



THE SCOPE OF TOOLS AND TECHNIQUES

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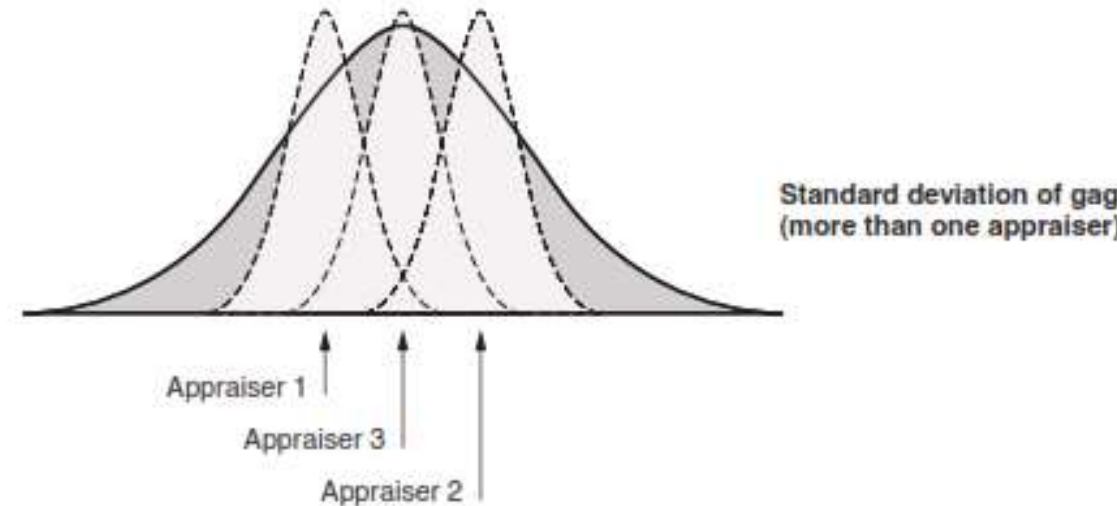
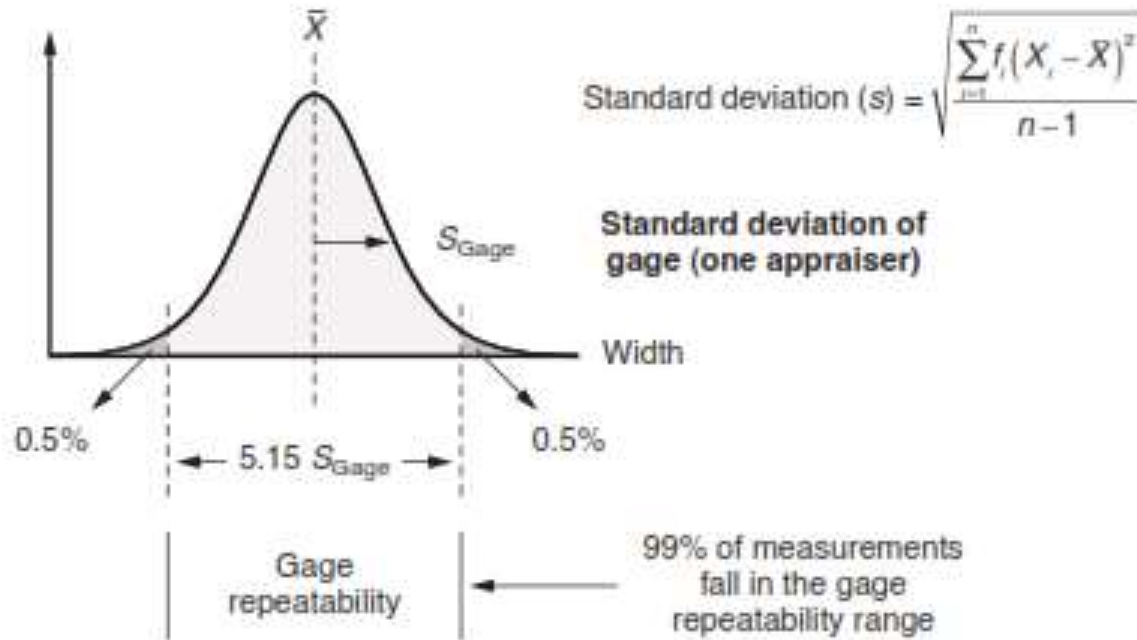
MEASUREMENT SYSTEM ANALYSIS

MSA – statistical study –explores variation in measurement

- Calibration
- Accuracy
- Precision
- Stability
- Repeatability
- Reproducibility
- Linearity
- Bias

GAUGE REPEATABILITY & REPRODUCIBILITY

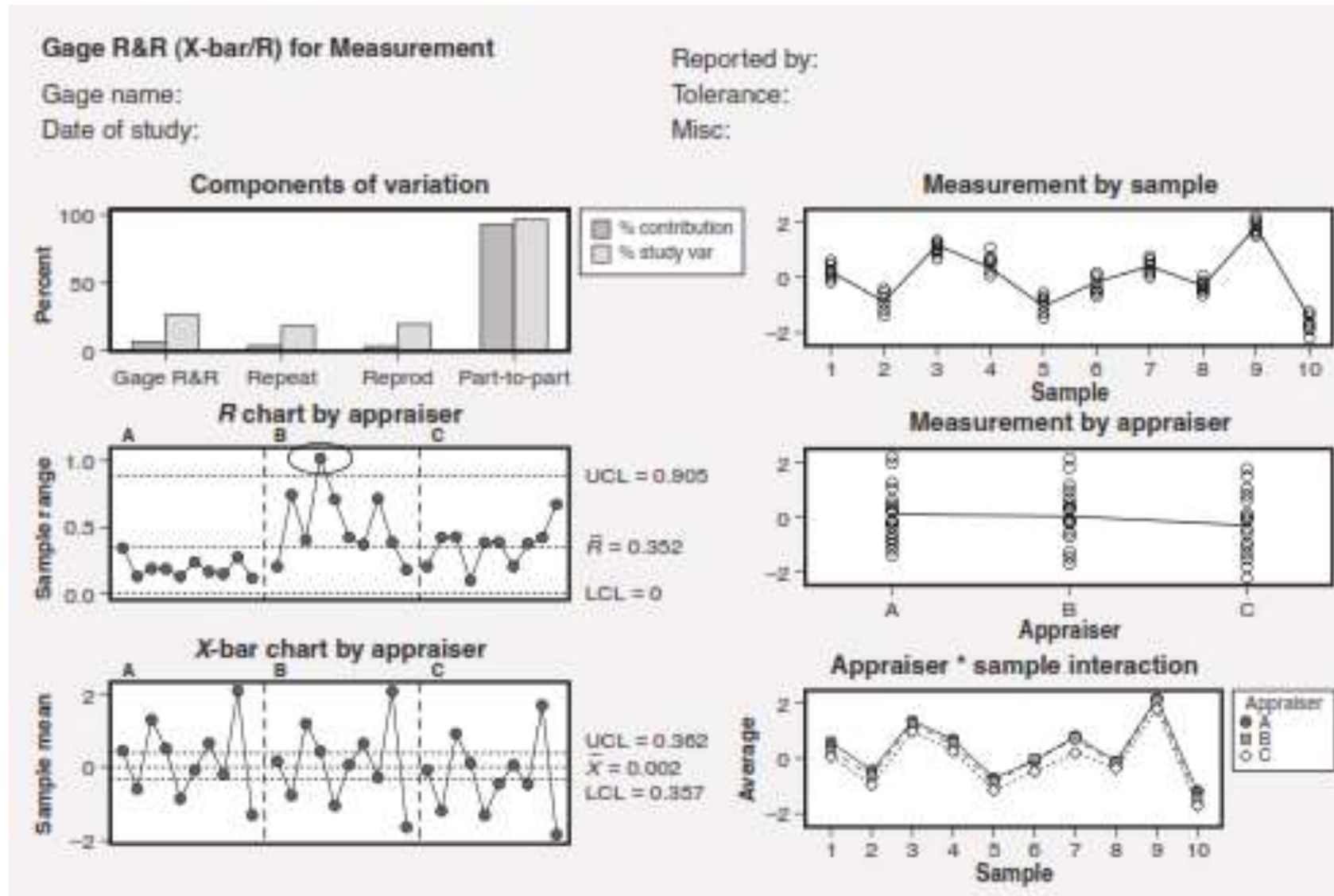
Repeatability – the equipment measurement variation expressed as standard deviation



Gage Repeatability



EXAMPLES OF GAGE R & R ANALYSIS









ACTIVITY

At the end of a lean six sigma project, who should be the primary beneficiary of the project results ?

- Customer
- Top Management
- Employees
- Sponsors

Match the following	
	Accurate but not Precise
	Not Accurate or Precise
	Accurate & Precise
	Precise but not Accurate



RANGE & AVERAGE METHOD

$$\text{Repeatability} = \frac{5.15\bar{R}}{d_2}$$

$$V_P = \frac{5.15R_p}{d_2}$$

$$\text{Reproducibility} = \sqrt{\left(\frac{5.15\bar{X}_{\text{range}}}{d_2}\right)^2 - \frac{\text{Repeatability}^2}{nr}}$$

$$V_T = \sqrt{R\&R^2 + V_P^2}$$

$$R\&R = \sqrt{\text{Repeatability}^2 + \text{Reproducibility}^2}$$



Appendix A - Values of d_2

z	w													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.41	1.91	2.24	2.48	2.67	2.83	2.96	3.08	3.18	3.27	3.35	3.42	3.49	3.55
2	1.28	1.81	2.15	2.40	2.60	2.77	2.91	3.02	3.13	3.22	3.30	3.38	3.45	3.51
3	1.23	1.77	2.12	2.38	2.58	2.75	2.89	3.01	3.11	3.21	3.29	3.37	3.43	3.50
4	1.21	1.75	2.11	2.37	2.57	2.74	2.88	3.00	3.10	3.20	3.28	3.36	3.43	3.49
5	1.19	1.74	2.10	2.36	2.56	2.78	2.87	2.99	3.10	3.19	3.28	3.36	3.42	3.49
6	1.18	1.73	2.09	2.35	2.56	2.73	2.87	2.99	3.10	3.19	3.27	3.35	3.42	3.49
7	1.17	1.73	2.09	2.35	2.55	2.72	2.87	2.99	3.10	3.19	3.27	3.35	3.42	3.48
8	1.17	1.72	2.08	2.35	2.55	2.72	2.87	2.98	3.09	3.19	3.27	3.35	3.42	3.48
9	1.16	1.72	2.08	2.34	2.55	2.72	2.86	2.98	3.09	3.19	3.27	3.35	3.42	3.48
10	1.16	1.72	2.08	2.34	2.55	2.72	2.86	2.98	3.09	3.18	3.27	3.34	3.42	3.48
11	1.15	1.71	2.08	2.34	2.55	2.72	2.86	2.98	3.09	3.18	3.27	3.34	3.41	3.48
12	1.15	1.71	2.07	2.34	2.55	2.72	2.85	2.98	3.09	3.18	3.27	3.34	3.41	3.48
13	1.15	1.71	2.07	2.34	2.55	2.71	2.85	2.98	3.09	3.18	3.27	3.34	3.41	3.48
14	1.15	1.71	2.07	2.34	2.54	2.71	2.85	2.98	3.09	3.18	3.27	3.34	3.41	3.48
15	1.15	1.71	2.07	2.34	2.54	2.71	2.85	2.98	3.08	3.18	3.26	3.34	3.41	3.48
>15	1.128	1.693	2.059	2.326	2.534	2.704	2.847	2.97	3.078	3.173	3.258	3.336	3.407	3.472



EXAMPLE

The thickness, in millimeters, of 10 parts have been measured by 3 operators, using the same measurement equipment. Each operator measured each part twice, and the data is given in Table 1

Part	Operator					
	A		B		C	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
1	65.2	60.1	62.9	56.3	71.6	60.6
2	85.8	86.3	85.7	80.5	92.0	87.4
3	100.2	94.8	100.1	94.5	107.3	104.4
4	85.0	95.1	84.8	90.3	92.3	94.6
5	54.7	65.8	51.7	60.0	58.9	67.2
6	98.7	90.2	92.7	87.2	98.9	93.5
7	94.5	94.5	91.0	93.4	95.4	103.3
8	87.2	82.4	83.9	78.8	93.0	85.8
9	82.4	82.2	80.7	80.3	87.9	88.1
10	100.2	104.9	99.7	103.2	104.3	111.5

Table 1. Range & Average method example data.



EXAMPLE

Repeatability is computed using the average of the ranges for all appraiser and all parts. This data is given in Table 2.

Part	Operator								
	A			B			C		
	Trial 1	Trial 2	R	Trial 1	Trial 2	R	Trial 1	Trial 2	R
1	65.2	60.1	5.1	62.9	56.3	6.6	71.6	60.6	11.0
2	85.8	86.3	0.5	85.7	80.5	5.2	92.0	87.4	4.6
3	100.2	94.8	5.4	100.1	94.5	5.6	107.3	104.4	2.9
4	85.0	95.1	10.1	84.8	90.3	5.5	92.3	94.6	2.3
5	54.7	65.8	11.1	51.7	60.0	8.3	58.9	67.2	8.3
6	98.7	90.2	8.5	92.7	87.2	5.5	98.9	93.5	5.4
7	94.5	94.5	0.0	91.0	93.4	2.4	95.4	103.3	7.9
8	87.2	82.4	4.8	83.9	78.8	5.1	93.0	85.8	7.2
9	82.4	82.2	0.2	80.7	80.3	0.4	87.9	88.1	0.2
10	100.2	104.9	4.7	99.7	103.2	3.5	104.3	111.5	7.2

$$\text{Repeatability} = \frac{5.15(5.20)}{1.128} = 23.7$$

Table 2. Example problem range calculations



EXAMPLE

Reproducibility example computations.

Part	Trial	Operator B	Operator C	R
1	1	62.9	71.6	8.7
2	1	85.7	92.0	6.3
3	1	100.1	107.3	7.2
4	1	84.8	92.3	7.5
5	1	51.7	58.9	7.2
6	1	92.7	98.9	6.2
7	1	91.0	95.4	4.4
8	1	83.9	93.0	9.1
9	1	80.7	87.9	7.2
10	1	99.7	104.3	4.6
1	2	56.3	60.6	4.3
2	2	80.5	87.4	6.9
3	2	94.5	104.4	9.9
4	2	90.3	94.6	4.3
5	2	60.0	67.2	7.2
6	2	87.2	93.5	6.3
7	2	93.4	103.3	9.9
8	2	78.8	85.8	7.0
9	2	80.3	88.1	7.8
10	2	103.2	111.5	8.3

$$\text{Reproducibility} = \sqrt{\left(\frac{5.15(7.015)}{1.91}\right)^2 - \frac{23.7^2}{10(2)}} = 18.2$$

The repeatability and reproducibility is

$$R \& R = \sqrt{23.7^2 + 18.2^2} = 29.9$$

Table 3. Reproducibility example computations.



EXAMPLE

Example part variability computations.

Part	Operator						Avg
	A		B		C		
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	
1	65.2	60.1	62.9	56.3	71.6	60.6	62.78
2	85.8	86.3	85.7	80.5	92.0	87.4	86.28
3	100.2	94.8	100.1	94.5	107.3	104.4	100.22
4	85.0	95.1	84.8	90.3	92.3	94.6	90.35
5	54.7	65.8	51.7	60.0	58.9	67.2	59.72
6	98.7	90.2	92.7	87.2	98.9	93.5	93.53
7	94.5	94.5	91.0	93.4	95.4	103.3	95.35
8	87.2	82.4	83.9	78.8	93.0	85.8	85.18
9	82.4	82.2	80.7	80.3	87.9	88.1	83.60
10	100.2	104.9	99.7	103.2	104.3	111.5	103.97

TABLE 4 EXAMPLE PART VARIABILITY COMPUTATIONS

$$V_P = \frac{5.15(44.25)}{3.18} = 71.7$$

The total measurement system variability is

$$V_T = \sqrt{29.9^2 + 71.7^2} = 77.7$$



REFERENCES

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2. <https://www.sixsigmadaily.com/cause-and-effect-diagram/>
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4. **What is Lean Six Sigma** By Michael L. George, David T. Rowlands, Bill Kastle



THANK YOU