurement system is declared to be quite reliable, although it still needs improvements in the repeatability aspect.



1. Introduction

The development of the manufacturing industry, especially in the automotive sector, has experienced a very rapid increase in recent years [1]. This condition encourages companies to continue to improve product quality in order to be able to compete and meet consumer demands [2]. One of the important aspects of maintaining product quality is the compatibility between the design specifications and the actual product produced [3]. This conformity can be found through an accurate measurement process [4]. In modern manufacturing systems, small deviations in measurement results can have a significant impact on product quality, process stability, and compliance with established standards [5]. Therefore, the accuracy and consistency of the measurement system is a crucial factor in quality control.

A measurement system is a combination of procedures, measuring tools, software, and operators (appraisers) used to obtain data on the characteristics of a product [6]. To ensure the adequacy of the measurement system, Measurement System Analysis (MSA) is used to evaluate measurement variation and measurement accuracy [7]. MSA does not rely on a single measurement characteristic. Gage Repeatability and Reproducibility (Gage R&R) evaluates variation associated with repeated measurements and differences among appraisers, whereas bias, linearity, and stability provide complementary information regarding systematic deviation, changes in bias across the measurement range, and measurement consistency over time, respectively [8]. Previous studies have demonstrated the importance of Gage R&R in identifying measurement-system variation in manufacturing and automotive applications [9], while a systematic literature review reported that Gage R&R studies differ in terms of measurement objects, instruments, experimental designs, statistical methods, and acceptance criteria [10]. However, the existing literature does not always evaluate these measurement characteristics simultaneously

within a single application context. This creates a gap in evaluating whether a measurement system is not only repeatable and reproducible, but also sufficiently consistent in terms of bias, linearity, and stability, particularly for dimensional gap measurements in automotive components.

Door trim is one of the interior components of a vehicle that provides both aesthetic and protective functions. Gap measurements on door trim components are generally performed using measurement gauges and visual inspection [11]. Because gap characteristics involve dimensional conformity between mating components, the measurement results can be affected by repeated measurement conditions and differences in measurement technique among appraisers [12]. In automotive manufacturing, measurement-system variation is important because measurement results are used to support product conformity decisions and process-quality evaluation. Previous research on automotive components has applied Gage R&R to assess measurement-system variation, demonstrating the relevance of measurement-system evaluation in real manufacturing conditions [13]. However, focusing only on repeatability and reproducibility does not provide information about whether the measurement system has systematic bias, whether the bias changes across the measurement range, or whether the measurement system remains stable over time. Therefore, a more comprehensive evaluation is required for door trim gap measurement, particularly when the measurement system is used as a basis for product acceptance and quality-control decisions.

This research was conducted at PT. XYZ, a company engaged in the production and assembly of automotive plastic components. In the development project of a new door trim model (3MOX) for PT. Honda Prospect Motor, variation in measurement results was observed during the inspection of component gaps using a checking fixture. This condition indicates the need to evaluate the measurement system from

multiple measurement characteristics rather than relying only on repeatability and reproducibility. Therefore, this study contributes an integrated evaluation of the door trim gap measurement system by combining Gage R&R, bias, linearity, and stability analyses within the same measurement application. The integration enables the study to distinguish measurement variation caused by repeated measurements and appraisers from potential systematic deviation and changes in measurement performance across the measurement range and over time. In this way, the study extends the assessment of measurement-system adequacy beyond Gage R&R alone and provides a more comprehensive basis for identifying improvement priorities in an automotive door trim measurement process.

Based on this research gap, this study aims to comprehensively evaluate the measurement system used for door trim gap inspection by integrating Gage R&R, bias, linearity, and stability analyses. Specifically, the study evaluates repeatability and reproducibility, examines potential systematic bias and linearity across the measurement range, and assesses measurement stability over time. The results are used to identify the dominant sources of measurement variation and formulate improvement recommendations for the measurement process. The contribution of this study lies in providing an integrated empirical assessment of a door trim gap measurement system in an automotive manufacturing context, thereby providing a broader basis for evaluating measurement-system adequacy than Gage R&R alone. The findings are expected to provide practical guidance for improving measurement consistency and supporting quality-control decisions in automotive component production.

2. Research Methods

This study uses a quantitative approach with the object of research in the form of a car door trim gap measurement system for checking fixtures at PT XYZ. Measurements are carried out using a taper gauge as one of the indicators of product quality. The focus of this research is

to evaluate the reliability of the measurement system using the Measurement System Analysis (MSA) method which includes the analysis of Gage Repeatability and Reproducibility (Gage R&R), bias, linearity, and stability [14].

The type of data used in this study consists of primary data and secondary data [15]. Primary data were obtained directly through gap measurement activities on 10 different door trim parts using a crossed measurement design involving three appraisers (X, Y, and Z). Each appraiser independently measured the same 10 parts in three trials, resulting in 90 observations (10 parts $\times$ 3 appraisers $\times$ 3 trials). The measurement procedure was performed using the same checking fixture and measurement instrument under the same measurement conditions. The repeated measurements were used to evaluate repeatability, while the differences among appraisers were used to evaluate reproducibility. Secondary data were obtained from company documents, including historical measurement data and previous Measurement System Analysis reports [16].

The data that has been collected is then processed using Minitab software with the Measurement System Analysis feature [13]. Data processing is carried out by grouping data based on part, operator, measurement time, and reference value used. The analysis was carried out through several stages, namely a bias test to determine the difference between the measurement result and the reference value, a linearity test to see the consistency of the bias in various measurement ranges, a stability test to evaluate the stability of the measuring instrument over time, and Gage R&R analysis with a crossed method to identify variations derived from the measuring instrument (repeatability) and operators (reproducibility). The results of each analysis are then compared with the applicable acceptance criteria to determine the level of reliability of the measurement system used.

The acceptance criteria for the measurement system were evaluated using the Gage R&R results based on %Contribution, %Study Variation (%SV), and %Tolerance. %Contribution was used to identify the proportion of total variance attributable to the

measurement system and part-to-part variation, whereas %Study Variation was used to assess the magnitude of measurement-system variation relative to the total study variation. %Tolerance was used to evaluate the measurement variation relative to the specified tolerance. A lower Gage R&R value indicates a smaller contribution of measurement-system variation. In this study, the commonly used criterion of less than 10% for Gage R&R was considered a good condition, while values between 10% and 30% indicated that the measurement system required further evaluation and improvement. These criteria were interpreted together with the bias, linearity, and stability results rather than using a single indicator.

3. Results and Discussions

a. Data Collection

Data collection in this study was carried out through direct observation on the measurement of the front door trim assy model 3MOX with three types of tests in Measurement System Analysis (MSA), namely Gage Repeatability and Reproducibility (Gage R&R), bias and linearity, and stability. Data collection in this

study was conducted through direct observation of the front door trim assembly model 3MOX using three MSA evaluations: Gage Repeatability and Reproducibility (Gage R&R), bias and linearity, and stability. For the Gage R&R study, 10 door trim parts were measured by three appraisers (X, Y, and Z), with each appraiser performing three independent trials on every part. Thus, the Gage R&R dataset consisted of 90 observations. The same measurement procedure and measurement equipment were maintained throughout the trials to minimize external sources of variation. The measurement results were subsequently analyzed to separate variation caused by repeatability, reproducibility, and differences among parts.

For the bias and linearity evaluation, five parts representing different reference values were measured in 10 trials. The stability evaluation was conducted over 15 days using three measurement points (P1, P2, and P3). This measurement design was applied to evaluate the measurement system from different aspects, including consistency of repeated measurements, consistency among appraisers, systematic deviation from reference values, and stability over time.

Table 1. Gage R&R Data Collection

Appraiser	Trial	Part									
		A	B	C	D	E	F	G	H	I	J
X	1	3.7	4.6	4.7	4.8	4.5	5.2	4.3	4.3	4.4	4
	2	3.7	4.5	4.8	4.8	4.4	5.1	4.4	4.4	4.5	4
	3	3.7	4.6	4.8	4.9	4.4	5.1	4.3	4.4	4.5	4
Y	1	3.8	4.6	4.6	4.8	4.5	5.3	4.4	4.4	4.6	4.1
	2	3.8	4.6	4.9	5	4.3	5	4.4	4.5	4.6	4.2
	3	3.7	4.4	4.7	4.7	4.6	5.2	4.2	4.3	4.7	4.3
Z	1	3.7	4.4	4.7	4.7	4.2	5.2	4.4	4.2	4.3	4
	2	3.6	4.4	4.7	4.8	4.3	5.2	4.4	4.2	4.4	3.9
	3	3.7	4.3	4.6	4.8	4.4	5.2	4.2	4.4	4.3	4

Based on Table 1, the measurement results carried out by three appraisers (X, Y, and Z) on 10 parts with three repetitions showed that the measurement values tended to be consistent and in close ranges. The variation that emerged between trials in each appraiser was relatively small, which indicates that the repeatability of

the measuring tool is quite good. In addition, the difference in measurement results between appraisers also does not show a significant difference, so the reproducibility between operators can be said to be quite consistent. Although there are slight differences in some parts, such as in parts C, D, and F, the variation

is still within reasonable limits and does not show extreme deviations. In general, these data show that the measurement system has a good level of consistency, both in terms of

repeatability and between operators, making it feasible to proceed to the Gage R&R analysis stage to evaluate the contribution of variation in more depth.

Table 2. Stability & Bias Study Data Collection

Part	Reference Value (mm)	Trial									
		1	2	3	4	5	6	7	8	9	10
A	3.7	3.8	3.7	3.7	3.7	3.6	3.6	3.6	3.7	3.7	3.8
B	4	4	3.9	3.9	3.9	4	4	4	4.1	3.9	3.9
C	4.5	4.4	4.5	4.5	4.5	4.6	4.6	4.5	4.5	4.5	4.6
D	5	5	5	4.9	4.9	5	5	5	5.1	5	4.9
E	5.3	5.2	5.3	5.3	5.3	5.2	5.2	5.3	5.3	5.4	5.2

Based on Table 2, the measurement results in five parts with different reference values showed that the measurement values in each trial tended to be around the reference value, with relatively small deviations. This indicates that the measurement system has a low level of bias because there is no significant difference between the value of the measurement result and the standard value. In addition, the consistency of the measurement results in each

trial also looked quite stable, as shown by the not too large fluctuations in the value in each part. Although there was slight variation in some measurements, such as in parts D and E, they were still within acceptable limits and did not show any systematic pattern of deviation. Overall, this data shows that the measurement system has good stability and relatively small bias, so it is reliable for the measurement process.

Table 3. Stability Data Collection

Day	P1	P2	P3
1	4.6	4.6	4.6
2	4.5	4.6	4.6
3	4.5	4.5	4.5
4	4.5	4.6	4.5
5	4.4	4.5	4.4
6	4.4	4.5	4.5
7	4.5	4.6	4.5
8	4.5	4.4	4.5
9	4.5	4.5	4.6
10	4.6	4.4	4.4
11	4.4	4.5	4.5
12	4.4	4.6	4.5
13	4.5	4.5	4.6
14	4.5	4.4	4.6
15	4.5	4.4	4.5

Based on Table 3, the results of the 15-day measurements at the three measurement points (P1, P2, and P3) show that the values obtained are relatively stable and are in a narrow range, which is around 4.4 to 4.6. The fluctuations that

occur between days and between measurement points are relatively small and do not show any significant deviation patterns or specific trends, either increasing or decreasing. This indicates that the measurement system has a good level of

stability over time. In addition, the consistency of values between P1, P2, and P3 also shows that the measurement variation is still within acceptable limits. Thus, it can be concluded that the measurement system is able to provide consistent results and is not significantly affected by the time factor, making it feasible to use in the continuous measurement process.

b. Data Processing Stability & Bias Study

Bias and linearity analysis was carried out to determine the relationship between the deviation of the measurement results to the reference value used. This relationship is important for evaluating whether measurement systems have a tendency to systematically deviate over a given measurement range. The results of the analysis are visualized in the form of a graph to make it easier to interpret the pattern of irregularities that occur.

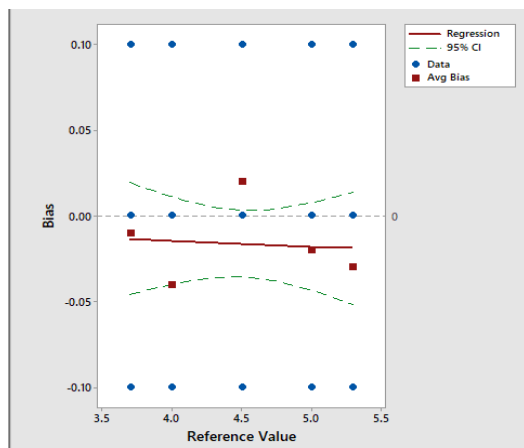


Figure 1. Measurement Bias Relationship Graph with Reference Value

Based on Figure 1, it can be seen that the blue dots representing the refractive value of each measurement are scattered around the zero line, which suggests that in general the measurement deviations are relatively small. The average value of the bias at each reference level indicated by the red box is also close to the zero line, thus indicating the absence of significant systematic deviations. The linear regression line (red line) shows a relatively flat tendency, which means that changes in reference values do not have a significant effect on bias. In addition, most of the data is within the 95% confidence interval limit (green dotted

line), so it can be concluded that the measurement system has good linearity characteristics and an acceptable bias.

Linearity analysis was performed to find out if there is a relationship between the refractive value and the variation of the reference value in the measurement system. This test aims to identify the tendency to systematically change bias over different measurement ranges. The results of linearity data processing are presented in Table 4.

Table 4. Stability Data Collection

Parameter	Coefficin	Standar Error (SE Coef)	P-Value
Constant	-0.00083	0.07399	0.991
Slope	-0.00337	0.0163	0.837
S	0.0687686		
R-Sq	0.10%		

Based on Table 4., a slope value of -0.00337 with a p-value of 0.837 was obtained, which shows that there is no significant relationship between the reference value and measurement bias. A p-Value greater than 0.05 indicates that the slope of the regression line is not significant, so the bias does not change systematically against the size variation. In addition, the R-Sq value of 0.10% indicates that the effect of reference values on bias variation is very small. Thus, it can be concluded that the measurement system has good linearity characteristics and meets the acceptance criteria.

Bias analysis was performed to evaluate the degree of deviation of measurement results from the reference value used in the measurement system. This test aims to find out if there is a significant difference between the measurement value and the standard value that should be. The results of biased data processing are presented in Table 5 below.

Table 5. Bias Gage Results

Reference Value	Bias	P-Value
Average	-0.016	0.088
3.7	-0.010	0.629
4	-0.040	0.081
4.5	0.02	0.345

Reference Value	Bias	P-Value
5	-0.020	0.345
5.3	-0.030	0.171

Based on Table 5, the average bias value is -0.016 with a p-Value of 0.088, which indicates that overall there is no significant difference between the measurement results and the reference value because the p-Value is greater than 0.05. At each reference value, the entire p-Value was also above 0.05, indicating that the deviation that occurred was not statistically significant. Although there is a variation in the bias value at each reference point, the value is relatively small and is still within acceptable limits. Thus, it can be concluded that the measurement system has a low level of bias and still meets the acceptance criteria.

c. Gage R&R Data Processing

Analysis of variation components is carried out to identify the sources of variation in the measurement system and to determine the contribution of each component to the total variation. This evaluation is important to determine whether the more dominant variation comes from the measurement system or from the differences between parts. The results of the analysis are presented in the form of a graph in Figure 2.

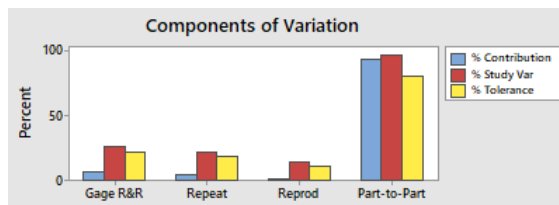


Figure 2. Components of Variation

Based on Figure 2, it can be seen that part-to-part components have the most variation contribution compared to Gage R&R, repeatability, and reproducibility. This shows that the variation that occurs is more influenced by the difference in characteristics between parts, which is the expected condition in a good measurement system. Meanwhile, Gage R&R's contribution, both in terms of repeatability and reproducibility, is relatively smaller, indicating that the variation derived from the measuring

instrument and operator is still within acceptable limits. In addition, the percentages for study variation and tolerance also show a similar pattern, where the components of the measurement system have a lower contribution than the variation between parts. Thus, the measurement system demonstrates a clear ability to distinguish variation among parts; however, the Gage R&R results indicate that the measurement system still requires improvement before it can be considered optimal for quality-control applications.

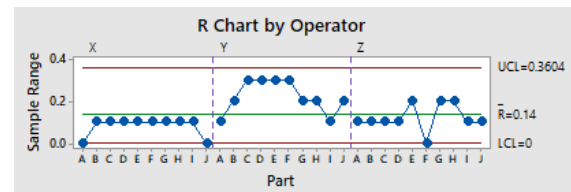


Figure 3. R Chart by Operator

Based on Figure 3, it can be seen that the entire value of the measurement range for each part and operator is within the specified control limit, which is between LCL = 0 and UCL = 0.3604. This shows that the variation that occurs in the measurement is still in a statistically controlled condition. Although there are some points that are close to the upper control limit, especially in operator Y, there is no data that crosses this limit, so there is no indication of variation caused by special causes. Thus, it can be concluded that the measurement consistency (repeatability) of the measurement system is in good and stable condition.

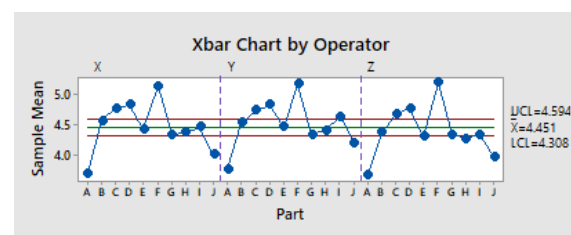


Figure 4. Xbar Chart by Operator

Based on Figure 4, it can be seen that most of the average values of the measurements for each part are outside the upper control limit (UCL) and the lower control limit (LCL). This condition shows that the variation that occurs is more caused by the difference between parts (part-to-part variation) than by the measurement

system. This is a good indication in the Gage R&R analysis, as it shows that the measurement system is able to clearly distinguish the characteristics between parts. In addition, the relatively consistent patterns between operators (X, Y, and Z) also indicate that there is no significant difference in measurement results between operators. Thus, it can be concluded that the measurement system has good and reliable discriminating capabilities in identifying variations between parts.

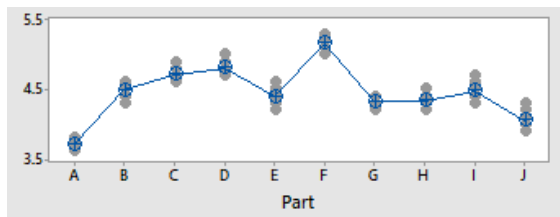


Figure 5. Value Graph by Part

Based on Figure 5, it can be seen that the distribution of the value of the measurement results for each part shows different variations. The individual measurement points scattered around the blue line indicate the consistency of the measurement results in each part, with a relatively small spread. In addition, the difference in value patterns between parts is quite obvious, which indicates a variation in characteristics between parts. This shows that the measurement system is able to distinguish the differences between parts well, and has a fairly high level of measurement consistency in each part. Thus, the measurement system can be said to have a good ability to discriminate against product variations.

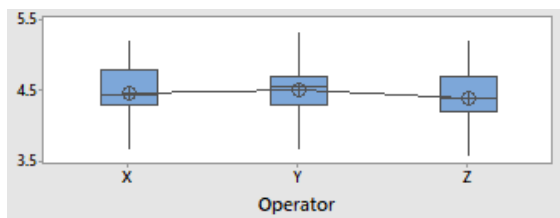


Figure 6. Graph Values by Operator

Based on Figure 6, it can be seen that the distribution of the measurement data for each operator (X, Y, and Z) has a relatively similar distribution pattern. The median values for each operator are in adjacent ranges, as well as interquartile ranges that do not differ

significantly, which indicates the consistency of measurement results between operators. In addition, there are no noticeable differences or extreme outliers that could indicate irregularities by a particular operator. This shows that the variation caused by the operator (reproducibility) is relatively small, so it can be concluded that the measurement system has a good degree of uniformity between operators and is reliable.

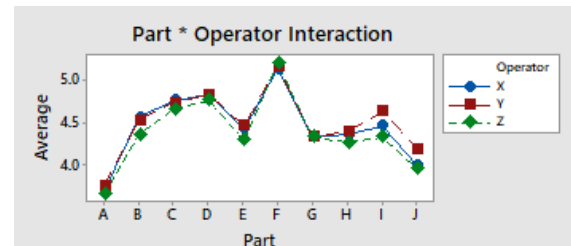


Figure 7. Graph of the interaction of the part with the operator

Based on Figure 7, it can be seen that the lines representing each operator tend to be close to each other and have a relatively parallel pattern on each part. This shows that there is no significant interaction between the part and the operator in the measurement process. In other words, the difference in measurement results is more influenced by variations between parts than by differences in operators. In addition, the consistency of the pattern between the operators indicates that each operator provides uniform measurement results to each part. Thus, it can be concluded that the measurement system has a good level of reproducibility and there is no significant interaction between the operator and the part.

Component variance analysis is carried out to determine the contribution of each source of variation in the measurement system, both from measuring instruments and from variations between parts. The results of data processing are presented in Table 6 below.

Tabel 6. Variance Component

Source	VarComp	%Contribution(of VarComp)
Total Gage R&R	0.011872	6.90
Repeatability	0.008496	4.94
Reproducibility	0.003376	1.96

Source	VarComp	%Contribution(of VarComp)
Operator	0.003376	1.96
Part-To-Part	0.160077	93.10
Total Variation	0.171948	100.00

Based on Table 6, the total Gage R&R accounts for 6.90% of the variance component, consisting of 4.94% repeatability and 1.96% reproducibility. In contrast, part-to-part variation contributes 93.10% of the total variance. These results indicate that the majority of the observed variance originates from differences among the measured parts, while the measurement system contributes a smaller proportion of the total variance. However, the 6.90% value represents %Contribution and should not be interpreted as equivalent to %Study Variation. Therefore, although the measurement-system contribution to the variance component is relatively small, the overall adequacy of the measurement

system must also be evaluated using %Study Variation and %Tolerance.

The relatively small reproducibility contribution of 1.96% indicates that differences among appraisers were limited. In contrast, repeatability contributed 4.94% to the variance component and was higher than reproducibility, indicating that variation within repeated measurements was the more dominant measurement-system component. This finding suggests that improvement should primarily focus on the consistency of repeated measurements, including the measurement instrument, fixture condition, measurement positioning, and standardization of the measurement procedure.

In addition to the variance component analysis, the evaluation of the measurement system was also carried out using the Gage evaluation table to determine the contribution of variation to Study variation and tolerance. The results of data processing are presented in Table 7 below.

Table 7. Fee Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.108958	0.65375	26.28	21.79
Repeatability	0.092172	0.55303	22.23	18.43
Reproducibility	0.058104	0.34862	14.01	11.62
Operator	0.058104	0.34862	14.01	11.62
Part-To-Part	0.400096	2.40057	96.49	80.02
Total Variation	0.414667	2.48800	100.00	82.93

Based on Table 7, the Total Gage R&R has a %Study Variation (%SV) of 26.28% and a %Tolerance of 21.79%. These two indicators provide a different interpretation from the %Contribution value presented in Table 6. The %Contribution of 6.90% describes the proportion of variance components attributable to the measurement system, whereas the %Study Variation of 26.28% describes the magnitude of measurement-system variation relative to the total study variation. Meanwhile, the %Tolerance of 21.79% indicates the proportion of the specified tolerance consumed by measurement-system variation. Therefore, the three percentages should not be interpreted interchangeably.

The %Study Variation of 26.28% indicates that the measurement system is not yet in an optimal condition and requires improvement. The value is below 30% but substantially higher than the commonly preferred level of less than 10%. The %Tolerance of 21.79% also indicates that a considerable portion of the specification tolerance is occupied by measurement-system variation. Furthermore, repeatability has a higher %Study Variation (22.23%) than reproducibility (14.01%), confirming that variation within repeated measurements is more dominant than variation among appraisers. Thus, the main improvement priority should be directed toward repeatability rather than operator-to-operator variation.

The dominance of repeatability over reproducibility suggests that the main source of measurement-system variation is associated with repeated measurements rather than differences among appraisers. In the context of door trim gap measurement using a checking fixture, this variation may be related to differences in measurement positioning, contact or seating conditions between the part and the fixture, instrument contact position, or the consistency of measurement technique during repeated trials. Although the available data do not allow each specific cause to be isolated quantitatively, the higher repeatability component provides an empirical basis for prioritizing improvements in fixture condition, measurement positioning, instrument condition, and standardized measurement procedures.

d. Linearity Data Processing

Stability analysis was performed to evaluate the stability of the measurement system over time using X-bar and R control graphs. The results of stability data processing are presented in Figure 8.

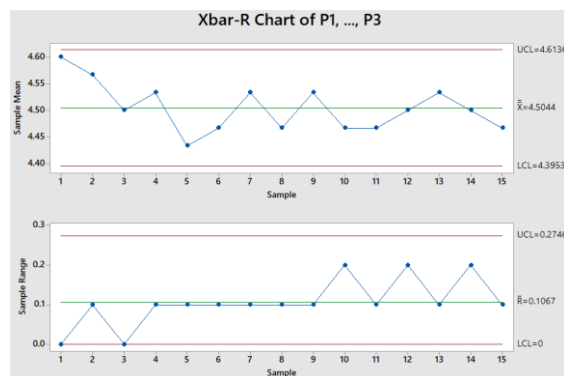


Figure 8. X-bar R Chart

Based on Figure 8, the X-bar graph shows that the entire average value of the measurement is within the upper control limit ($UCL = 4.6136$) and the lower control limit ($LCL = 4.3953$), with an overall average of 4.5044. This shows that the measurement process is under control and there is no indication of special causes. On the R graph, all range values are also within the set control limits, i.e. $UCL = 0.2746$ and $LCL = 0$, with an average range of 0.1067. The absence of points out of bounds of control on both charts indicates that the measurement variation is

consistent and stable over time. Thus, it can be concluded that the measurement system has a good level of stability and is reliable in the measurement process.

e. Analysis and Discussion

The results of the MSA evaluation indicate that the measurement system performs differently across the evaluated characteristics. The linearity analysis produced a slope of -0.00337 with a p-value of 0.837, while the mean bias was -0.016 with a p-value of 0.088. Both p-values are greater than 0.05, indicating that no statistically significant systematic bias or change in bias across the reference measurement range was detected. The R-squared value of 0.10% further indicates that the reference value explains only a very small proportion of the variation in bias. These findings suggest that systematic deviation and non-linearity were not the dominant issues in the evaluated measurement system.

The Gage R&R results provide a more nuanced assessment of measurement-system adequacy. The %Contribution of Total Gage R&R was 6.90%, consisting of 4.94% repeatability and 1.96% reproducibility, while part-to-part variation accounted for 93.10%. The high part-to-part contribution indicates that the measurement system can distinguish differences among the evaluated parts. However, this result should not be interpreted independently as evidence of high measurement-system reliability. The %Contribution value describes the variance-component composition, whereas the %Study Variation and %Tolerance provide additional information about the magnitude of measurement-system variation relative to total study variation and specification tolerance.

The %Study Variation of Total Gage R&R was 26.28%, with repeatability contributing 22.23% and reproducibility contributing 14.01%. The %Tolerance was 21.79%. These results indicate that the measurement system is usable but is not yet optimal and requires improvement. The difference between the 6.90% %Contribution and the 26.28% %Study Variation demonstrates why the two indicators should not be interpreted as equivalent measures. In practical terms, the measurement

system contributes a relatively small proportion to the variance component, but the magnitude of measurement variation remains sufficiently large relative to the total study variation to warrant improvement.

The higher repeatability value compared with reproducibility indicates that variation within repeated measurements is more dominant than variation between appraisers. For door trim gap measurement, repeated measurement variation may arise from differences in part positioning on the checking fixture, contact positioning of the measuring instrument, fixture seating conditions, or inconsistencies in the measurement procedure. Therefore, improvement should prioritize fixture condition, measurement positioning, instrument condition, and standardized work instructions before focusing primarily on differences among operators. Operator training should nevertheless be maintained to ensure consistent application of the standardized procedure.

The findings are also consistent with the observed control-chart results. The X-bar and R charts showed no observations outside the established control limits, indicating that the measurement process was statistically stable during the evaluated period. However, statistical stability does not necessarily mean that the measurement system is sufficiently accurate or capable for all quality decisions. In this study, the stability result indicates that the measurement variation was consistent over time, while the Gage R&R results indicate that the magnitude of that variation still requires improvement. Thus, stability and measurement-system adequacy should be interpreted as complementary rather than interchangeable criteria.

From a practical perspective, the MSA results have direct implications for door trim gap inspection. Because door trim gap measurements are used to support product-quality decisions, excessive measurement variation may increase the risk of inconsistent inspection results, particularly when measured values are close to specification limits. The relatively higher repeatability component suggests that improvements should focus on controlling the conditions under which the same

part is repeatedly measured. Standardized positioning of the door trim on the checking fixture, verification of fixture and instrument condition, clear measurement-point definitions, and periodic MSA evaluation can reduce the potential for inconsistent measurement results.

Overall, the MSA results indicate that the measurement system is statistically stable and does not show significant bias or linearity problems, while the Gage R&R results indicate that the system remains in need of improvement, particularly in repeatability. Therefore, the appropriate interpretation is not that the measurement system has high reliability, but that it is usable under the evaluated conditions while further improvement is required to reduce measurement variation and strengthen its suitability for quality-control decisions.

4. Conclusions and Recommendations

Based on the results of the MSA evaluation, the door trim measurement system at PT. Kasai Teck See Indonesia showed no statistically significant bias or linearity problems, with a mean bias of -0.016 ($p = 0.088$) and a linearity slope of -0.00337 ($p = 0.837$). The stability evaluation also showed that the measurement process remained statistically stable during the observation period. The Gage R&R analysis produced a %Contribution of 6.90%, consisting of 4.94% repeatability and 1.96% reproducibility, while part-to-part variation contributed 93.10%. However, the Total Gage R&R %Study Variation was 26.28% and the %Tolerance was 21.79%, indicating that the measurement system is usable but is not yet optimal and still requires improvement. The higher repeatability component compared with reproducibility indicates that improvement should primarily focus on measurement consistency during repeated measurements, including fixture condition, measurement positioning, instrument condition, and standardization of measurement procedures. Therefore, the measurement system should not be classified as having high reliability solely based on the 6.90% %Contribution value; instead, its adequacy should be interpreted by considering %Contribution, %Study Variation,

%Tolerance, bias, linearity, and stability simultaneously. Regular calibration, operator training, standardized measurement procedures, and periodic MSA evaluation are recommended to reduce measurement variation and improve the consistency of door trim gap inspection.

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