I. Process Capability Ratio (Cp ratio)

A. A measure of the capability of the process to operate within part specification limits.

B. Calculation of Cp ratio

\[
\text{Cp} = \frac{\text{USL} - \text{LSL}}{6\sigma_x} = 1.19
\]

The Cp ratio is the range or distance between the upper and lower specification limits (USL - LSL), divided by the distance between the upper and lower 3σ control limits (6σx) for individual parts. In this example, the Cp ratio is 1.19. The specification limits for parts are 1.19 wider than the 3σ control limits for these same parts.
C. Calculating the probable number of parts that will fall outside the specification limits, based on the Cp ratio.

<table>
<thead>
<tr>
<th>Cp</th>
<th>total parts</th>
<th>outside upper limit</th>
<th>outside lower limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>2700</td>
<td>1350</td>
<td>1350</td>
</tr>
<tr>
<td>1.20</td>
<td>320</td>
<td>160</td>
<td>160</td>
</tr>
<tr>
<td>1.40</td>
<td>30</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>1.50</td>
<td>3</td>
<td>1.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

At a Cp ratio of 1.00, the specification limits and the 3σ control limits are the same. So 99.73% of the parts would be within specification. The total number of out-of-spec parts would be .27%, or 2700 per million; that's 1350 parts outside each of the specification limits. At a Cp ratio of 1.20, the probable number of out of specification parts is 320 per million, 160 outside each specification limits. Note that these numbers are based on the process range not changing, and the process average not drifting. In reality, the process average can, and probably will, drift as time goes on. The Cpk ratio takes this drift into account.

II. Process Capability Index (Cpk)

A. The Cpk is a measure of how far the current process average is from each specification limit, based on 3σ control limits.

B. Calculation of the Cpk ratio

\[
\text{Upper Cpk} = \frac{\text{USL} - \bar{X}}{3\sigma_x} \quad \text{Lower Cpk} = \frac{\bar{X} - \text{USL}}{3\sigma_x}
\]

Cpk ratios are the difference between the process average and the specification limit (USL or LSL), divided by 3σ. The Cpk ratio is calculated separately for the upper and lower specification limit.
What the Cpk Ratio Tells Us

\[
Cp = \frac{USL - LSL}{6\sigma_x} = \frac{1.6}{1.34} = 1.19
\]

Upper Cpk = \( \frac{USL - \bar{X}}{3\sigma_x} = \frac{0.8 - 0.13}{0.67} = 1.0 \)

Lower Cpk = \( \frac{\bar{X} - LSL}{3\sigma_x} = \frac{0.13 - (-0.8)}{0.67} = 1.39 \)

We'll assume our process average (\( \bar{X} \)) has drifted from 0 to .13. Looking at the Cp ratio, we calculated previously, we see it has not changed; the process is still as capable as it was before. The \( 3\sigma \) control limits are still .67 above and .67 below the \( \bar{X} \). And the customer specification limits are still .8 and -.8. So the process capability (Cp) is still 1.19. But the operating average has changed, affecting the number of parts that fall within each specification limit. At the upper specification limit, more parts are going to be beyond the limit. Unlike the Cp calculation, the Cpk calculation will show this process drift.

Notice now that the upper Cpk ratio is 1.0. A Cpk of 1.0 means that the specification limit is exactly \( 3\sigma \) from the process average. The control limit and specification limit are on the same line.

The lower Cpk ratio is 1.39.
D. Calculating the probable number of parts outside each specification.

<table>
<thead>
<tr>
<th>Cp</th>
<th>outside upper limit</th>
<th>outside lower limit</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>1350</td>
<td>1350</td>
<td>Upper Cpk = 1.00</td>
</tr>
<tr>
<td>1.20</td>
<td>160</td>
<td>160</td>
<td>Lower Cpk = 1.39</td>
</tr>
<tr>
<td>1.40</td>
<td>15</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>1.50</td>
<td>1.5</td>
<td>1.5</td>
<td></td>
</tr>
</tbody>
</table>

To find the probable number of parts outside each specification limit for the Cpk ratios we just calculated, we can use the same table we used for Cp. We look at the upper and lower specification limits separately to determine the number of parts outside each specification limit. In our example, at the USL, a Cpk of 1.00 will result in about 1350 parts per million outside of this specification limit. At the LSL, a Cpk of 1.39, very close to the 1.40 shown in the table, results in about 15 parts per million out-of-spec.

**NOTE:** The importance of the Cpk ratio is that a change in this number during a production run indicates a process drift. So a Cpk ratio can be used to monitor for process changes. The probable number of out-of-spec parts for any Cpk ratio can also be calculated using a probability table.

It's very important to compare customer specification limits to process capability. But remember, the comparison can only be made on the basis of the control limits for individual parts ($UCL_x$, $LCL_x$) not subgroups ($UCL_s$, $LCL_s$).