

Gauge Capability for Manual Measurement Equipment

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Abstract

Gauge repeatability and reproducibility study is still relevant today in many industries and the manufacturing sector. It is becoming most important as the requirements of manufacturing tolerances are becoming more stringent. Variability in measurement systems has come under heavy scrutiny as requirement for tolerances becomes tighter. This paper focuses on the variability of a manual measurement system in determining the gauge capability. The paper is also a further study of a previous paper titled: “Design of Experiment for Gauge Capability and Comparison of Variability for Discrete and Scanning Methods of Obtaining Data”. Vernier caliper is the manual measurement system used in this paper for the capability study. The experiment designed in the previous paper mentioned above was adapted to the manual system and put to use here. Results were obtained, analyzed, discussed and conclusions were deduced thus: though automatic measurement systems might be more expensive and very in outputs, they have smaller variability.

Keywords

Gauge Capability, Variability, Manual Measurement, Vernier Caliper

1. Introduction

The study of gauge repeatability and reproducibility (GR & R) has become significant since gauges are sometimes used as a standard for verifying other measuring equipment [1], but also because they are used as quality-control tools during in-process inspection in manufacturing. Measuring instruments and the methods employed in carrying out measurements are very critical to the accuracy, reproducibility and repeatability of such measurements [2]. Measurements that are not accurate could lead to false signals as statistics or analysis drawn from such data could be misleading. One can only trust data produced from a trusted measure-

ment system otherwise it is not easy to trust such data [1]. Measurement Systems Analysis (MSA) is a key component of establishing, improving and maintaining quality systems [3]. Whether you're engaged in a Six Sigma project or an ISO-9000 certification, an MSA helps to identify problems with measurement systems and determine if you can trust the data [4]. Several factors such as measurement procedures, level of operator skills and limitations of the instrument used can affect the result of measurement [5] [6]. In this paper, the focus will be on manual measurement for Gauge capability and variability.

Measurement systems in metrology can be manual, semi-automated or fully automated [7]. Automated systems are becoming more attractive, because they are more reliable and eliminate human error but manual set-ups are seen almost everywhere [8]. Manual metrology requires a high level of skill for good measurements and perhaps less expensive equipment and is sometimes less flexible than automatic measurement systems [7].

Manual Measurement System

A manual measurement system in metrology involves using tools and instruments like calipers and micrometers that require physical manipulation by an operator to obtain measurements [9]. Measurement results obtained by manual measurement systems are subjective often depending on operator skill and experience and process [2] [10] for accuracy. Manual metrology requires a high level of skill for good measurements and perhaps less expensive equipment and is sometimes less flexible than automatic measurement systems. These systems are often used for tasks like measuring dimensions, angles, and other characteristics of objects. Some tools used include: Calipers, Micrometers, Go/no-go devices [11], Dial indicators, Protractors, Rulers & Measuring tapes.

Most manual measurement systems are less expensive than automated systems and can be used for a wide range of measurements and applications. The drawback of manual measurement systems is that they can be time-consuming and are subject to human error: Measurements can be affected by operator bias and inaccuracies [4] [12].

2. Previous Work [13]

[13] presented a paper for the design of experiment to analyze gauge capability. The same designed experiment was used to test and compare the variation for two automatic measurement systems. Three metrology factors were used as a starting point and the factors were compared at two levels. Test results were analyzed using the expanded ANOVA method [13] in Minitab. Results discussion ensued and the conclusion showed that even automatic measuring systems can significantly vary in variability especially when subjected to different factors. [13] also focused only on automatic measurement systems but here, the same designed experiment is used for the GR & R study on manual measurement systems such as a vernier caliper shown in **Figure 1**.



Figure 1. A digital vernier caliper.

2.1. Randomization

Minitab the application used here for the analysis as statistical tool has a built-in process for randomization. Therefore, there was no need for doing it manually.

2.2. Replication

Replication means repetitions of an entire experiment or a portion of it, under more than one condition. This is demonstrated by running the experiment ten times by three operators at two levels.

2.3. Blocking

The idea is to arrange similar experimental runs into blocks or groups. This was achieved by first creating two large blocks of two manual measuring systems. These blocks were then divided into smaller blocks representing the three operators. The smaller blocks were further sub-divided on two levels.

3. Measurement Strategy to Determining Gauge Capability

Four parts: diameters of three holes of a connecting rod (workpiece) and its full length are measured by three operators (1-Lucky, 2-Victor, 3-Yousaf) using two factors (digital and manual). Each operator measures the four parts ten times. The variations would be part-to-part, variation due to measurement instrument or repeatability and variation due to operators or reproducibility. This case has three components: repeatability, reproducibility, and part-to-part variation [11]. The workpiece is shown in **Figure 2**.

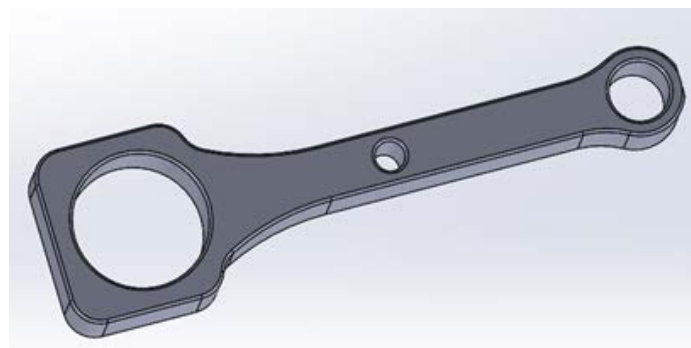


Figure 2. Schematic of work piece.

Each operator measured the parts with the above-mentioned Vernier in line with ISO 13385-1:2019 [14] measurement systems using the approach shown in Figure 3.

Summary of the Designed Experiment in [13]

The experiment investigated the effect of three parameters on measurement uncertainty of the automatic equipment at two levels. It was designed to investigate the effect of three factors on two levels of measurement uncertainty using the full factorial design with 10 replicates. The designed experiment in [13] was adapted to suit the manual measurement system. Therefore, there is no design of experiment in this paper.

Parts/Measurands:

- 1) Diameter of the large circle
- 2) Diameter of the medium circle
- 3) Diameter of the small circle
- 4) Length of the connecting rod

Factors:

- 1) Manual and
- 2) Digital

Manual Instrument:

- 1) Vernier Caliper

Number of Runs

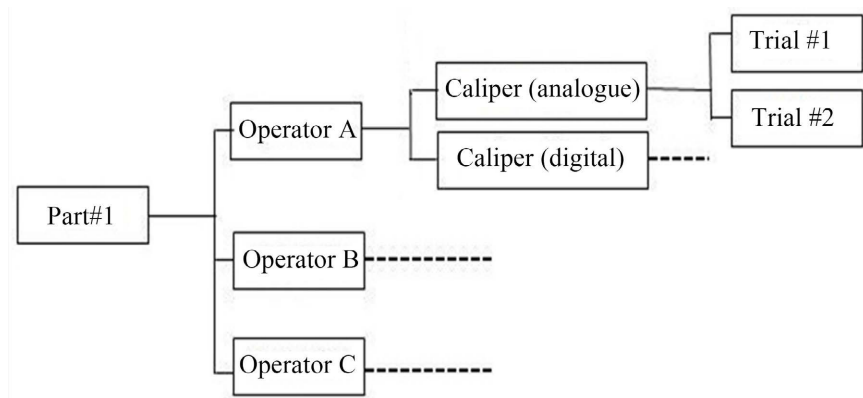


Figure 3. Data collection plan.

The number of runs would be:

$$(4 \text{ parts}) \times (3 \text{ operators}) \times (10 \text{ repeats}) \times (2 \text{ gauges}) = 240 \tag{1}$$

(measurements):

4. Results, Analyses and Discussion

This section captures the results obtained, the analyses using Minitab and then, the discussion of the results.

4.1. Results

Three operators measured the three circle diameters (\emptyset) and the length of the connecting rod (Con-rod) with manual Vernier Caliper and digital Vernier Caliper. Where X is mean and R is range (difference between max and min data values) (Tables 1-4).

Table 1. Large circle diameter measured by three operators with mean and range.

Large Circle Diameter measured with Vernier Caliper [mm]									
Operator 1		Operator 2		Operator 3		X (Digital)	X (Manual)	X (Overall)	\bar{R}
Digital	Manual	Digital	Manual	Digital	Manual				
44.90	44.90	45.44	45.02	44.83	45.05	45.06	44.99	45.02	0.61
44.93	44.75	45.00	45.12	44.76	45.00	44.90	44.96	44.93	0.37
44.96	45.00	45.00	44.93	44.94	45.10	44.97	45.01	44.99	0.17
44.98	45.00	45.52	45.00	45.03	44.95	45.18	44.98	45.08	0.57
44.89	44.65	45.67	45.14	45.01	44.90	45.19	44.90	45.04	1.02
44.94	44.80	45.34	45.23	44.91	45.15	45.06	45.06	45.06	0.54
44.97	44.70	45.40	44.97	45.00	45.20	45.12	44.96	45.04	0.70
44.89	44.70	45.00	45.21	45.04	44.95	44.98	44.95	44.97	0.51
44.92	44.95	44.92	44.93	44.97	45.07	44.94	44.98	44.96	0.15
44.89	44.90	44.67	45.17	44.98	45.00	44.85	45.02	44.94	0.50
						45.02	44.98	45.00	0.51

Table 2. Medium circle diameter measured by three operators with mean and range.

Medium Circle Diameter measured with Vernier Caliper [mm]									
Operator 1		Operator 2		Operator 3		X (Digital)	X (Manual)	X (Overall)	\bar{R}
Digital	Manual	Digital	Manual	Digital	Manual				
19.74	20.00	19.85	19.72	19.96	20.00	19.85	19.91	19.88	0.28
19.93	19.80	19.55	19.63	19.95	20.05	19.81	19.83	19.82	0.50
19.78	20.00	19.73	19.59	19.99	20.20	19.83	19.93	19.88	0.61
19.86	19.95	19.81	19.86	19.91	19.96	19.86	19.92	19.89	0.15
19.82	20.00	19.62	19.74	19.96	19.90	19.80	19.88	19.84	0.38
19.87	19.70	19.78	19.77	19.97	20.05	19.87	19.84	19.86	0.35
19.92	19.80	19.83	19.67	19.96	20.15	19.90	19.87	19.89	0.48
19.79	19.95	19.98	19.75	20.02	20.23	19.93	19.98	19.95	0.48
19.84	19.80	19.86	19.80	20.06	20.19	19.92	19.93	19.93	0.39
19.90	19.70	19.88	19.68	20.01	19.97	19.93	19.78	19.86	0.33
						19.87	19.89	19.88	0.40

Table 3. Small circle diameter measured by three operators with mean and range.

Small Circle Diameter measured with Vernier Caliper [mm]									
Operator 1		Operator 2		Operator 3		X (Digital)	X (Manual)	X (Overall)	\bar{R}
Digital	Manual	Digital	Manual	Digital	Manual				
9.62	9.60	9.23	9.22	9.88	9.95	9.58	9.59	9.58	0.73
9.52	9.70	9.24	9.33	9.75	9.90	9.50	9.64	9.57	0.66
9.66	9.50	9.53	9.28	9.69	9.85	9.63	9.54	9.59	0.57
9.64	9.65	9.63	9.35	9.90	9.90	9.72	9.63	9.68	0.55
9.84	9.75	9.57	9.37	9.92	9.95	9.78	9.69	9.73	0.58
9.76	9.80	9.52	9.44	9.91	9.91	9.73	9.72	9.72	0.47
9.68	9.70	9.50	9.47	9.89	9.88	9.69	9.68	9.69	0.42
9.59	9.40	9.44	9.35	9.94	9.78	9.66	9.51	9.58	0.59
9.80	9.80	9.47	9.42	9.93	9.80	9.73	9.67	9.70	0.51
9.78	9.80	9.52	9.49	9.93	9.93	9.74	9.74	9.74	0.44
						9.68	9.64	9.66	0.55

Table 4. Small circle diameter measured by three operators with mean and range.

Length of connecting rod measured with Vernier Caliper [mm]									
Operator 1		Operator 2		Operator 3		X (Digital)	X (Manual)	X (Overall)	\bar{R}
Digital	Manual	Digital	Manual	Digital	Manual				
214.21	215.54	214.19	215.09	214.21	214.91	214.20	215.18	214.69	1.35
214.22	215.45	214.23	214.89	214.19	215.19	214.21	215.18	214.70	1.26
214.20	214.85	214.45	214.45	214.20	215.02	214.28	214.77	214.53	0.82
214.23	214.93	214.22	214.72	214.14	214.74	214.20	214.80	214.50	0.79
214.19	215.12	214.23	214.67	214.18	214.88	214.20	214.89	214.55	0.94
214.20	215.08	214.30	214.73	214.38	214.67	214.29	214.83	214.56	0.88
214.22	215.15	214.25	214.55	214.23	214.53	214.23	214.74	214.49	0.93
214.32	214.98	214.18	214.68	214.21	214.89	214.24	214.85	214.54	0.80
214.20	214.99	214.32	215.32	214.22	214.28	214.25	214.86	214.56	1.12
214.18	215.05	214.36	215.06	214.18	214.78	214.24	214.96	214.60	0.88
						214.23	214.91	214.57	0.98

4.2. Results

Analyses were done with the ANOVA method for GR & R studies in Minitab application where X is the mean and R is the difference between max and min data values.

4.2.1. Using Minitab: Part # 1 (Large Circle Diameter)

The result for digital and manual Vernier Caliper for part 1 are analyzed and presented in **Figure 4** and **Figure 5** respectively.

Gauge R&R (ANOVA) Report for Digital Vernier on Large Circle Diameter

Gage name: Digital Vernier
Date of study: 09 July, 2025

Reported by: Joel A
Tolerance: +/- 0.02 mm
Misc: NA

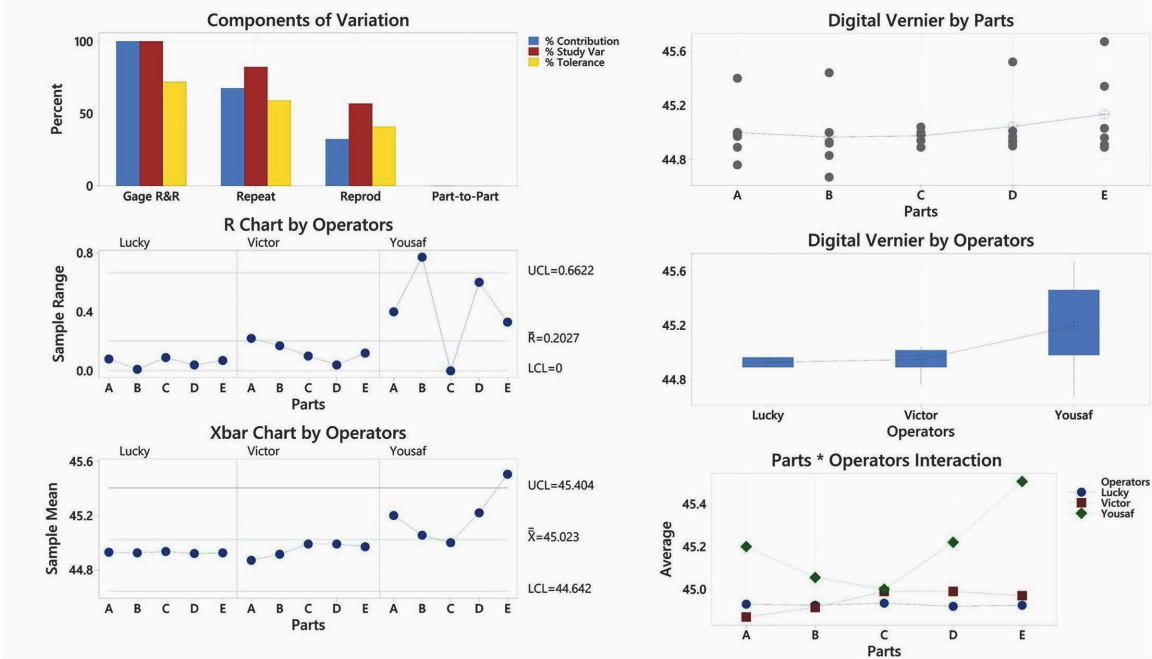


Figure 4. Gauge R&R report for digital vernier on large circle diameter.

Gauge R&R (ANOVA) Report for Manual Vernier on Large Circle Diameter

Gage name: Manual Vernier
Date of study: 09 July, 2025

Reported by: Joel A
Tolerance: +/- 0.02 mm
Misc: NA

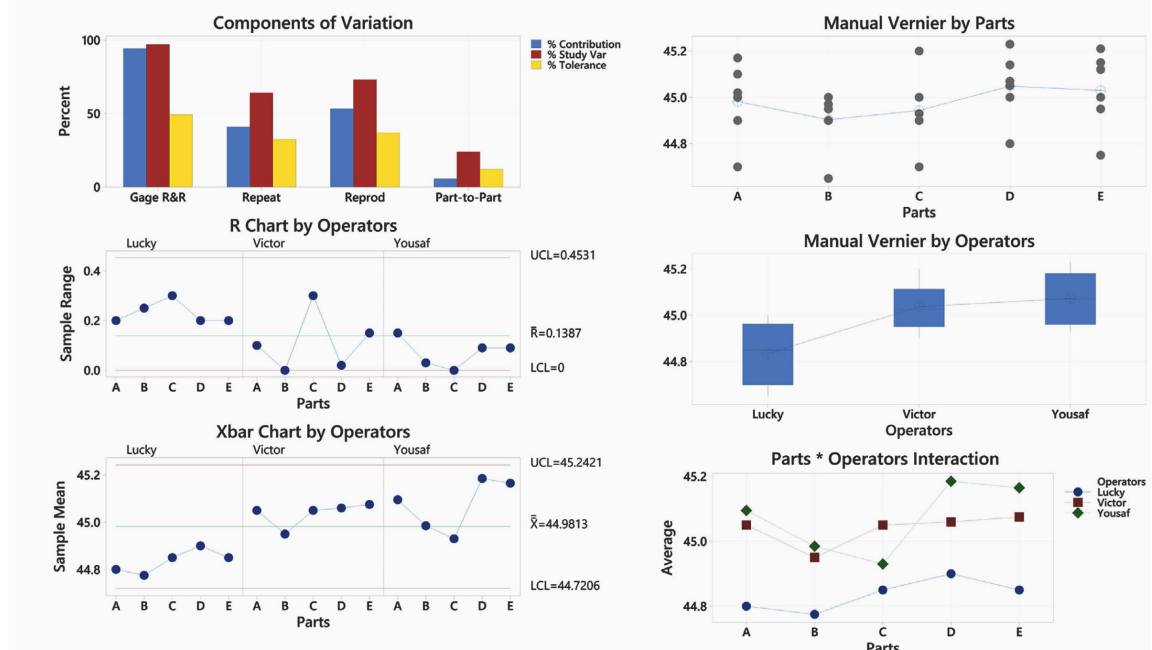


Figure 5. Gauge R&R report for manual vernier on large circle diameter.

4.2.2. Using Minitab: Part # 2 (Medium Circle Diameter)

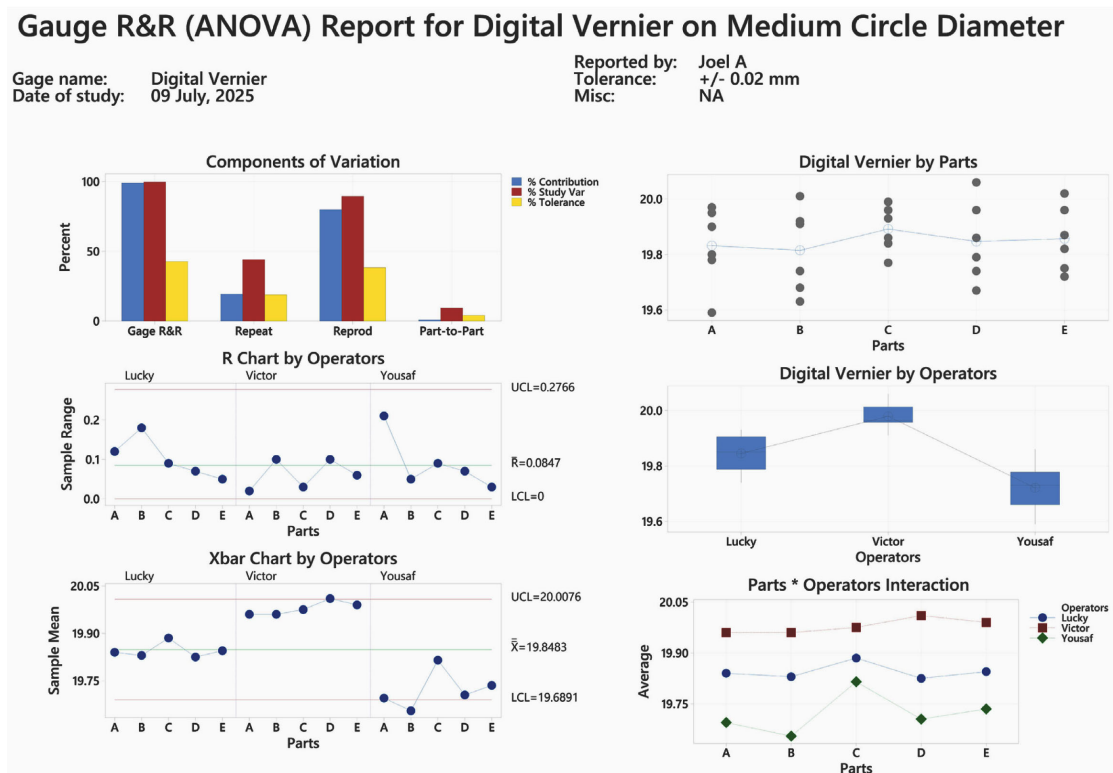


Figure 6. Gauge R&R report for digital vernier on medium circle diameter.

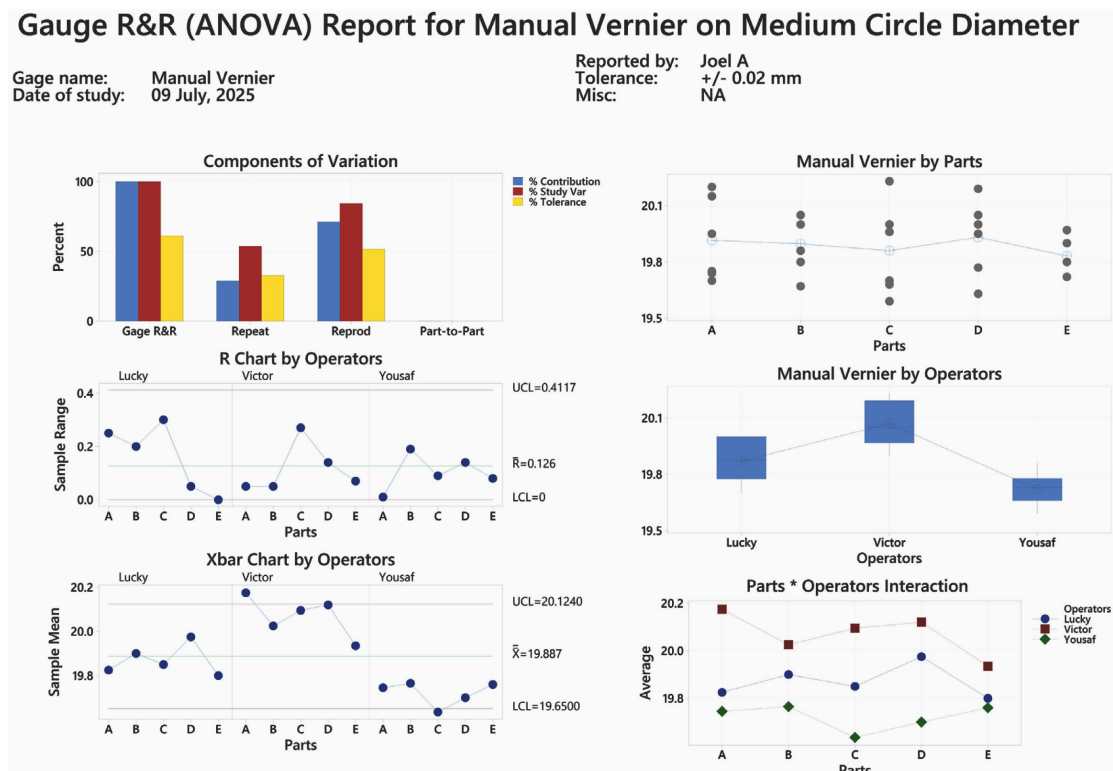


Figure 7. Gauge R&R report for manual vernier on medium circle diameter.

The result for digital and manual Vernier Caliper for part 2 are analyzed and presented in **Figure 6** and **Figure 7** respectively.

4.2.3. Using Minitab: Part # 3 (Small Circle Diameter)

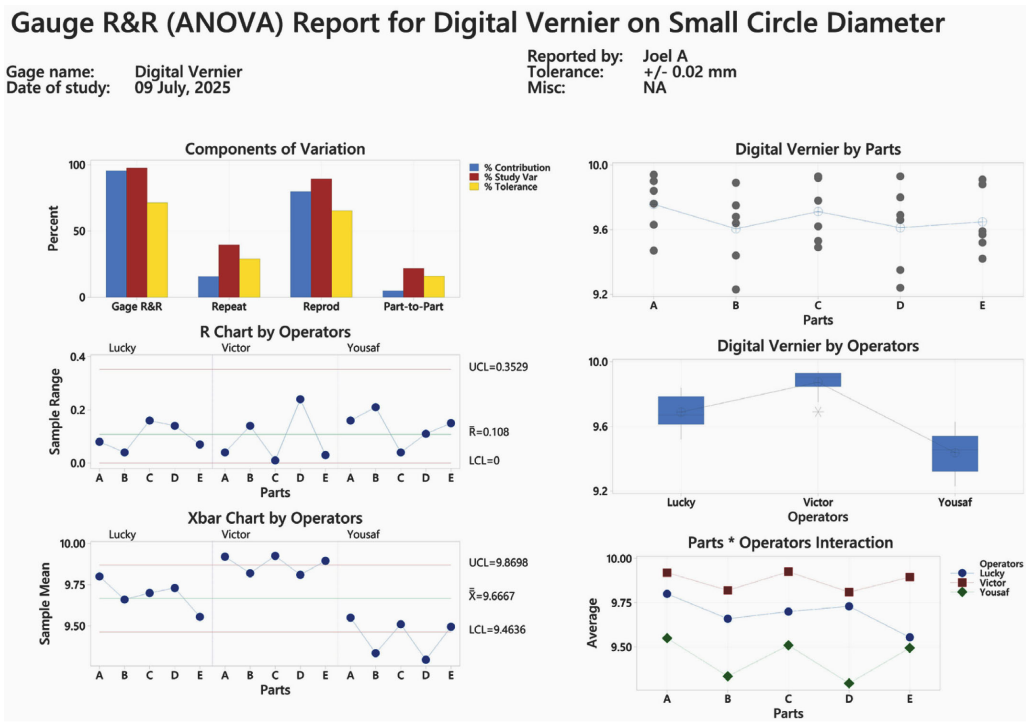


Figure 8. Gauge R&R report for digital vernier on small circle diameter.

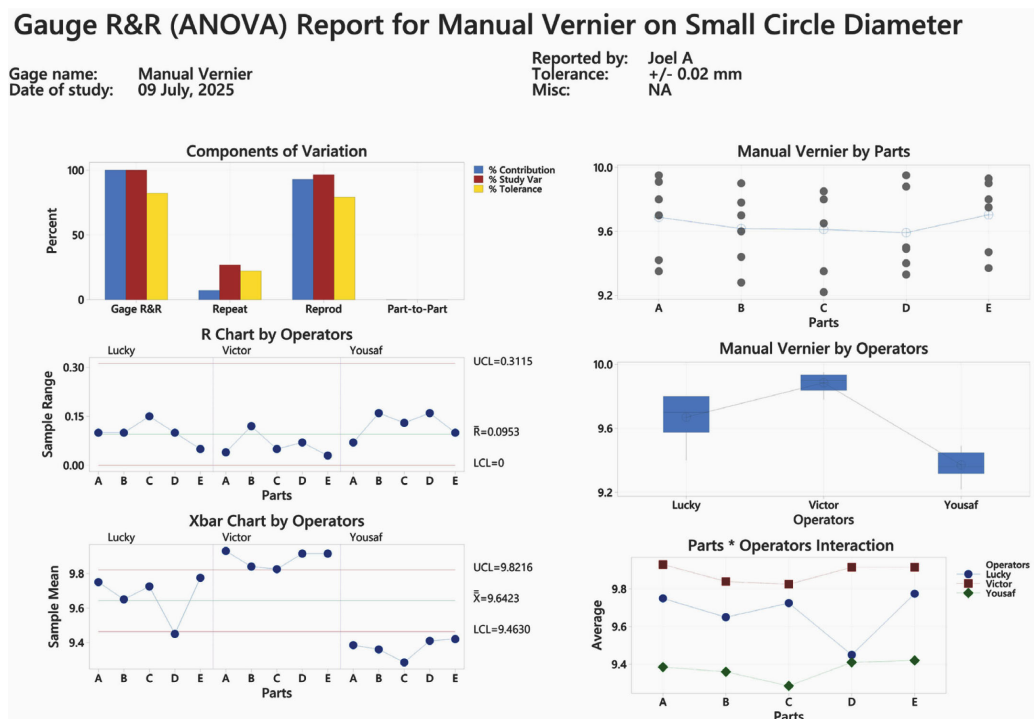


Figure 9. Gauge R&R report for manual vernier on small circle diameter.

The result for digital and manual Vernier Caliper for part 3 are analyzed and presented in **Figure 8** and **Figure 9** respectively.

4.2.4. Using Minitab: Part # 4 (Con-Rod Length)

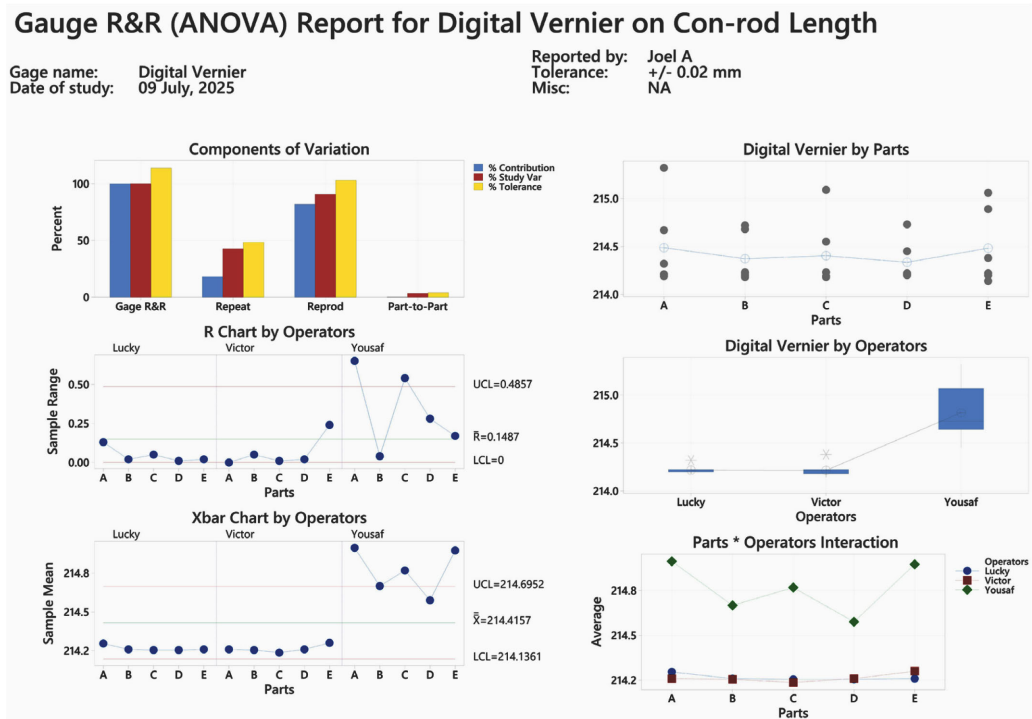


Figure 10. Gauge R&R report for digital vernier on con-rod length.

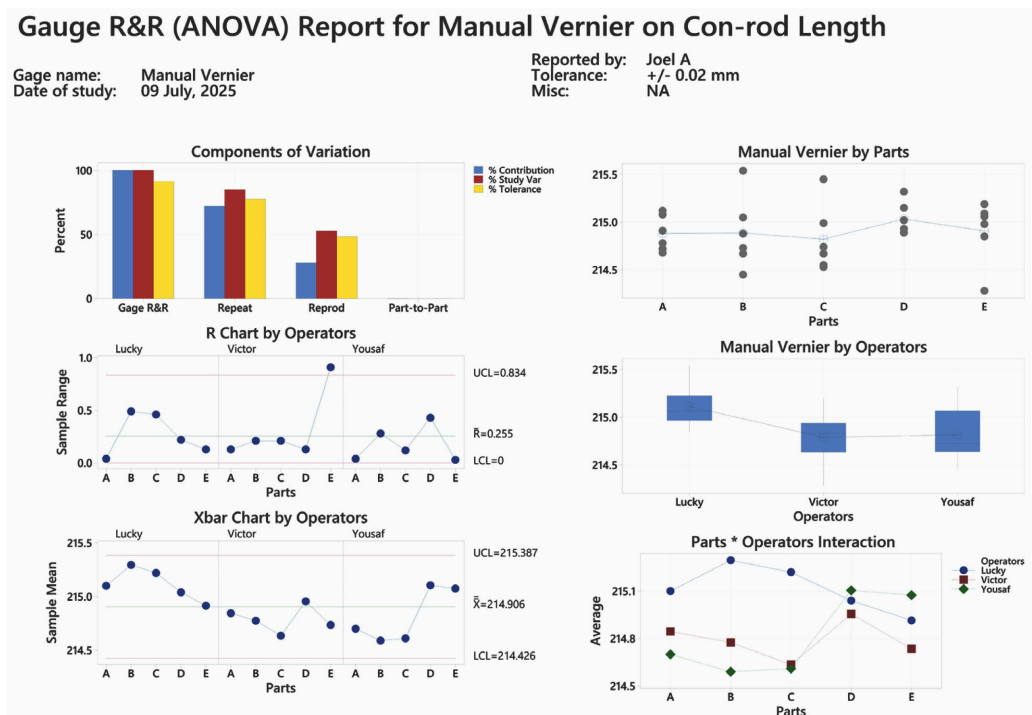


Figure 11. Gauge R&R report for manual vernier on con-rod length.

The result for digital and manual Vernier Caliper for part 4 are analyzed and presented in **Figure 10** and **Figure 11** respectively.

4.3. Discussion

The 3 operators measured a select part using a manual and digital Vernier caliper with 10 replicates. In a typical nested gage study, 10 parts, 3 operators and 2 replicates with a total of 60 measurements are usually the standard [5] [15] and the degree of freedom for error equals 30, which allows one to have about 90% confidence in estimating the repeatability within 20% of the true value [16]. Under this typical setting, the estimate for repeatability is reasonably precise.

In this paper, four parts were chosen. 10 replicates were then divided into 2 groups of 5 parts using the principle of blocking. The number of replicates was increased to 10 instead of the standard 2 replicates using the principle of replication to cater for the shortfall in the number of parts. Details of this experimental set-up are given by [13]. Therefore, to mimic a typical gauge study, the true representation of the runs was:

$$5 \text{ similar parts} \times 2 \text{ replicates} \times 3 \text{ operators} \times 2 \text{ gauges} = 60 \tag{2}$$

This was done for the 4 different parts; therefore, the total number of runs was:

$$60 \times 4 = 240 \tag{3}$$

A total of 240 measurements were done using blocking and replication principles compared to the usual 60 measurements.

A summary of these results is thus (**Table 5**):

- It was observed that variation was due to operators/part interaction, reproducibility and repeatability and no variation from part to part (one part repeatedly measured).
- There is a noticeable difference by between the variations of the digital and manual Vernier;
- A careful look at **Figures 4-11** reveals that the data is skewed as shown in the sample range and sample mean graph.
- Part-to-operator variations vary widely and there is no perfect agreement between the operators.

Table 5. Comparison of total variation between digital and Vernier caliper.

	Total variation (Standard Dev)	
	Digital Vernier	Manual Vernier
Large Diameter	0.245997	0.27157
Medium Diameter	0.130528	0.18643
Small Diameter	0.23732	0.23732
Con-rod	0.072637	0.30321
	0.17162055	0.2496325

5. Conclusions

It was uncovered from this GR & R study that variability in using hand instruments, such as a digital and manual Vernier caliper was largely due to operator/instrument interaction. Repeatability and reproducibility contributed much to the overall variations. A critical review of the study revealed that the standard deviation of the data acquired by the use of the manual Vernier had a larger standard deviation compared to the digital Vernier. This implies that data acquired using manual Vernier has a larger data scatter as such using digital Vernier will yield data with a smaller range compared to the manual Vernier. This is attributed to operators' manual handling.

This paper showed that there is greater variability when manual measurement systems are used in a measurement compared to automatic measurement systems. For automatic measuring systems, variability was mostly due to reproducibility rather than repeatability. However, in the manual measurement system, variability is substantially a contribution of the three components: repeatability, reproducibility and operator/instrument interaction.

Though automatic measurement systems might be more expensive and vary in outputs when affected by different factors, they have smaller variability which translates to higher accuracy and efficiency compared to manual measurement systems.

More manual and automatic measuring systems might be of interest in furtherance of this work.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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