To properly estimate process variability, it is important to understand that variability in observed data is equal to the sum of the variances from both the manufacturing and the measurement processes. In equation (1), which represents this relationship, the variances from left to right are the total in the data, the process, and the measurement. Once an estimate of the measurement system variability is obtained, it is a simple matter to subtract it from the total data variance (2). The resulting variance for the manufacturing process is then used to calculate parts per million (PPM) defective, fraction defective, or capability indices.

\[ \sigma_T^2 = \sigma_P^2 + \sigma_M^2 \]  
(1)

\[ \sigma_P^2 = \sigma_R^2 - \sigma_M^2 \]  
(2)

The same types of control charts, XBar and R, that are used to monitor manufacturing processes for stability, can be used to provide an estimate of measurement system variability. These charts, once generated, can then serve as stability monitors for the measurement system and as training tools for new operators. Data for the measurement control charts are generated by repeatedly measuring the same part. Care needs to be taken to properly subgroup the data, but then any variability in the data is attributed, wholly, to the measurement system.

For example, suppose there is interest in knowing the capability of a manufacturing process that generates shafts with diameter tolerances of 0.250 +/- 0.020 inches. The control charts (Figure 1 subgroup size n=5 and Figure 2 n=3) were respectively generated by measuring 125 consecutively manufactured shafts, and by measuring the same shaft 99 times. The following calculations were made using information from the control charts that, in this case, demonstrate both a stable manufacturing process and a stable measurement process.

**Observed data:**  
\( \sigma_T = \frac{RBar}{d_2} = \frac{0.01199}{2.326} = 0.0052 \)

**Measurement variability:**  
\( \sigma_M = \frac{RBar}{d_2} = \frac{0.0071}{1.693} = 0.0042 \)

**Manufacturing variance:**  
\( \sigma_P^2 = \sigma_T^2 - \sigma_M^2 = 0.000027 - 0.000018 = 0.0000094 \)

**Manufacturing variability:**  
\( \sigma_P = 0.0031 \)

**Manufacturing mean level:**  
0.246

**Specifications:**  
LSL = 0.230, USL = 0.270

**Manufacturing process**

**Capability:**  
\( \text{Cp} = \frac{\text{USL} - \text{LSL}}{6\sigma_P} = \frac{0.270 - 0.230}{6 \times 0.0031} = 2.15 \quad ** 1.28 \)

\( \text{Cpk} = \frac{\text{mean} - \text{LSL}}{3\sigma_P} = \frac{0.246 - 0.230}{3 \times 0.0031} = 1.72 \quad ** 1.03 \)

**Resulting erroneous capability if measurement variability is not subtracted**

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**Figure 1**

Xbar/R Chart for Diameter n

**Figure 2**

Means

Ranges

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