Available at e-Journal Universitas Sultan Ageng Tirtayasa

JOURNAL INDUSTRIAL SERVICESS

journal homepage: http://jurnal.untirta.ac.id/index.php/jiss

eISSN 2461-0631

Case study article

Strengthening screw shaft measurement system in teaching factory through measurement system analysis: A case study

Fredy Sumasto [*], Bayu Samudra, Ali Rachman Hakim, Febriza Imansuri, and Indra Rizki Pratama

Department of Automotive Industrial Engineering, Politeknik STMI Jakarta, DKI Jakarta 10510, Indonesia

ARTICLE INFO

Article history:
Received 16 December 2024
Received in revised form 3 June 2025
Accepted 5 June 2025
Published online 28 June 2025

Keywords:
Automotive part
Case study
Metrology
MSA
Quality
Teaching factory

Editor:
Bobby Kurniawan

Publisher's note:
The publisher remains neutral regarding jurisdictional claims in published maps and institutional affiliations, while the author(s) bear sole responsibility for the accuracy of content and any legal implications

ABSTRACT

Ensuring accurate measurement of precision components is critical in the automotive industry. This study investigates measurement challenges for screw shaft components at the Teaching Factory of Politeknik STMI Jakarta. The initial measurement system performed poorly, with 100% total variation attributed to measurement error and a Number of Distinct Categories (Ndc) of 1, indicating an inability to distinguish product variations. To address this, a Measurement System Analysis (MSA) using the Gage Repeatability and Reproducibility (GRR) method was conducted. Improvements, including operator training, regular calibration, and a custom jig fixture, were implemented. As a result, the GRR value decreased to 26.27%, with repeatability contributing 25.40% and reproducibility 6.74%. The Ndc value increased to 5, reflecting improved capability to differentiate product variations. These outcomes demonstrate that MSA is an effective strategy for evaluating and enhancing measurement systems. It is particularly valuable in vocational education settings to ensure measurement reliability, maintain quality standards, and support industry-relevant skill development.

1. Introduction

In the automotive industry, consistent product quality and compliance with precision standards are absolute requirements to meet the needs of an increasingly competitive global market [1]–[5]. Automotive components, such as screw shafts, require high measurement standards to ensure optimal functionality and safety [6], [7]. Accuracy and precision in the measurement of these components is essential to avoid product defects that can cause losses to manufacturers and customers [8]–[12]. Therefore, the application of Measurement System Analysis (MSA) in automotive product measurement becomes very relevant in identifying and controlling sources of variation in the measurement system [13]–[15].

Measurement System Analysis (MSA) aims to assess the reliability and accuracy of the measurement system to ensure that each component produced meets the set quality standards [8], [16]–[21]. MSA allows the industry to evaluate the measurement system's performance, identify elements that cause inconsistencies, and provide the correct information in making decisions related to product quality [16], [22]. In the context of the automotive industry, MSA plays an essential role in ensuring that every production and measurement process takes place with an acceptable level of accuracy, especially for high-precision components such as screw shafts. This improves product quality and reduces the potential for warranty claims or customer complaints [2], [16], [23]–[25].

Several studies have demonstrated the effectiveness of Measurement System Analysis in manufacturing industries, particularly within precision-driven sectors such as automotive. Guleria et al. highlighted the effectiveness of combining Gage R&R and Six Sigma tools to improve dimensional stability and reduce measurement variation in gear cutting processes [26]. This is reinforced by research from Pop and Elod who emphasized MSA's importance in improving measurement reliability in ISO/TS 16949-certified environments [27], and Guleria et al., who applied MSA

*Corresponding author:
Email: fredy.sumasto90@gmail.com

http://dx.doi.org/10.62870/jiss.v11i1.30298

within a Lean Six Sigma framework for gear manufacturing [26]. Saikaew [8] applied MSA to assess lathe machine variability and part measurement errors in turning operations, revealing substantial gains in consistency and dimensional control. Similarly, Cepova et al. validated MSA-based gauge control methods in industrial metrology [28], while Sharma et al. [22] and Almeida et al. [15] showcased the use of Gage R&R for evaluating resistance spot welding quality and production measurement reliability. These studies underline the growing relevance of MSA as a core quality assurance technique, especially in highly regulated, precision-demanding sectors like the automotive and aerospace industries [8], [15], [28], [29].

Teaching Factory, one vocational education method connecting education and industry significantly improves students' technical skills. The application of the MSA method to the screw shaft measurement process aims to provide a practical understanding of quality standards and the importance of a reliable measurement system in the automotive industry. This approach allows students to become familiar with the challenges in quality control of automotive components while understanding the analysis and improvement process required to ensure product quality.

While MSA has been widely adopted in industrial settings to validate and improve measurement systems, there remains a lack of research that applies MSA in educational production environments such as Teaching Factories. Most existing studies focus on large-scale manufacturing contexts, leaving a gap in understanding how MSA performs in simulated real-industry settings designed for vocational training. This study addresses that gap by evaluating the measurement system of screw shaft components in a Teaching Factory environment using a structured Gage R&R approach.

This research aims to identify weaknesses in the measurement system of screw shafts in the Teaching Factory through the application of MSA and implement improvements to enhance measurement reliability and accuracy. The results of this research are expected to improve measurement quality and product consistency and provide practical recommendations that can be applied in an automotive industry environment to ensure better measurement standards.

The MSA approach, particularly the Gage R&R technique, was selected due to its proven capacity to quantify and decompose sources of measurement variation, repeatability, and reproducibility into actionable components. Technically, Gage R&R offers a robust statistical framework to assess measurement error, identify inconsistencies, and guide improvement strategies. Practically, it is well-suited for implementation in vocational education settings because it can be performed using commonly available tools such as Vernier calipers and statistical software. The method's diagnostic value makes it ideal for training environments where both measurement precision and operator learning outcomes are equally prioritized.

2. Material and method

2.1. *Material*

This research was conducted at the Teaching Factory of Politeknik STMI Jakarta, Indonesia, with the main object being screw shaft components used in the automotive industry. The screw shaft is a critical component that requires high accuracy and dimensional consistency to function according to set quality standards. For the measurement of this component, a Vernier Caliper measuring instrument with an accuracy level of 0.02 mm is used. The selection of this tool is based on its reliability in meeting the need for high precision in the production process [28], [30]–[32]. Measurements were carried out by several operators who had received introductory training in the use of the measuring instrument, allowing for a more comprehensive analysis of variations in measurement results that operator skills may influence.

2.2. *Method*

This research method uses a MSA approach focusing on repeatability and reproducibility (R&R) tests. This MSA approach aims to evaluate how much variation appears in the measurement system, which can impact the quality and consistency of production results [16], [26], [27], [29], [30], [33]. This approach aligns with methodologies applied by Sharma et al. in evaluating resistance spot welding and by Cepova et al. using gauge control methods [22], [28]. In this study, the Gage R&R method is used to measure the consistency of measurement results when performed by the same operator (repeatability) and between different operators (reproducibility).

The first stage of the method involves repeated measurements of the same screw shaft samples (Fig. 1) by the same operator. Each operator takes measurements on the same sample multiple times under identical conditions [8], [16], [29], [30]. The data collected from these measurements is then analyzed to identify repeatability or the extent to which the measurement results remain consistent when performed by the same operator. In the next stage, a reproducibility test is conducted to see the differences in measurement results between operators [8], [34]. Measurements are taken on the same sample by several different operators under the same conditions to evaluate the level of consistency between operators. Through this test, inter-operator variations can be identified and used as a reference to understand how operator differences affect the overall measurement results [27], [29], [35].

The measurement results from these two R&R tests are then statistically analyzed to determine the contribution of variation caused by the measurement system compared to the total variation [8], [16], [29]. This analysis provides an overview of the reliability of the measurement system used in producing screw shafts.

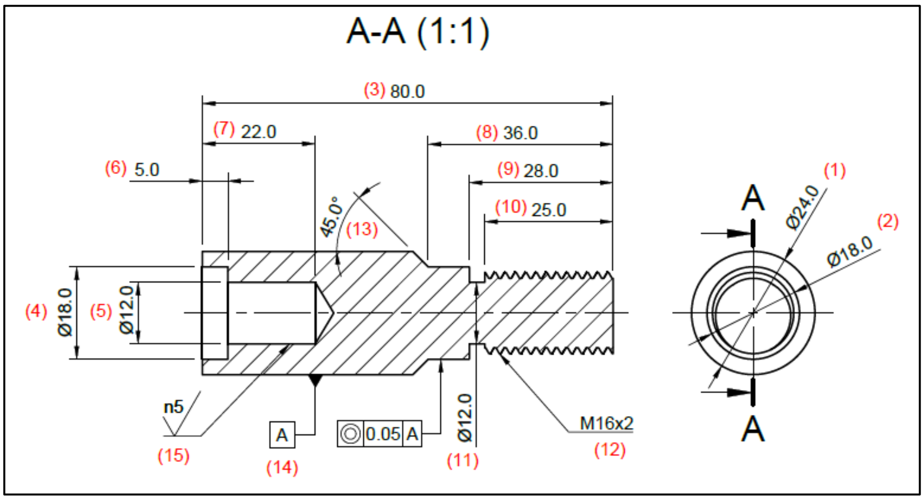

Fig. 1. Engineering drawing of screw shaft.

Table 1
Border value of % GRR and NDC [6], [7], [15], [16], [27]–[29], [35]

Value	Description
% GRR < 10%	The measuring system is acceptable and provides reliable information about process changes.
10% < % GRR < 30%	The measuring system is conditionally acceptable and can be used for several applications.
% GRR > 30%	The measuring system is unacceptable and does not provide reliable information about process changes.
Ndc ≥ 5	The measuring system is acceptable and provides reliable information about process changes.
2 ≤ Ndc ≤ 4	Unacceptable for estimating process parameters; gives rough estimates. Requires more sensitive equipment.
Ndc = 1	The measuring system is unacceptable and does not provide reliable information about process changes.

Based on the results of the analysis, improvement recommendations can be developed to improve measurement accuracy and consistency so that the quality of screw shaft components can meet the standards set in the automotive industry. Measurement data from the GRR test were statistically analyzed using Minitab® Statistical Software [6], [16], [35]. This analysis involves calculating the value of repeatability (EV), reproducibility (AV), variation between parts (PV), total variation (TV), and the Number of Distinct Categories (Ndc) (Table 1) value using the following Eq. (1) to (7).

Repeatability - Equipment Variation *(EV)*:

$$EV = \bar{\bar{R}}\ x\ K_1 \tag{1}$$

Reproducibility – Appraiser Variation *(AV)*:

$$AV = \sqrt{(\bar{X}_{DIFF} \times K_2) - (EV^2/(nr))} \tag{2}$$

where, n denote the number of samples, r denotes the number of trials,

Repeatability & Reproducibility *(GRR)*:

$$GRR = \sqrt{EV^2 + AV^2} \tag{3}$$

Part Variation *(PV)*:

$$PV = R_p\ \text{x}\ K_3 \tag{4}$$

Total Variation *(TV)*:

$$TV = \sqrt{GRR^2 + PV^2} \tag{5}$$

% Total Variation *(TV)*:

$$\begin{aligned} \%\ EV &= 100[EV/TV] \\ \%\ AV &= 100[AV/TV] \\ \%\ GRR &= 100[GRR/TV] \\ \%\ PV &= 100[PV/TV] \end{aligned} \tag{6}$$

$$ndc = 1.41(PV/GRR) \tag{7}$$

2.3. *Rationality of Measurement Design*

The measurement design used in this study (3 operators, 10 parts, 3 trials) adheres to the guidelines in the AIAG Measurement Systems Analysis Manual (4th Edition) and aligns with ISO 22514-7 standards for gauge studies. These guidelines recommend 2–3 operators, 10 parts, and 2–3 repetitions to provide sufficient data for calculating meaningful estimates of repeatability and reproducibility while maintaining practical feasibility in educational or production settings.

The selection of 10 parts ensures adequate part-to-part variability, capturing dimensional differences typical in real-world manufacturing. Additionally, three operators simulate realistic measurement variation across personnel, a critical component of reproducibility. Three repetitions per measurement enable robust estimation of consistency within individual operators (repeatability). This design balances statistical rigor with operational efficiency, rendering it suitable for a Teaching Factory environment, where both training value and industrial representativeness are prioritized. Senol similarly proposed optimizing repeatability and reproducibility (R&R) study designs by balancing α and β error risks for industrial applications [30].

3. Results and discussions

3.1. Result

The initial stage of data collection focused on collecting quantitative data related to the dimensions and tolerances of the Screw Shaft. Measurements were taken using precision gauges, particularly to the critical dimensional point at 18 mm with a tolerance of ±0.06 mm. This process was repeated for multiple Screw Shaft samples to capture variations across the part. This quantitative data helps identify product variations and potential sources of measurement uncertainty (see Fig. 1).

Three raters measured 10 Screw Shafts in three trials, and the data from each trial was recorded for further analysis (Table 2). This table shows the measurement data taken by each rater for each part, which provided an essential basis for the subsequent Measurement System Analysis (MSA). The MSA data were processed using specialized software, Minitab® Statistical Software, which produced results for Gage R&R, including Repeatability (Equipment Variation), Reproducibility (Ratio Variation), and Part-to-Part Variation. This data is critical for identifying sources of variation and ensuring the measurement system's reliability in capturing accurate Screw Shaft dimensions.

Table 3 shows the results of the two-way analysis of variance (Two-Way ANOVA) with the interaction between parts and operators. This table analyzes four sources of variance: Parts, Operators, interaction between Parts and Operators, and Repeatability. From the analysis results, the source of variance for Parts shows a free degree (DF) of 9 with a sum of squares (SS) of 0.013040 and a mean square (MS) of 0.0014489. The resulting F value is 3.86180, with a P value of 0.007. This indicates a significant difference in quality between the parts tested, as the P value is less than α = 0.05.

Meanwhile, for the Operators' source of variance, the DF is 2, with SS of 0.000780 and MS of 0.0003900. The F value obtained is 1.03949, with a P value of 0.374. This indicates no significant difference in measurement quality between operators, as the P value is greater than α = 0.05. The interaction between Parts and Operators was also analyzed, with a DF of 18, SS of 0.006753, and MS of 0.0003752. The F value for this interaction was 0.16816, with a P value 1.000. This indicates that the interaction between parts and operators is insignificant, meaning that the operator's influence is independent of the tested parts. For Repeatability, the DF was 60 with an SS of 0.133867 and MS of 0.0022311. The total free degree for this analysis was 89, with a total SS of 0.154440. These results indicate that the effect of variation in measurement (repeatability) has also been considered but not presented in the form of F and P values. Overall, this analysis shows that the parts factor contributes significantly to variation in measurement quality, while the operator and its interaction do not significantly contribute.

Table 4 presents the results of the two-way analysis of variance (Two-Way ANOVA) without considering the interaction between Parts and Operators. This analysis evaluated three sources of variance: Parts, Operators, and Repeatability. The results for the Parts source of variance showed a free degree (DF) of 9, with a sum of squares (SS) of 0.01304 and a mean square (MS) of 0.0014489. The resulting F value is 0.803679, with a P value of 0.614. This indicates no significant difference in quality between the parts tested, as the P value is greater than the significance level α = 0.05.

Furthermore, for the Operators' source of variance, the DF is 2, with SS of 0.00078 and MS of 0.0003900. The F value is 0.216328, with a P value of 0.806. This indicates no significant difference in measurement quality between operators, as the P value is greater than α = 0.05. Repeatability, which serves as a measure of variability in measurement, showed a DF of 78 with an SS of 0.14062 and MS of 0.0018028.

Table 2
Measurement data before improvement

Appraiser	Trial	Parts									
		1	2	3	4	5	6	7	8	9	10
		18.10	18.02	18.00	18.01	18.05	18.12	18.01	18.03	18.02	18.00
1	2	18.00	18.11	17.99	18.10	18.00	18.08	18.05	17.98	18.12	18.03
	3	18.02	18.00	18.10	18.00	18.01	18.05	18.00	18.12	17.98	18.05
2	1	18.11	17.99	18.05	18.02	18.00	18.10	18.02	18.01	18.10	18.00
	2	18.05	18.08	18.00	18.10	18.03	18.00	18.11	18.02	18.00	18.05
	3	18.02	18.00	18.08	18.01	18.01	18.05	18.00	18.05	18.03	18.00
3	1	18.12	18.00	18.02	18.10	18.05	17.98	18.05	18.00	18.03	18.01
	2	18.00	18.10	18.01	18.02	18.00	18.08	18.02	18.11	18.01	17.99
	3	18.01	17.98	18.05	18.00	18.03	18.10	18.00	18.02	18.00	18.05

Table 3
Two-Way ANOVA table with interaction before improvement

Source	DF	SS	MS	F	P
Parts	9	0.013040	0.0014489	3.86180	0.007
Operators	2	0.000780	0.0003900	1.03949	0.374
Parts* Operators	18	0.006753	0.0003752	0.16816	1.000
Repeatability	60	0.133867	0.0022311		
Total	89	0.154440			

Table 4
Two-Way ANOVA table without interaction before improvement

Source	DF	SS	MS	F	P
Parts	9	0.01304	0.0014489	0.803679	0.614
Operators	2	0.00078	0.0003900	0.216328	0.806
Repeatability	78	0.14062	0.0018028		
Total	89	0.15444			

Table 5
Variance components of screw shaft for measurement before improvement.

Source	VarComp	% Contribution of VarComp
Total Gage R&R	0.0018028	100.00
Repeatability	0.0018028	100.00
Reproducibility	0.0000000	0.00
Operators	0.0000000	0.00
Part-To-Part	0.0000000	0.00
Total Variation	0.0018028	100.00

Table 6
Gage evaluation of screw shaft for measurement before improvement (Ndc = 1).

Source	SD	SV (6 × SD)	% SV
Total Gage R&R	0.0424596	0.254758	100.00
Repeatability	0.0424596	0.254758	100.00
Reproducibility	0.0000000	0.000000	0.00
Operators	0.0000000	0.000000	0.00
Part-To-Part	0.0000000	0.000000	0.00
Total Variation	0.0424596	0.254758	100.00

Note: SD = standard deviation, SV = standard variation

The total free degree for this analysis was 89, with a total SS of 0.15444. Overall, this analysis shows that neither parts nor operators contribute significantly to the variation in measurement quality. This implies that all the parts and operators tested performed similarly, and any variation is more likely to be caused by other factors, including repeatability.

Table 5 presents the variance components of the screw shaft measurement, focusing on the Gage Repeatability and Reproducibility (Gage R&R) analysis. Total Gage R&R shows a variance component value of 0.0018028, which includes all variations in the measurement, with a contribution of 100%. This indicates that all variations in the measurement can be considered part of Gage R&R. The variance component for repeatability is also recorded as 0.0018028, which means that variations due to internal factors (such as measuring instruments) fully contribute 100% to the measured variance. Meanwhile, the variance component for reproducibility, which relates to variation caused by operators, was recorded at 0.0000000, indicating no significant contribution from this variable.

The variance components for Operators and Part-To-Part were also recorded at 0.0000000 each, indicating that no variation resulted from differences between operators or the parts tested. With a total measured variation of 0.0018028, all the values obtained indicate that the variation in the measurement is entirely due to the repeatability of the measuring instrument. At the same time, the factors of reproducibility, operators, and part-to-part differences do not contribute to the variation. This shows that the measuring device has good consistency in providing results, but it should be noted that other factors do not contribute to the measurement uncertainty.

Table 6 presents the Gage evaluation for the screw shaft measurement, highlighting the components of variation in the measurement process. The Total Gage R&R shows a standard deviation (StdDev) of 0.0424596, which results in a study variation (Study Var) of 0.254758. The contribution of this variation to the total variation is 100%, which indicates that all the variation measured in the measurement can be considered as part of the Gage R&R. For the Repeatability component, the StdDev value is also the same at 0.0424596, resulting in an identical Study Var and 100% contribution. This indicates that all variation in the measurement can be attributed to factors related to the repeatability of the gauge, and no variation comes from the consistency of the measurement.

On the other hand, the Reproducibility component, which includes variations caused by the operator and part-to-part differences (Operators and Part-To-Part), all recorded StdDev and Study Var values of 0.0000000. This indicates that there is no significant contribution from these factors, meaning that neither operators nor part-to-part differences add to the variability in the measurements. As such, the Number of Distinct Categories (Ndc) value is 1, indicating that only one measurement category was identified. Overall, the results of this evaluation show that the repeatability of the measuring instrument entirely determines the variation in the screw shaft measurement. At the same time, other factors do not contribute to the variation, indicating that the measuring instrument performs well in terms of the consistency of its measurement results.

Based on Fig. 2 of the Gage R&R (ANOVA) Report for Measurement Data, an understanding of:

a. Components of Variation

Gage R&R: The most significant component of variation comes from the measurement itself, indicating that the variation is significant.

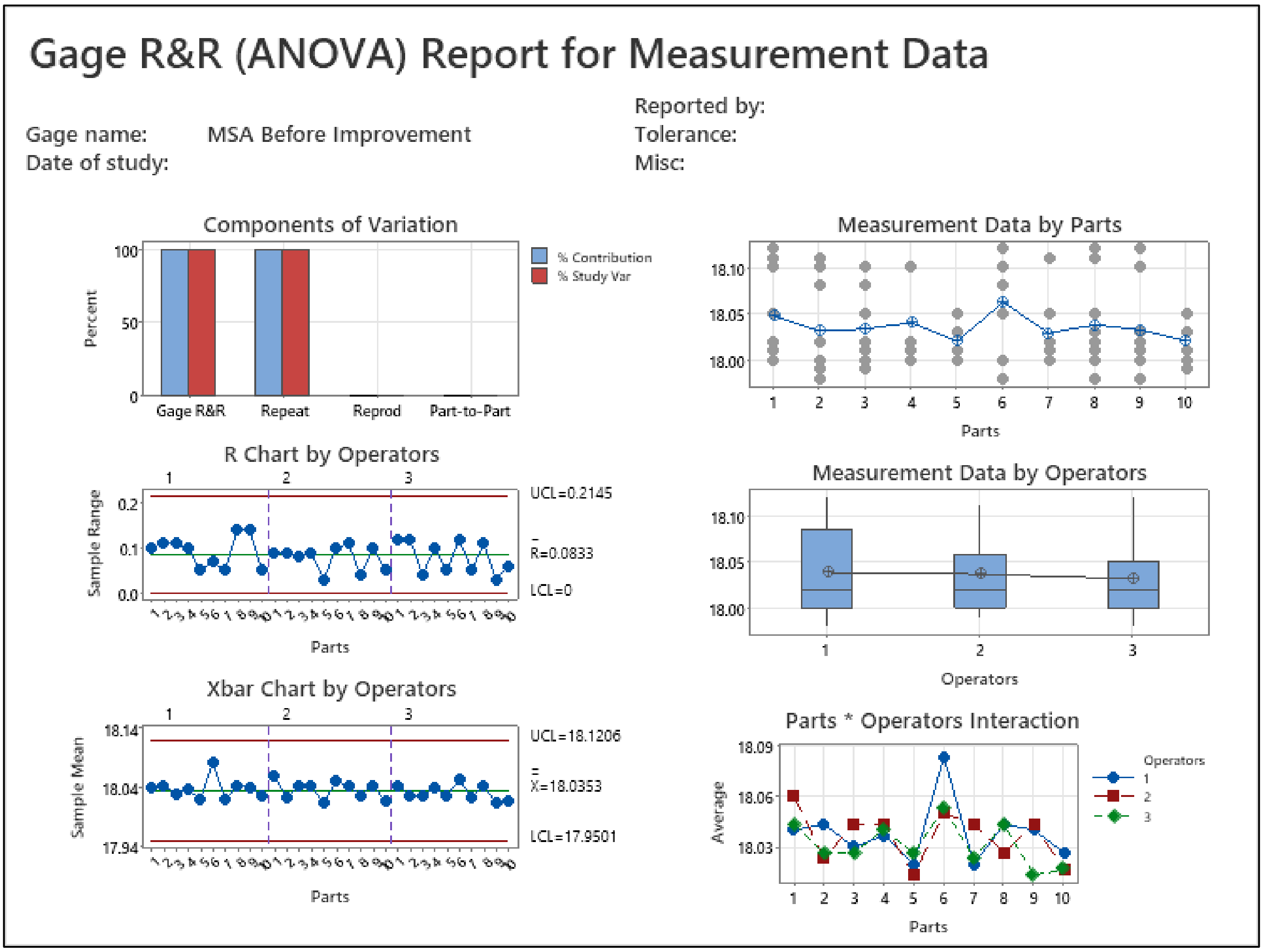

Fig. 2. Result of GAGE R&R analysis of screw shaft before improvement.

Repeatability and Reproducibility: Both contribute almost equally to total variation. This indicates that the measurement system has problems with repeatability consistency and inter-operator variation.

Part-to-Part: The contribution of part variation to the total variation is minimal, which indicates that the differences between parts are insignificant compared to the variation from the measurement.

b. R Chart by Operators

The R chart shows the measurement range between trials by each operator. The fluctuating range values indicate that operators have considerable variability in measurements on some parts but are still within the control limits (UCL = 0.2145). However, the presence of some significant fluctuations indicates a problem in repeatability.

c. Xbar Chart by Operators

The Xbar chart shows the average measurement results of each operator. There is a slight fluctuation in the average measurement between operators, but it remains within the control limits (UCL = 18.1206, LCL = 17.9501). However, these minor variations may contribute to reproducibility issues, as each operator may not consistently use the measuring instrument in the same way.

d. Measurement Data by Parts

This graph shows the distribution of measurements for each part. The data shows minimal differences between parts, which aligns with the low NDC results. The differences between the parts are not significant enough to be clearly distinguished by the measurement system.

e. Measurement Data by Operators

This box plot shows the distribution of measurements from each operator. Although the measurement ranges between operators are relatively similar, there are slight differences that indicate the variability between operators in taking measurements. This is an indication of problems in reproducibility.

f. Parts * Operators Interaction

This graph shows the interaction between parts and operators. Ideally, the lines between operators should be consistent for each part, but this graph shows apparent differences between operators on some parts, indicating poor reproducibility. Especially in parts 4 and 7, the measurements have significant differences between operators.

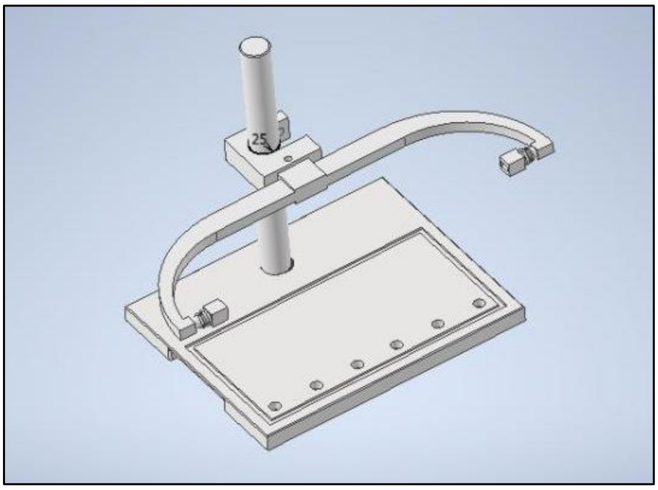

Fig. 3. Design of tools to assist measurement.

Fig. 2 shows that the measurement system prior to improvement was heavily dominated by equipment variation (repeatability). The Xbar and R charts indicate inconsistencies between repeated measurements by the same operator, with several points fluctuating but remaining within control limits. Additionally, the interaction plot between parts and operators demonstrates overlapping lines, indicating poor reproducibility. The overall low number of distinct categories confirms that the system could not reliably differentiate between parts.

Based on the results, the measurement system has poor repeatability and reproducibility, reflected by the significant contribution of gage R&R and fluctuations between trials and operators. Part-to-part variation is very low, which results in low NDC and indicates that the measurement system cannot distinguish variations between parts well. This indicates that improvements need to be made in the measurement method to improve consistency between operators and repeatability in measurement. Suggested improvements include retraining operators, selecting more precise measuring instruments, or improving the measurement procedure. A jig is proposed for the measurement procedure.

In the improvement stage, a jig and fixture for a 150 mm vernier caliper (Fig. 3) have been made. This is a supporting tool for using the vernier caliper, especially for novice users. This tool has several essential functions: Holding the Vernier Caliper and Holding the Workpiece. However, these tools have measurement limitations because they can only take measurements in the size range of 5 mm to 150 mm. This limitation needs to be considered when choosing a tool for the measurement process.

After implementing the improvement, a re-measurement is carried out with the same scenario to validate the improvement results. Table 7 shows the measurement data after the improvement. Table 8 shows the results of the Two-Way ANOVA with the interaction between the factors “Parts” and “Operators” to evaluate the variation in the measurement system. The Parts factor has a high F-value (181.623) and a significant P-value (0.000), indicating significant variation between the measured parts. This indicates that the measuring instrument can distinguish parts from each other well, and the variation between parts is a major component of the total variation. The Operators factor is also statistically significant with a P-value of 0.029, indicating differences between operators in measurement. However, the variation contribution from operators is much smaller than that of parts, which is evident from the low SS.

The interaction between Parts and Operators is insignificant, with a P-value of 0.831. This indicates that the way operators measure parts has no significant interaction; in other words, there are no consistently different measurement patterns for different operators on specific parts. Repeatability represents the variation in repeated measurements of the same part by the same operator. With very small SS and MS, repeatability is quite good, indicating that the variation in measurements by operators on the same part is low. The total variation (SS Total) is 0.0906, mostly from differences between parts, followed by a small contribution from differences between operators, and parts-operators interaction does not make a significant contribution.

Table 7
Measurement data after improvement

Appraiser	Trial	Parts									
		1	2	3	4	5	6	7	8	9	10
1	1	18.12	18.04	18.01	18.05	18.09	18.13	18.06	18.09	18.07	18.03
	2	18.11	18.06	18.00	18.07	18.08	18.11	18.05	18.10	18.08	18.04
	3	18.10	18.05	18.02	18.06	18.07	18.12	18.06	18.09	18.09	18.03
2	1	18.13	18.05	18.02	18.06	18.08	18.10	18.05	18.09	18.07	18.03
	2	18.12	18.07	18.01	18.08	18.09	18.11	18.06	18.10	18.08	18.04
	3	18.11	18.06	18.03	18.07	18.08	18.12	18.05	18.09	18.09	18.05
3	1	18.12	18.04	18.01	18.05	18.09	18.10	18.05	18.08	18.07	18.03
	2	18.11	18.06	18.00	18.07	18.08	18.11	18.06	18.09	18.08	18.04
	3	18.10	18.05	18.02	18.06	18.09	18.12	18.05	18.08	18.09	18.03

Table 8
Two-Way ANOVA table with interaction after improvement.

Source	DF	SS	MS	F	P
Parts	9	0.0845556	0.0093951	181.623	0.000
Operators	2	0.0004467	0.0002233	4.317	0.029
Parts * Operators	18	0.0009311	0.0000517	0.665	0.831
Repeatability	60	0.0046667	0.0000778		
Total	89	0.0906000			

a to remove interaction term = 0.05

Table 9
Two-Way ANOVA table without interaction after improvement

Source	DF	SS	MS	F	P
Parts	9	0.0845556	0.0093951	130.912	0.000
Operators	2	0.0004467	0.0002233	3.112	0.050
Repeatability	78	0.0055978	0.0000718		
Total	89	0.0906000			

Table 10
Variance components of screw shaft for measurement after improvement

Source	VarComp	%Contribution of VarComp)
Total Gage R&R	0.0000768	6.90
Repeatability	0.0000718	6.45
Reproducibility	0.0000051	0.45
Operators	0.0000051	0.45
Part-To-Part	0.0010359	93.10
Total Variation	0.0011127	100.00

Table 9 shows the Two-Way ANOVA results after removing the interaction between the factors "Parts" and "Operators." These results were used to evaluate the contribution of each factor to the total variation in the measurement system. The Parts factor has a high F-value (130.912) and a high significant P-value (0.000). This indicates that the variation between parts is highly significant. This means that the measuring instrument can distinguish parts from one another well, and this variation is a significant component of the total variation. The Operator factor is also close to the significance level, with a P-value of 0.050. This suggests that the differences between operators may be statistically significant, although the contribution to variation from operators is much smaller than that from parts. In other words, operators have slight differences in taking measurements, but they are not significant enough compared to the variation between parts.

The variation from repeatability, representing the repetition of measurements on the same part by the same operator, is very low. This is reflected in the small MS, indicating that the measurement system has good repeatability. The total variation (SS Total) is 0.0906, most of which comes from variation between parts. While variation from operators exists, its contribution is relatively small compared to that of parts. The repeatability variation is also tiny, indicating the operators' consistent repetition of measurements. Thus, most of the variation in this measurement system comes from parts, while the influence of operators is negligible, and the repeatability of measurements shows consistent results.

Table 10 shows the results of the Variance Components analysis in screw shaft measurement broken down into several sources of variation, including Gage R&R, Repeatability, Reproducibility, and Part-To-Part. Total Gage R&R is the total contribution to variation from the measurement system itself, including repeatability and reproducibility. 6.90% of the total variation comes from gage R&R, indicating that the measurement system contributes relatively little to the overall variation, which is desirable in an effective measurement system. Repeatability is the ability of a measurement system to produce consistent results when measurements are taken repeatedly on the same part by the same operator. A contribution of 6.45% of the total variation comes from repeatability, which means the measurement system is relatively consistent and has good repeatability. Reproducibility measures the variation in measurement results when different operators measure the same parts. Only 0.45% of the total variation comes from reproducibility, which shows that the differences between operators are minimal and hardly contribute significantly to the total variation.

The variation between operators also accounts for only 0.45% of the total variation, indicating that the influence of operators on the measurement results is minimal. This reflects that the measurement system is quite good regarding reproducibility, where different operators hardly cause any variation in the measurement. Most of the variation, 93.10%, comes from part-to-part variation, which means that differences between parts are the primary source of variation. This is a desirable result as the measurement system should be able to detect significant differences between parts. The high contribution from part-to-part variation indicates that the measuring instrument does an excellent job distinguishing parts. The total variation measured in the measurement system is 0.0011127, with the majority coming from variation between parts (93.10%), while variation from the measurement system (gage R&R) only accounts for 6.90%. This shows that the measuring instrument is accurate because most variation comes from the measured product, not errors in the measuring system itself. Based on this, the measurement system has good repeatability and reproducibility, with total gage R&R only accounting for 6.90% of the total variation. Part-to-part variation is the primary source of variation, indicating that the measuring instrument can distinguish parts well. The operator's influence is minimal, with a low reproducibility (0.45%), meaning that measurements between operators are consistent.

Table 11
Gage evaluation of screw shaft for measurement after improvement (Ndc = 5)

Source	StdDev (SD)	Study Var (6 × SD)	% Study Var
Total Gage R&R	0.0087646	0.052588	26.27
Repeatability	0.0084715	0.050829	25.40
Reproducibility	0.0022477	0.013486	6.74
Operators	0.0022477	0.013486	6.74
Part-To-Part	0.0321857	0.193114	96.49
Total Variation	0.0333578	0.200147	100.00

Table 11 shows the gage evaluation using several parameters such as Standard Deviation (SD), Study Variation (6 × SD), %Study Variation (SV), and Number of Distinct Categories (Ndc). Total Gage R&R is a combination of repeatability and reproducibility. A StdDev value of 0.0087646 results in a study variation of 0.052588, with 26.27% of the total variation coming from the measurement system. The Number of Distinct Categories (Ndc) is 5, indicating that the measurement system can distinguish five distinct categories within the measured parts. Although NDC >= 5 is generally considered good, 26.27% %SV is still relatively high for exact applications.

Repeatability indicates the consistency of the measurement system when repetitions are performed by the same operator on the same part. The lower StdDev of 0.0084715 results in a study variation of 0.050829, and 25.40% of the variation comes from repeatability. This indicates that most of the variation in the measurement system comes from repeatability. Reproducibility measures the difference between operators when using the measuring instrument. With a smaller StdDev of 0.0022477, study variation of only 0.013486, and %Study Var of 6.74%, the variation caused by operators is relatively low. This indicates that the differences between operators in taking measurements are minor so that the measurement system can be used by various operators with relatively consistent results. Similar to reproducibility, the variation caused by operators is minimal (6.74%), confirming that different operators produce similar measurement results, indicating consistency between operators in the use of measuring instruments.

Most of the variation comes from part-to-part differences. With a StdDev of 0.0321857, a study variation of 0.193114, and a %Study Var of 96.49%, the measurement system can effectively distinguish differences between parts, which is the primary goal of good measurement. The high percentage of variation between parts indicates that the variation in parts is more significant than the variation in the measurement system. Total variation incorporates all sources of variation, with a StdDev of 0.0333578 and a study variation of 0.200147. This value covers 100% of the measured variation, a combination of measurement system variation and variation between parts.

Fig. 4 shows the Components of Variation, Measurement Data by Parts, Measurement Data by Operators, R Chart by Operators, Xbar Chart by Operators, and Parts * Operators Interaction. The bar chart on Components of Variation shows the contribution of variation from each source, both in the form of percentage contribution (% Contribution) and percentage of Study Variation (% Study Var). Most variation comes from part to part, which is desirable as it indicates that differences between parts are more significant than variations caused by the measurement system. Total Gage R&R, Repeatability, and Reproducibility have much lower contributions, indicating that the measurement system variation is slight and the measurement system is quite precise.

As shown in Fig. 4, the measurement system after improvement demonstrates a significant shift. Most of the variation now originates from part-to-part differences, indicating effective measurement of real product variation. The Ndc increased to 5, showing the improved capability to distinguish product characteristics. The Xbar and R charts reflect greater measurement stability within operators, and the operator interaction lines show more consistent behavior across parts, which reflects better reproducibility.

The line diagram in Measurement Data by Parts shows the measurement data for each part. Measurement data fluctuates between parts, which indicates significant variation between parts. This apparent variation demonstrates the measurement system's ability to distinguish between different parts, indicating that the system is working well.

This boxplot diagram (Measurement Data by Operators) shows the distribution of measurement data by operator. All three operators gave similar results with almost the same measurement range, indicating that none of the operators gave very different measurement results (low reproducibility). This means that the variability between operators is minimal. The R chart monitors the range of variation of measurements by each operator. The average value of the measurement range (R) is small, indicating that the measurement variation between operator trials is relatively consistent. The range of values is below the upper control limit (UCL), indicating that the variation is within acceptable limits.

Meanwhile, the Xbar chart monitors the average measurement by each operator. The data shows that all measurements are within the control limits (between the UCL and LCL). This indicates that none of the operators provided highly deviated measurement results. The Parts * Operators Interaction diagram shows the interaction between parts and operators. This chart shows that each operator provides consistent results for each part, although there are minor differences in measurement patterns between operators. However, overall, the measurement results from all operators follow the same pattern, indicating good reproducibility.

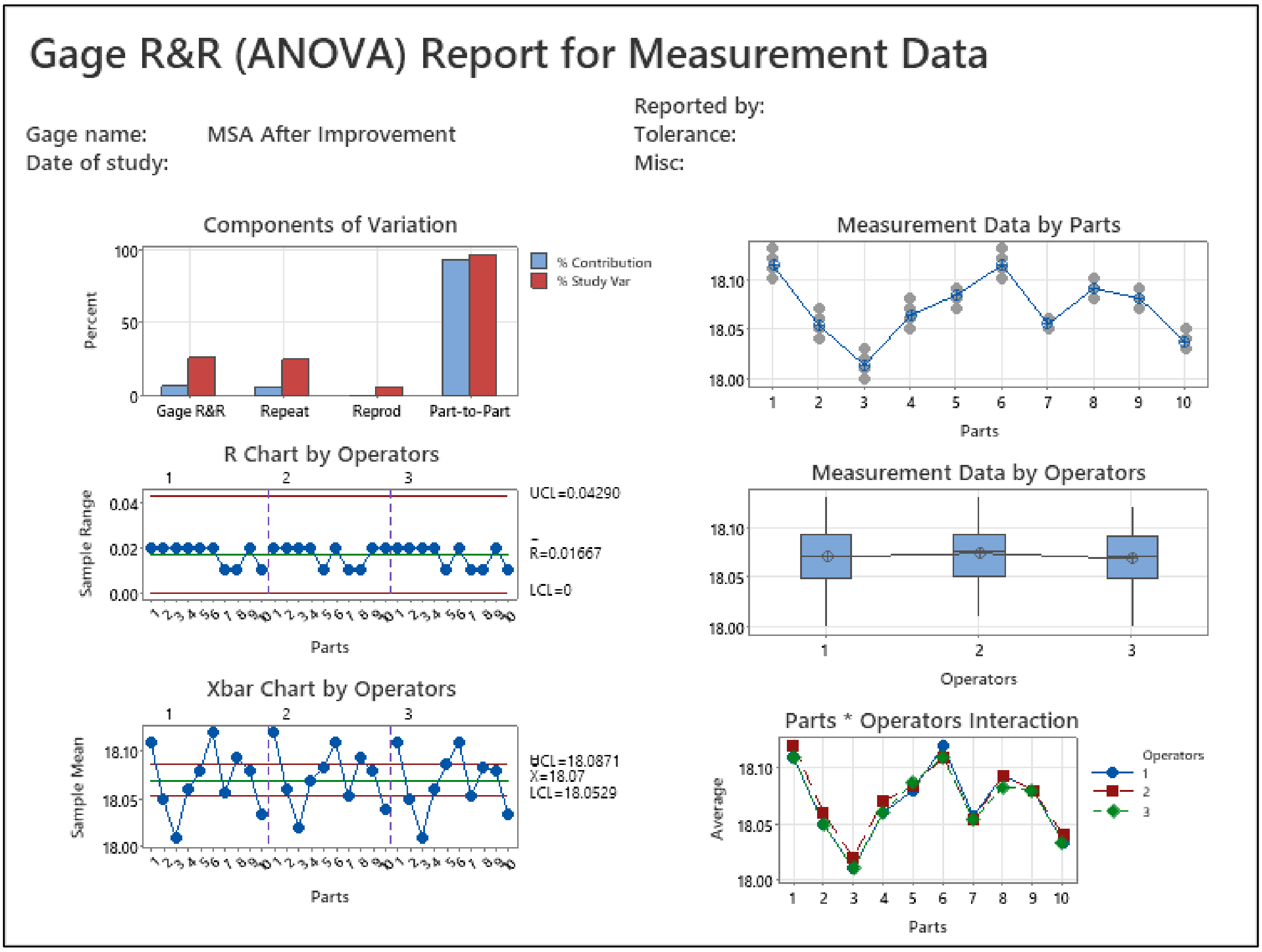

Fig. 4. Result of GAGE R&R analysis of screw shaft after improvement.

These findings align with the results reported by Saikaew, who applied MSA in turning operations and found that systematic operator training and equipment calibration significantly reduced measurement error, as well as Abhilash & Thakkar who applied DMAIC to reduce defects in manufacturing operations using MSA, confirming its role in process control [36]. Additionally, Down et al. in the AIAG MSA 4th edition manual recommend thresholds and methodologies reflected in this study, while Almeida et al. emphasize the multivariate GR&R approach for capturing deeper instrument variability [15], [29]. Similarly, Setyabudhi et al. [17] demonstrated that the application of Gage R&R on base plate magazine measurement improved the consistency and interpretability of the data across multiple operators. Compared to those studies, the present research also confirms that structured MSA, even in an educational production setting, can yield performance improvements comparable to industrial environments. The increased Ndc and reduced GRR percentage after improvement validate the effectiveness of using jigs and operator retraining in reducing both repeatability and reproducibility errors.

Furthermore, the post-intervention GRR value of 26.27% falls within the "conditionally acceptable" range defined by AIAG, indicating practical usability in low-volume or training-based production environments. These parallels strengthen the study's contribution to the broader discourse on measurement system evaluation in applied and educational contexts.

Based on Fig. 4, the MSA results show that the improved measurement system provides reliable and precise results in measuring screw shafts. This result is obtained from:

a. Most of the variation occurs from part to part, which means that the measuring instrument can distinguish the differences between parts very well.
b. The variation of Gage R&R, which includes repeatability and reproducibility, is slight, indicating that the measurement system is stable and accurate.
c. There was no significant variation between operators, indicating that all operators could take measurements consistently.
d. The measurement system can distinguish between parts with an Ndc value of at least 5.

3.2. *Discussion*

Occur in the measurement of screw shaft components can be caused by several factors that affect measurement quality [8]. One of the main factors affecting repeatability is the precision level of the Vernier Caliper measuring instrument [6], [16].

Although this tool has an accuracy of 0.02 mm, external factors such as measurement technique, operator stress during measurement, and environmental conditions can significantly affect measurement results. Mohamed and Davahran support this by stating that instrument performance is often degraded by lack of operator consistency, as evidenced in simple R&R studies [7]. This highlights the importance of improving standard operating procedures in the use of measuring instruments and training for operators to ensure consistency.

Reproducibility factors that show inter-operator variation indicate the need to standardize skills and measurement techniques between operators. This inter-operator variation could potentially result in non-uniformity of production results, which in turn could affect the overall quality of the screw shaft product. Therefore, increased training and certification for operators in measuring instruments is crucial to reducing inter-operator variation.

The implementation of MSA results also shows that the measurement system needs to be improved regarding tools and procedures. Using measuring instruments with higher precision and regular calibration can help reduce variations in measurement results. In addition, regular implementation of MSA procedures can be an integral part of quality control in the Teaching Factory, ensuring that measurement results are always within the desired quality standards.

Overall, this research demonstrates the importance of Measurement System Analysis as an evaluation tool in the measurement system of the automotive industry. By making improvements based on MSA findings, the Teaching Factory is expected to improve the quality and consistency of screw shaft components, which in turn contributes positively to the reputation and competitiveness of products in the automotive industry.

The use of advanced GR&R methods has also been explored by Cepova et al. , emphasizing the importance of properly quantifying measurement system performance using standard guidelines [28]. Integrating such approaches in Teaching Factory settings could further improve training effectiveness and system robustness.

4. Conclusion

This research has successfully evaluated and improved the measurement system of screw shaft components at the Teaching Factory of Politeknik STMI Jakarta using the Measurement System Analysis (MSA) method, specifically Gage Repeatability and Reproducibility (GRR). The purpose of this study is to identify and improve the measurement system's weaknesses to achieve a better level of accuracy and precision according to automotive industry standards. The analysis results before and after improvement showed significant changes in measurement variation and consistency of results.

Before the improvement, the GRR results showed a less-than-ideal value, with measurement variation contributing 100% to the total variation. This was due to low repeatability, which showed significant variation in repeated measurements by the same operator with no measurable reproducibility. The Number of Distinct Categories (Ndc) value is only 1, indicating that the measurement system in the initial condition can only distinguish one product category, which is very limited in detecting variations in the product.

After improvements were made through operator training, more routine calibration of measuring instruments, and implementation of more standardized measurement procedures, the measurement results showed significant improvement. GRR was reduced from 100% to 26.27%, with the primary contributions coming from repeatability at 25.40% and reproducibility at 6.74%. Interoperator variation also started to become measurable, showing an improvement in the consistency of the measurement results. In addition, Ndc increased from 1 to 5, indicating an improvement in the measurement system's ability to distinguish more product variations more accurately. Part-to-part variation also became more dominant, at 96.49%, indicating that the measured differences in the product represent more variation from the product than from the measurement system.

This improvement proves that the application of MSA serves as an evaluation and a measurement system improvement strategy. This conclusion aligns with recent findings from who reported that continuous MSA implementation improves reliability and customer satisfaction in manufacturing environment. These findings emphasize the importance of applying MSA in maintaining product quality, particularly in the automotive industry, to reduce the risk of products not meeting specifications. For future research, exploration of more advanced measurement technologies, such as Coordinate Measuring Machine (CMM), can further improve the accuracy and precision of the measurement system while ensuring consistent product quality and compliance with industry standards.

Declaration statement

Fredy Sumasto: Conceptualization, Methodology, Writing-Original Draft. **Bayu Samudra, Ali Rachman Hakim, Fredy Sumasto**: Collecting data. **Febriza Imansuri, Indra Rizki Pratama**: Writing-Review & Editing.

Acknowledgement

We extend our gratitude to the TEFA at Politeknik STMI Jakarta and the PLP at the Laboratory of PIM and Laboratory of Metrology for their invaluable contributions to this research.

Disclosure statement

The author declares that this manuscript is free from conflict of interest and is processed by applicable journal provisions and policies to avoid deviations from publication ethics in various forms.

Funding statement

The authors received funding from Politeknik STMI Jakarta for this research. The author thanks to Politeknik STMI Jakarta, which has financially supported this Project with decree number 531/BPSDMI/STMI/KEP/VI/2024.

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article or its supplementary materials.

AI Usage Statement

This manuscript utilizes generative AI and AI-assisted tools to improve readability and language. All AI-generated content has been reviewed and edited by the authors to ensure accuracy and scientific integrity. The authors take full responsibility for the content and conclusions of this work and disclose the use of AI to maintain transparency and comply with publisher guidelines.

References

[1] V. K. Singh, R. Kumar, C. V. Joshi, and S. Poddar, "Improving operational performance with world class quality (WCQ) technique: A case in Indian automotive industry," *Mater. Today: Proc.*, 2022, doi: 10.1016/j.matpr.2022.09.387.

[2] F. Sumasto, D. A. Arliananda, F. Imansuri, S. Aisyah, and B. H. Purwojatmiko, "Enhancing automotive part quality in SMEs through DMAIC implementation: A case study in Indonesian automotive manufacturing," *Qual. Innov. Prosper.*, vol. 27, no. 3, pp. 57–74, 2023, doi: 10.12776/QIP.V27I3.1889.

[3] F. Sumasto, D. A. Arliananda, F. Imansuri, S. Aisyah, and I. R. Pratama, "Fault tree analysis: A path to improving quality in part stay protector A comp," *J. Eur. Syst. Autom.*, vol. 56, no. 5, pp. 757–764, 2023, doi: 10.18280/jesa.560506.

[4] M. Asplund and J. Lin, "Evaluating the measurement capability of a wheel profile measurement system by using GR&R," *Measurement*, vol. 92, pp. 19–27, 2016, doi: 10.1016/j.measurement.2016.05.090.

[5] G. B. Turna, "Application of lean six sigma for yield improvement in the stainless steel industry: A recipe from Türkiye," *Int. J. Lean Six Sigma*, vol. 14, no. 3, pp. 534–554, 2023, doi: 10.1108/IJLSS-02-2022-0049.

[6] F. Sumasto, I. R. Pratama, F. Imansuri, A. R. Hakim, and B. Samudra, "Evaluation of measurement system analysis techniques for screw shaft manufacturing in teaching factory setting," *J. Inotera*, vol. 9, no. 1, pp. 119–126, 2024, doi: 10.31572/inotera.vol9.iss1.2024.id311.

[7] N. Mohamed and Y. Davahran, "Measurement system analysis using repeatability and reproducibility techniques," *Statistika*, vol. 6, no. 1, pp. 37–41, 2006.

[8] C. Saikaew, "An implementation of measurement system analysis for assessment of machine and part variations in turning operation," *Measurement*, vol. 118, pp. 246–252, 2018, doi: 10.1016/j.measurement.2018.01.008.

[9] M. N. Akram and W. Abdul-Kader, "Electric vehicle battery state changes and reverse logistics considerations," *Int. J. Sustain. Eng.*, vol. 14, no. 3, pp. 390–403, 2021, doi: 10.1080/19397038.2020.1856968.

[10] N. Thawesaengskulthai and P. Jarumanee, "Improvement of vehicle service system by the application of lean six sigma," *Eng. J.*, vol. 20, no. 2, pp. 159–178, 2016, doi: 10.4186/ej.2016.20.2.159.

[11] N. Yadav, M. Kaliyan, T. Saikouk, S. Goswami, and Ö. F. Görçün, "Framework for zero-defect manufacturing in Indian industries – Voice of the customer," *Benchmarking*, vol. 30, no. 7, pp. 2303–2329, 2023, doi: 10.1108/BIJ-01-2022-0001.

[12] M. V. Sánchez-Rebull, R. Ferrer-Rullan, A. B. Hernández-Lara, and A. Niñerola, "Six sigma for improving cash flow deficit: A case study in the food can manufacturing industry," *Int. J. Lean Six Sigma*, vol. 11, no. 6, pp. 1119–1140, 2020, doi: 10.1108/IJLSS-12-2018-0137.

[13] V. E. Kane, "Useful paths for identifying lean six sigma improvement opportunities," *Int. J. Qual. Reliab. Manag.*, vol. 39, no. 8, pp. 2058–2077, 2022, doi: 10.1108/IJQRM-08-2020-0274.

[14] M. Awad and Y. A. Shanshal, "Utilizing Kaizen process and DFSS methodology for new product development," *Int. J. Qual. Reliab. Manag.*, vol. 34, no. 3, pp. 378–394, 2017, doi: 10.1108/IJQRM-09-2014-0139.

[15] F. A. Almeida *et al.*, "A multivariate GR&R approach to variability evaluation of measuring instruments in resistance spot welding process," *J. Manuf. Process.*, vol. 36, pp. 465–479, 2018, doi: 10.1016/j.jmapro.2018.10.030.

[16] F. Sumasto *et al.*, "Enhancing quality control in the Indonesian automotive parts industry: A defect reduction approach through the integration of FMEA and MSA," *Instrum. Mesure Metrologie*, vol. 23, no. 1, pp. 43–53, 2024, doi: 10.18280/i2m.230104.

[17] A. L. Setyabudhi *et al.*, "Penerapan metode measurement system analysis gage R&R pada pengukuran produk base plate magazine," *J. Rekayasa Syst. Ind.*, vol. 6, no. 2, pp. 86–89, 2021, doi: 10.33884/jrsi.v6i2.3642.

[18] M.-H. Bui, F. Villeneuve, and A. Sergent, "Evaluation of different methods in quantification of manufacturing defects," *Asian Int. J. Sci. Technol. Prod. Manuf. Eng.*, vol. 4, p. 10, 2011. [Online]. Available: http://hal.archives-ouvertes.fr/hal-00633775/en/

[19] S. Pumkrachang, K. Asawarungsaengkul, and P. Chutima, "Design and analysis of the slider shear test system using nested GR&R measurement system," *Eng. J.*, vol. 27, no. 3, pp. 11–23, 2023, doi: 10.4186/ej.2023.27.3.11.

[20] J. L. Maire, M. Pillet, and N. Baudet, "Gage R2&E2: An effective tool to improve the visual control of products," *Int. J. Qual. Reliab. Manag.*, vol. 30, no. 2, pp. 161–176, 2013,

doi: 10.1108/02656711311293571.

[21] M. Uluskan and E. P. Oda, "A thorough six sigma DMAIC application for household appliance manufacturing systems: Oven door-panel alignment case," *TQM J.*, vol. 32, no. 6, pp. 1683–1714, 2020, doi: 10.1108/TQM-06-2019-0171.

[22] G. V. S. S. Sharma, P. S. Rao, and B. S. Babu, "Quality assurance through process improvement—A concise review," *Eng. J.*, vol. 20, no. 5, pp. 103–114, 2016, doi: 10.4186/ej.2016.20.5.103.

[23] S. Cox *et al.*, "A new method to improve the objectivity of early six sigma analysis," *Int. J. Qual. Reliab. Manag.*, vol. 33, no. 9, pp. 1364–1393, 2016, doi: 10.1108/IJQRM-02-2015-0023.

[24] E. G. Santacruz, D. Romero, J. Noguez, and T. Wuest, "Integrated quality 4.0 framework for quality improvement based on six sigma and machine learning techniques towards zero-defect manufacturing," *TQM J.*, vol. 37, no. 4, pp. 1115–1155, 2024, doi: 10.1108/TQM-11-2023-0361.

[25] S. Nallusamy and A. Ahamed, "Implementation of lean tools in an automotive industry for productivity enhancement - A case study," *Int. J. Eng. Res. Afr.*, vol. 29, pp. 175–185, 2017. [Online]. Available: https://api.semanticscholar.org/CorpusID:114015207

[26] P. Guleria, A. Pathania, R. K. Shukla, and S. Sharma, "Lean six-sigma: Panacea to reduce rejection in gear manufacturing industry," *Mater. Today: Proc.*, vol. 46, pp. 4040–4046, 2020, doi: 10.1016/j.matpr.2021.02.559.

[27] L. D. Pop and N. Elod, "Improving a measuring system according to ISO/TS 16949," *Procedia Technol.*, vol. 19, pp. 1023–1030, 2015, doi: 10.1016/j.protcy.2015.02.146.

[28] L. Cepova, A. Kovacikova, R. Cep, P. Klaput, and O. Mizera, "Measurement system analyses - Gauge repeatability and reproducibility methods," *Meas. Sci. Rev.*, vol. 18, no. 1, pp. 20–27, 2018, doi: 10.1515/msr-2018-0004.

[29] M. Down, F. Czubak, G. Gruska, S. Stahley, and D. Benham, *Measurement System Analysis*, 4th ed. General Motors Corporation, 2010.

[30] S. Senol, "Measurement system analysis using designed experiments with minimum α - β risks and n," *Measurement*, vol. 36, no. 2, pp. 131–141, 2004, doi: 10.1016/j.measurement.2004.05.001.

[31] D. Placko, *Metrology in Industry: The Key for Quality*. 2006.

[32] G. A. Tetteh, K. Amoako-Gyampah, and A. Kwarteng, "Detecting faking responses during empirical research: A study in a developing country environment," *Int. J. Lean Six Sigma*, vol. 12, no. 5, pp. 889–922, 2021, doi: 10.1108/IJLSS-03-2019-0019.

[33] J. N. Pan, "Determination of the optimal allocation of parameters for gauge repeatability and reproducibility study," *Int. J. Qual. Reliab. Manag.*, vol. 21, no. 6, pp. 672–682, 2004, doi: 10.1108/02656710410542061.

[34] R. B. Murti, M. Mahmudi, and A. Nurfauziya, "An analysis of performance measurement system used in Indonesia local government," *J. Contemp. Account.*, vol. 3, no. 2, pp. 64–76, 2021, doi: 10.20885/jca.vol3.iss2.art2.

[35] F. Sumasto *et al.*, "Implementation of measurement system analysis to reduce measurement process failures on part Reinf BK6," *Indones. J. Ind. Eng. Manag.*, vol. 4, no. 2, pp. 212–220, 2023, doi: 10.22441/ijiem.v4i2.20212.

[36] A. C. R. and J. J. Thakkar, "Application of six sigma DMAIC methodology to reduce the defects in a telecommunication cabinet door manufacturing process: A case study," *Int. J. Qual. Reliab. Manag.*, vol. 36, no. 9, pp. 1540–1555, 2019, doi: 10.1108/IJQRM-12-2018-0344.

Author information

Fredy Sumasto, born in Jakarta, Indonesia in 1990, has distinguished himself in the field of industrial engineering. He obtained his Bachelor's degree from the Institut Sains dan Teknologi Nasional in 2012, followed by a Master's degree from Universitas Indonesia in 2018. Since 2019, he has been shaping the minds of future engineers as an Assistant Professor at the Industrial Engineering Department, Politeknik STMI Jakarta. His research passions lie in industrial engineering, with a particular focus on industrial engineering, e-waste management, lean manufacturing, and quality improvement. Through his academic and professional journey, he continues to inspire and lead in the pursuit of engineering excellence.

Bayu Samudra is an Automotive Industrial Engineering student at Politeknik STMI Jakarta. Born in Jakarta in December 2004, he shows a deep interest in the automotive industry, especially in production and manufacturing technology. As a student, he is active in deepening his understanding of production efficiency, technology application, and lean manufacturing techniques that are increasingly relevant in the modern industrial era. He has a high passion to keep learning and exploring innovative solutions that can advance the Indonesian automotive industry.

Ali Rachman Hakim is an Automotive Industrial Engineering student at Politeknik STMI Jakarta. Born in Jakarta in September 2004, he is passionate about the automotive world and modern manufacturing processes. He is interested in technology development and efficiency improvement in the production process, with the aim of helping to push the automotive industry in a more advanced and sustainable direction. During his time as a student, he actively explored concepts such as lean manufacturing, quality management, and industrial process automation. His dedication to understanding and applying new technologies shows his determination to contribute significantly to the automotive industry sector in Indonesia.

Febriza Imansuri, born in Bandung, Indonesia, in 1992, is a dedicated academic and researcher specializing in industrial engineering. She obtained both her Bachelor's and Master's degrees in Industrial Engineering from Universitas Andalas, where she honed her skills in optimizing industrial processes and systems. Currently serving as an Assistant Professor at Politeknik STMI Jakarta, she plays a pivotal role in shaping the future of engineering education and research. With a robust portfolio of 37 articles, her research focuses on industrial engineering, innovative product design, and effective supply chain management strategies. Her scholarly contributions reflect her passion for enhancing operational efficiency and fostering innovation within industrial contexts. Her work continues to influence and advance the field of industrial engineering, making her a respected authority in her area of expertise.

Indra Rizki Pratama, born in Jakarta, Indonesia, in 1994, is an esteemed lecturer and researcher in the field of industrial engineering, with a focus on automotive applications. He completed his academic training in industrial engineering and has since built a career that combines teaching, research, and industry collaboration. Indra joined Politeknik STMI Jakarta, where he has been instrumental in educating future engineers and contributing to practical solutions in industrial processes. His research encompasses industrial engineering, occupational health and safety, ergonomics, and work system design. He is particularly passionate about developing ergonomic solutions to improve worker safety and efficiency, as well as creating streamlined systems that enhance productivity in industrial settings. His contributions address real-world challenges, making his research valuable for both academic advancement and industrial application.