

Evaluation of Measurement System Analysis Techniques for Screw Shaft Manufacturing in Teaching Factory Setting

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ABSTRACT

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This study examines the Evaluation of Measurement System Analysis (MSA) Techniques for Screw Shaft Manufacturing in a Teaching Factory Setting at Politeknik STMI Jakarta. The research investigates the precision and accuracy of the measurement system using statistical methods such as Analysis of Variance (ANOVA), Number of Distinct Categories (NDC), and metrics like Total Gauge Repeatability and Reproducibility (GRR), Repeatability, and Reproducibility. Through comprehensive data collection, including multiple appraisers across various trials measured quantitative surveys and qualitative observations, Screw Shaft dimensions and tolerances. The collected data underwent thorough statistical analysis utilizing ANOVA to explore the sources of variation in measurements. The results of the MSA analysis provided critical insights into the measurement system's performance. Repeatability variability (9.97%) and reproducibility variability (3.80%) contribute to a total GRR of 10.67%, indicating an acceptable measurement system. Part-to-part variation emerged as the primary source of variability, emphasizing the importance of addressing part differences in quality control processes. Moreover, ANOVA highlighted the influence of different factors on measurement consistency. Part variations significantly impacted measurement variability, underscoring the need to manage part differences effectively. The assessment of repeatability and reproducibility revealed insights into measurement consistency and reliability. These findings carry significant implications for both industry and education. Understanding the factors affecting measurement variability enables the implementation of corrective measures to enhance product quality and consistency. Additionally, advancements in measurement techniques and quality management practices in Teaching Factory environments contribute to improved product quality and competitiveness in industrial settings. Continued research and evaluation are crucial for further enhancing measurement systems and manufacturing processes.

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I. Introduction

In today's industrial landscape, the significance of quality and precision cannot be overstated, as they directly influence the success and competitiveness of products [1]–[3]. The demand for meticulous and systematic measurements is steadily rising with advancing technology. This study delves into the Teaching Factory (TEFA) concept, which integrates educational principles with industrial practices to yield top-notch products. Specifically, the research focuses on implementing the TEFA concept within the Screw Shaft manufacturing process at Politeknik STMI Jakarta.

In measurement, metrology is a cornerstone in ensuring the precision and dependability of production outcomes [4]–[7]. Through a thorough examination of metrology and measurement system analysis, this study aims to unravel the intricacies of applying these principles within a TEFA



framework, particularly concerning Screw Shaft products where minute dimensions and tolerances profoundly impact final performance. By comprehending the nuances of metrology within a TEFA context, this research endeavors to pinpoint and surmount challenges encountered in maintaining product quality.

The quality of products plays an instrumental role in determining industrial competitiveness [8]–[11]. Consequently, this research concentrates on the technical facets of measurement and overarching quality management considerations, drawing from Total Quality Management (TQM) principles and Lean Manufacturing methodologies [1][2][12]. The objective is to devise strategies that enhance the efficiency and reliability of the Screw Shaft production process, thereby fostering improved product quality and diminished waste in manufacturing operations.

Moreover, it is imperative to acknowledge the broader implications of this research in engineering education. Embracing the TEFA paradigm aims to elevate industrial practices at Politeknik STMI Jakarta and cultivate a new generation of skilled technicians equipped to thrive in the global employment arena. Hence, this study serves as a cornerstone for shaping a relevant and adaptive engineering education curriculum that caters to present-day industry requisites and anticipates future trends. Encompassing various pivotal aspects of industrial engineering, from measurement and metrology to quality management and educational innovation, this research, centered on Screw Shaft products within the TEFA ecosystem of Politeknik STMI Jakarta, is poised to make a substantial contribution to both the manufacturing sector and engineering education landscape in Indonesia.

II. Method

This research employs a comprehensive mixed-methods approach, integrating both quantitative and qualitative methodologies to investigate the intricacies of measurement system analysis, metrology, and quality management within the Teaching Factory (TEFA) context at Politeknik STMI Jakarta, with a specific focus on Screw Shaft manufacturing. Initially, a quantitative investigation will be conducted, involving a thorough survey of the Screw Shaft production process (refer to Figure 1) within the TEFA facility. Precision gauges will be utilized to gather data on dimensions, tolerances, and other pertinent characteristics, particularly emphasizing the critical process point at point 2 (refer to Figure 1), featuring a dimension of 18 mm and a tolerance of ± 0.06 mm. This quantitative approach aims to elucidate product variation dynamics and identify contributing factors.

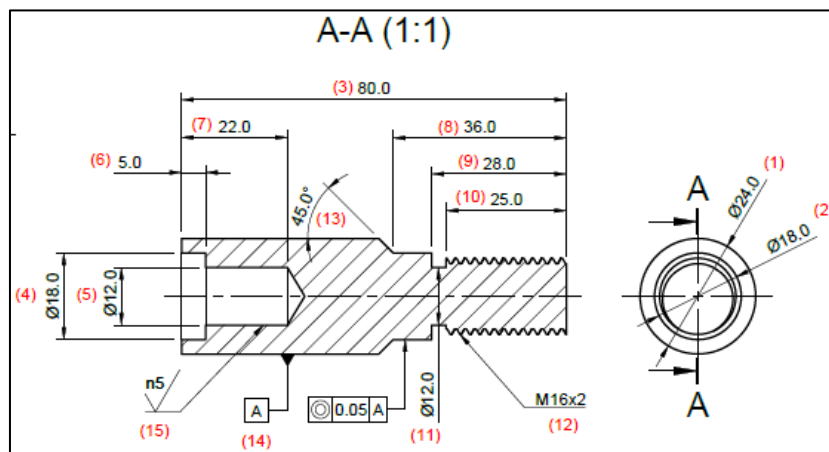


Fig 1. Engineering drawing of screw shaft

Subsequently, a rigorous measurement system analysis will ensue to assess the precision and accuracy of the measurement system employed in gauging Screw Shaft dimensions. Methodologies such as Gage R&R will be implemented to discern variations attributed to measurement equipment, operators, and environmental factors, thereby ensuring the reliability and consistency of measurement outcomes [1]-[2]. Concurrently, a qualitative approach will complement these efforts through interviews and direct observations of the production process at TEFA. This qualitative inquiry will provide invaluable insights into the practical implementation of measurement, metrology, and quality

management protocols within the simulated industrial setting [13]–[16], shedding light on inherent challenges encountered in attaining desired quality benchmarks.

Utilize specialized software, such as Minitab® Statistical Software, to execute the MSA analysis. Employ the GRR formula provided in the draft to compute values for GRR, EV, AV, PV, and TV [1]. Assess the outcomes of the MSA analysis to ascertain the measurement system's ability to deliver dependable results. If the %GRR and NDC values align with the standards specified in Table 1, the system is deemed satisfactory. Alternatively, pinpoint the source of uncertainty and implement required enhancements. Based on the improvement results, if the variance diminishes, it becomes imperative to regulate MSA, necessitating measurements at least once every three months. The calculation method employed adheres to equations (1) through (7) outlined below:

Repeatability - Equipment Variation (*EV*):

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

Reproducibility – Appraiser Variation (*AV*):

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

where, n = sample of parts, r = trials.

Repeatability & Reproducibility (*GRR*):

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

Part Variation (*PV*):

$$PV = R_p \times K_3 \tag{4}$$

Total Variation (*TV*):

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

% Total Variation (*TV*):

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

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

Table 1. Border value of %GRR and NDC [1][2][6][11][15][17][18]

Value	Description
%GRR < 10%	Acceptable measuring system. The measuring system provides reliable information about process changes.
10% < %GRR < 30%	Conditionally acceptable measurement system. It can be used for several applications.
%GRR > 30%	Unacceptable measurement system. The measuring system does not provide reliable information about process changes.
NDC ≥ 5	Acceptable measuring system. The measuring system provides reliable information about process changes.
2 ≤ NDC ≤ 4	Generally unacceptable for estimating process parameters and indices since it only provides coarse estimates. Rejected measurement equipment - more sensitive equipment needs to be used.
NDC = 1	Unacceptable measurement system. The measuring system does not provide reliable information about process changes.

The amalgamation of quantitative and qualitative analyses will culminate in a synthesized examination of key findings and actionable recommendations aimed at refining the measurement

system, enhancing quality management practices, and optimizing the Screw Shaft production process within the TEFA framework. These proposed improvement measures will be meticulously crafted based on a holistic integration of analytical outcomes, ensuring coherence and efficacy in augmenting quality and efficiency parameters.

III. Results and Discussion

The findings of this study shed light on crucial aspects concerning measurement, metrology, measurement system analysis, and quality management pertinent to Screw Shaft manufacturing within the Teaching Factory (TEFA) at Politeknik STMI Jakarta. Initially, the analysis of measurement data unveiled noteworthy variations in Screw Shaft dimensions and tolerances, underscoring the imperative of implementing robust quality control methodologies in the production process. The tabulated measurement data, as depicted in Table 2, encompass measurements conducted by three appraisers across ten Screw Shaft parts, replicated thrice.

Table 2. Measurement data of screw shaft

Appraiser	Trial	Parts									
		1	2	3	4	5	6	7	8	9	10
1	1	18.10	18.06	17.98	17.98	18.06	18.08	18.05	18.15	17.68	17.99
	2	18.09	18.07	17.95	17.98	18.06	18.06	18.07	18.19	17.70	17.99
	3	18.10	18.09	17.97	17.98	18.06	18.07	18.05	18.19	17.70	17.99
2	1	18.10	18.06	18.00	17.98	18.05	18.09	18.04	18.16	17.70	18.00
	2	18.10	18.06	17.95	17.98	18.05	18.09	18.04	18.16	17.71	17.99
	3	18.10	18.07	17.96	17.98	18.04	18.08	18.04	18.14	17.72	18.01
3	1	18.11	18.05	17.94	17.97	18.05	18.08	18.03	18.14	17.72	17.98
	2	18.10	18.06	17.99	17.97	18.05	18.08	18.04	18.14	17.69	17.98
	3	18.10	18.05	17.95	17.96	18.03	18.07	18.02	18.16	17.71	17.98

Consequently, an exhaustive evaluation of the Measurement System Analysis (MSA) technique applied to the Screw Shaft manufacturing process within the TEFA milieu was conducted. The results gleaned from the MSA analysis were delineated through two Two-Way ANOVA tables, elucidating the multifaceted influences of various factors on Screw Shaft measurement variability. Firstly, the ANOVA table with interactions (Table 3) underscored the significant impact of both the part being measured and the operator conducting the measurement, alongside their interaction, on measurement variability ($F = 610.620$, $p < 0.05$). This data underscores the intricate interplay between parts and operators in determining the consistency of Screw Shaft measurements.

Moreover, findings from the ANOVA table without interaction (Table 4) revealed that while the interaction between parts and operators did not attain statistical significance, both factors individually exerted substantial influences on measurement variability ($F = 896.383$ for parts, $F = 5.353$ for operators, $p < 0.05$). This observation underscores the significance of discerning the individual roles of parts and operators in influencing Screw Shaft measurement quality, even in the absence of their interaction in the analysis.

These revelations furnish critical insights into devising more efficacious measurement practices tailored to Screw Shaft manufacturing within Teaching Factories. By comprehending the nuanced influences of parts and operators, alongside their interaction, on measurement variability, remedial measures can be devised to enhance product quality and consistency. Further discourse on the implications of these findings can serve as a compass for developing more sophisticated and efficient measurement methodologies, along with pragmatic recommendations for industries to bolster the performance of their measurement systems. In summation, this research furnishes a profound comprehension of MSA evaluation within this specific context and lays the groundwork for ameliorating manufacturing practices holistically.

Table 3. Two-Way ANOVA table with interaction

Source	DF	SS	MS	F	P
Parts	9	1.24092	0.137880	610.620	0.000
Operators	2	0.00165	0.000823	3.646	0.047
Parts * Operators	18	0.00406	0.000226	1.708	0.063
Repeatability	60	0.00793	0.000132		
Total	89	1.25456			

α to remove interaction term = 0.05

Table 4. Two-Way ANOVA table without interaction

Source	DF	SS	MS	F	P
Parts	9	1.24092	0.137880	896.383	0.000
Operators	2	0.00165	0.000823	5.353	0.007
Repeatability	78	0.01200	0.000154		
Total	89	1.25456			

This investigation conducted an assessment of the Measurement System Analysis (MSA) technique as applied to the Screw Shaft manufacturing process within a Teaching Factory setting. Our evaluation primarily relied on Gage R&R data, specifically Variance Components and Gage Evaluation, to discern the performance of the measurement system. Variance Components (Table 5) furnish insights into the proportion of variance attributed to different components within the measurement process. Our analysis delineates that the predominant portion of variation (98.86%) in Screw Shaft measurement stems from variations between the measured parts (Part-To-Part), underscoring its substantial influence. Conversely, the contributions from Repeatability (0.99%) and Reproducibility (0.14%) are comparatively minor, suggesting a lesser impact on the overall variation within the measurement system.

Moreover, the Gage Evaluation (Table 6) provides a more granular depiction of the measurement system's efficacy. Here, the Standard Deviation (SD) and Study Variation values offer insights into the level of variability attributable to repeatability and reproducibility in measurements. Notably, the SD value for repeatability (0.012402) is lower than that for reproducibility (0.004724), indicating a relatively higher consistency in repeatability compared to reproducibility across measurements conducted by different operators. Nevertheless, both components contribute significantly to the total variation observed in Screw Shaft measurements.

These findings hold critical implications for understanding and enhancing the performance of the measurement system within the context of Screw Shaft manufacturing in a Teaching Factory environment. While variation between parts emerges as the primary driver of measurement variation, acknowledging the contributions of other components, such as repeatability and reproducibility, remains imperative. By discerning the relative contributions of each component to the total variation, tailored corrective measures can be devised to enhance measurement consistency and accuracy. Subsequent discussions on the implications of these findings are poised to inform the development of more sophisticated and efficient measurement methodologies, offering actionable recommendations for industries to bolster the performance of their measurement systems.

Table 5. Variance components of screw shaft for measurement

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0001761	1.14
Repeatability	0.0001538	0.99
Reproducibility	0.0000223	0.14
Operators	0.0000223	0.14
Part-To-Part	0.0153029	98.86
Total Variation	0.0154790	100.00

Table 6. Gage evaluation of screw shaft for measurement

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)	Number of Distinct Categories (ndc)
Total Gage R&R	0.013272	0.079629	10.67	13
Repeatability	0.012402	0.074414	9.97	
Reproducibility	0.004724	0.028345	3.80	
Operators	0.004724	0.028345	3.80	
Part-To-Part	0.123705	0.742228	99.43	
Total Variation	0.124415	0.746488	100.00	

Upon conducting the GR&R analysis, the findings reveal a repeatability variability of 9.97%, indicating that the measurement device continues to influence the variation in repeat measurements. Conversely, the reproducibility element demonstrates a result of 3.80%, suggesting insignificance in the operator's impact on repeatability. Notably, the total GR&R result of 10.67% raises interest, signaling conditional acceptability of the measurement system. Additionally, the NDC analysis with a value of 13 elucidates the system's capability to furnish consistent information concerning process changes. Based on ANOVA standpoint, the GR&R percentage stands at 1.14%, with a part-to-part contribution of 98.86%. Despite the predominance of variation attributed to differences between parts, the total GR&R contribution falling below 10% suggests the acceptability of the operator measurement process in discerning diameter discrepancies among different parts.

Figure 2 provides a comprehensive depiction of variance and standard deviation components, emphasizing the substantial variation originating from disparities between parts. Although several points on the Xbar diagram surpass the control limits, indicative of measurement variation primarily stemming from part differences, the main effect and interaction plots corroborate significant variation attributable to part disparities.

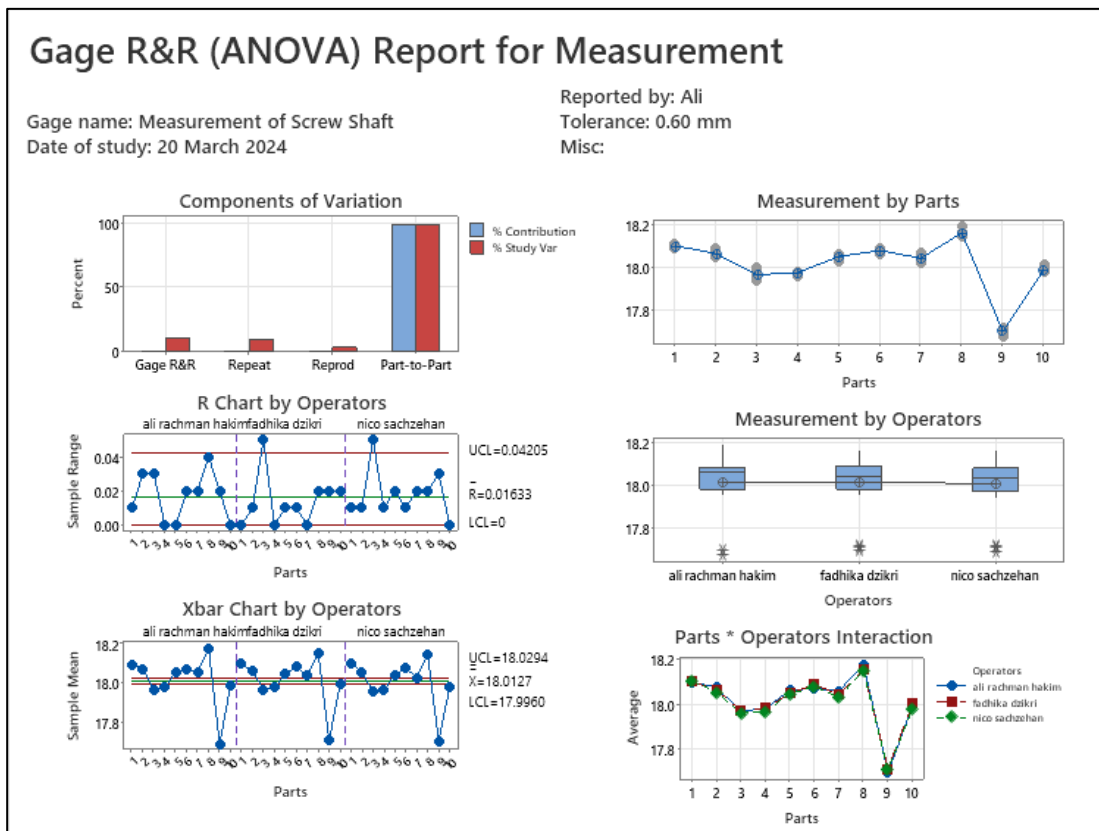


Fig 2. Results from GR&R analysis of screw shaft

In summation, the MSA results underscore the presence of measurement consistency and accuracy. Despite variation emanating from part differences, the enhanced measurement system exhibits proficiency in furnishing consistent and reliable insights into changes within the production process. Continued evaluation and monitoring of the system are imperative to sustain the efficacy of implemented improvements.

IV. Conclusion

The evaluation of MSA techniques in Screw Shaft manufacturing within the TEFA setting at Politeknik STMI Jakarta has yielded valuable insights into the intricacies of measurement variability and quality management practices. Through a comprehensive mixed-methods approach, combining quantitative surveys and qualitative observations, we have uncovered significant findings that shed light on the measurement system's performance and its impact on product quality.

The findings from the MSA analysis revealed several crucial aspects of measurement variability. Firstly, the GR&R analysis indicated that the measurement device plays a significant role in the variation of repeat measurements. While repeatability variability was 9.97%, suggesting a moderate influence of the measurement device, reproducibility variability was lower at 3.80%, indicating a relatively minor impact of operator differences on measurement consistency. However, the total GR&R result of 10.67% suggests that the measurement system is conditionally acceptable and can provide consistent information about process changes.

Further analysis through ANOVA highlighted the influences of different factors on measurement variability. The ANOVA results revealed that the variation between parts (Part-to-Part) accounts for the majority of the variance in Screw Shaft measurements, emphasizing the importance of addressing part variations in quality control efforts. Additionally, the interaction between parts and operators was found to significantly impact measurement variability, underscoring the complexity of factors influencing measurement consistency. Moreover, the assessment of Repeatability and Reproducibility provided insights into the consistency and reliability of measurement outcomes. While repeatability exhibited relatively higher consistency compared to reproducibility across measurements conducted by different operators, both components contributed significantly to the total variation observed in Screw Shaft measurements.

Overall, the findings from the MSA analysis underscore the critical importance of implementing effective quality control measures to address measurement variability in Screw Shaft manufacturing. By understanding the influences of factors such as part variations, operator effects, and measurement equipment precision, corrective measures can be devised to enhance product quality and consistency. These findings have significant implications for both industry and education, informing the development of more sophisticated measurement techniques and contributing to the advancement of manufacturing practices in Teaching Factory settings. Further research and continuous evaluation are essential to ensure the continual improvement of measurement systems and the enhancement of product quality in Screw Shaft manufacturing.

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