Cpk Alone is Not Sufficient

What is the Cpk value of your process? No matter what the value, by itself it is not sufficient to really tell you much. But we sure do seem to like Cpk values, don't we? This month's SPC Knowledge Base publication continues with the topic we started last month: process capability.

Externally, your customers want to know your process capability – some want a Cpk greater than 1.33. In fact, one of your best customers wants you to report a Cpk value for each lot you ship. And guess what – your Cpk value varies, even if your process is consistent and predictable (in statistical control). Why is that?

Internally, your leadership is looking at what those Cpk values are as well. They want to get a "feel" for how you are doing. Maybe you report your monthly Cpk values for the monthly production report. And guess what – your Cpk values varies, even if your process is in statistical control. What does leadership say about that?

Everyone seems concerned about Cpk values.   You may apply the same approach to your suppliers.   You want your supplier to provide a certain Cpk – again, maybe 1.33 or higher.   Supplier A has a Cpk of 1.70 while Supplier B has a Cpk of 1.25. What can you say about Supplier A versus Supplier B? Temptation is to say that Supplier A's process is better than Supplier B's process. Don't let temptation get the better of you.

The fact is that you can draw no conclusions based on a Cpk value alone. There are three things you need to do before you calculate a Cpk value. And, after you calculate your Cpk value, you must combine the four observations into a conclusion.

This month's SPC Knowledge Base publication examines process capability analysis in more detail. In this publication:

- Process Capability Review
- The Process Capability Checklist
- Step 1: Plot the Data as a Control Chart and Interpret the Chart
- Step 2: Construct a Histogram and Compare to Specifications
- Step 3: Determine the Natural Variation of the Process
- Step 4: Calculate Cp and Cpk
- Step 5: Combine All the Information When Summarizing Process Capability
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Process Capability Review

Last month we took an interactive look at process capability. In that SPC Knowledge Base publication, we reviewed the process capability calculations, including Cp and Cpk. You could download an Excel workbook that let you visually see how changing the average and standard deviation of your process

impacts your process capability. You were able to see visually how the process shifts versus your specifications. In addition, the workbook showed how Cp, Cpk, the sigma level, and the ppm out of specification changed as the average and sigma changed. If you are new to process capability, please take a moment to review that publication.

The Process Capability Checklist

Understanding the calculations is definitely needed. However, you should also understand that there is a process to follow when figuring out your process capability. The best process I have seen comes from Dr. Don Wheeler in his book **Beyond Capability Confusion**. In this book, he lays out a five step "checklist" for conducting a process capability. These steps form the basis of this newsletter. I highly recommend that you read this book. You can access all his publications at this link: www.spcpress.com.

The five steps in Dr. Wheeler's checklist are basically:

1. Plot your data using a control chart to determine if the process is in statistical control (consistent and predictable)
2. For a process that is in statistical control, construct a histogram with the specifications added
3. For a process that is in statistical control, calculate the natural variation in the process data
4. For a process that is in statistical control, calculate Cp and Cpk
5. Combine these four items together and present them **_all_** when talking about process capability

A few things to note from these five steps. See how often "for a process that is in statistical control" occurs? How often is this just ignored? And the last point – combining all the information together to present the process capability analysis. Hard to fit that all into a monthly report. We will take a look at each step in more detail.

Step 1: Plot the Data as a Control Chart and Interpret the Chart

Check the stability of the process by plotting the data from your process using a control chart. A process that is in statistical control is consistent and predictable. It is a stable process. You can predict, within limits, what the process will do in the future as long as the process remains the same.

One key point here is the time frame covered by the control chart. It needs to be "long" enough. How long depends on your process. One hour is not enough. One year is too much. But the longer the process has been consistent and predictable, the more faith you have the process will continue that way. It is like relationship with people. You know what to expect from people whose actions are consistent and predictable. Same with your process. And your control chart on your process tells you if the process is consistent and predictable.

Consider the following example. You sample your process four times a day. It doesn't really matter what the process is. You form a subgroup from those four samples, calculate the subgroup average (the daily average) and calculate the subgroup range (the within day variation). You then use an $\overline{X}$-R control chart to analyze the data. You have data for 30 days. That data are shown in Table 1.

Table 1: Process Data

Day	X1	X2	X3	X4	Day	X1	X2	X3	X4
1	90.2	113.8	111.8	104.4	16	100.8	106	101.5	108.8
2	105.6	98.8	109.3	113.5	17	96.7	101.3	100.4	95.1
3	104	84.5	98.9	97	18	105.1	92	92.5	95
4	112.4	86.2	85.5	106.5	19	104.5	94.5	91.3	82.7
5	96.6	99.9	112.9	96.8	20	110.1	110.7	104	115.6
6	91.7	101.3	107.1	101.2	21	116.9	86.3	96.4	99.3
7	112	97.9	109	95.2	22	78.9	91.4	96.5	109.2
8	91.8	98	98.1	79.2	23	112.2	110.5	98.3	109.2
9	94.9	87.1	104.3	112.7	24	88.8	105.9	86.3	76
10	101.1	104	101.1	102.7	25	98.6	93.5	106.2	92.8
11	100.6	83.3	96.6	88.5	26	99.1	99.6	83.6	106.5
12	80.5	95	98.3	113.6	27	90.5	110	82.6	86
13	89.2	93.9	98.5	106.7	28	106.7	107.9	109.9	108.8
14	96.7	96.8	106.2	90	29	87.4	95	108.5	96.7
15	74.2	104.3	111.2	108.7	30	112.7	78.4	112.8	81.1

The $\overline{X}$-R control chart for these data are shown in Figure 1. The $\overline{X}$ and the R chart are in statistical control. There are no out of control points. The process is consistent and predictable.
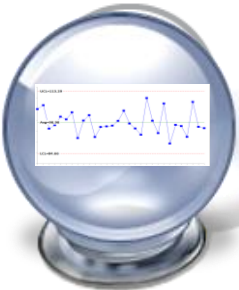
What does that really mean? Being consistent and predictable? It means that you know what the process will produce in the future – like having a crystal ball to gaze into the future. From the $\overline{X}$ chart: each day, the subgroup average will be between 84.66 (the lower control limit) and 113.29 (the upper control limit) with a long-term average of 98.98. From the range chart: each day, the subgroup range will be between 0 (there is no lower control limit for the range chart when the subgroup size is 4) and 44.83 (the upper control limit).

This information can be used to calculate the variation in the individual values you would expect (step 3), i.e., you can determine where essentially all your individual values will lie. The **only reason** you can do this though is because the process is in statistical control.

Since the process is consistent and predictable, you can move on to step 2. What if the process is not consistent and predictable? How can you calculate the process capability? The answer is simple – you can't. Yes, you can go through the motions of calculating a Cpk value. It might satisfy the customer or your leadership – but the value you get has no meaning. The data used are not consistent and predictable. You cannot predict where those individual values will lie in the future.

Figure 1: $\bar{X}$-R Control Chart for Process Data

Process Subgroup Averages

Process Subgroup Range

Est. Sigma = 9.54
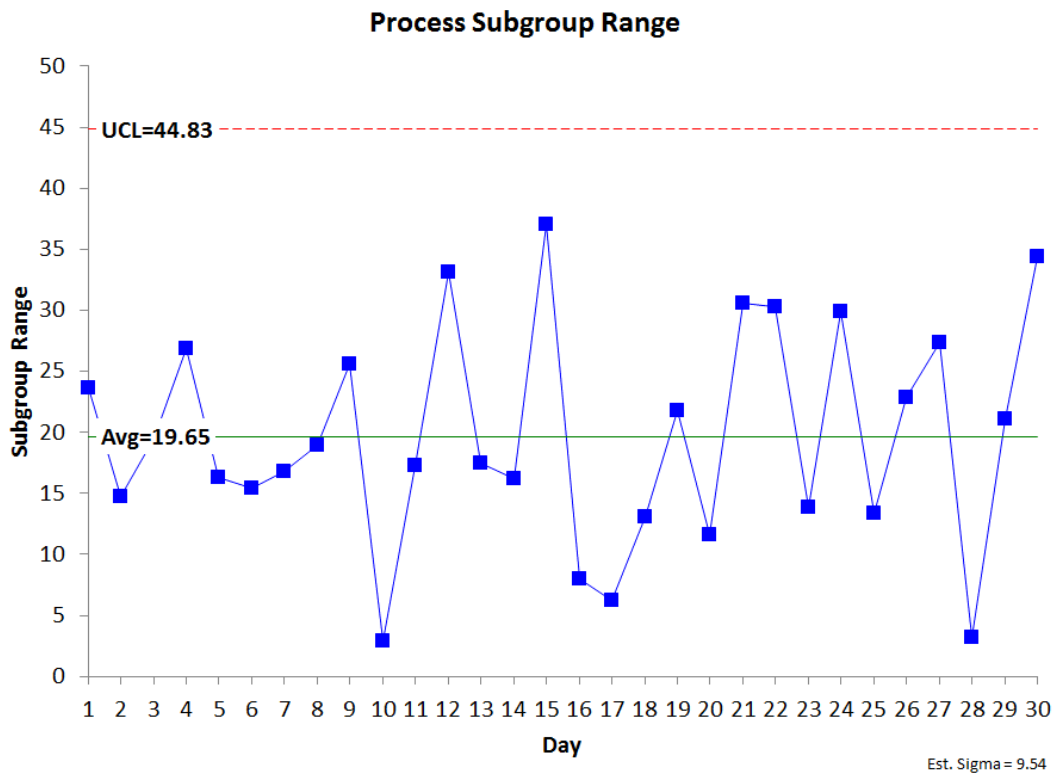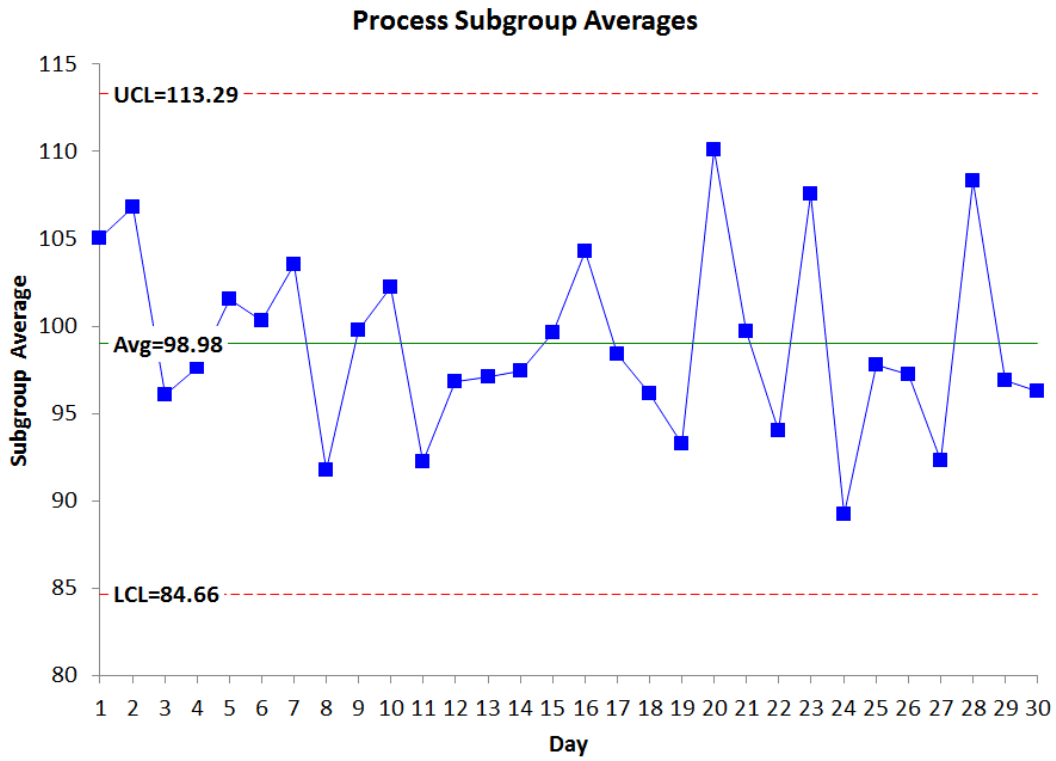
**Step 2: Construct a Histogram and Compare to Specifications**

In this step, you use the individual data points to construct a histogram and add the specifications to the histogram. You use the individual data points since that is what specifications apply to – not the subgroup averages.

Note that when looking at whether the process was in statistical control, we did not say a word about specifications. That is because specifications do not enter into the discussion of whether or not a process is in statistical control. The process itself (and the way you sample it) define the control limits and whether it is in statistical control.

Specifications are set externally to the process – e.g., by the customer. Suppose the specifications for your process are 65 to 145. Using that information and the data from Table 1, the histogram in Figure 2 can be constructed.

Figure 2: Process Data Histogram
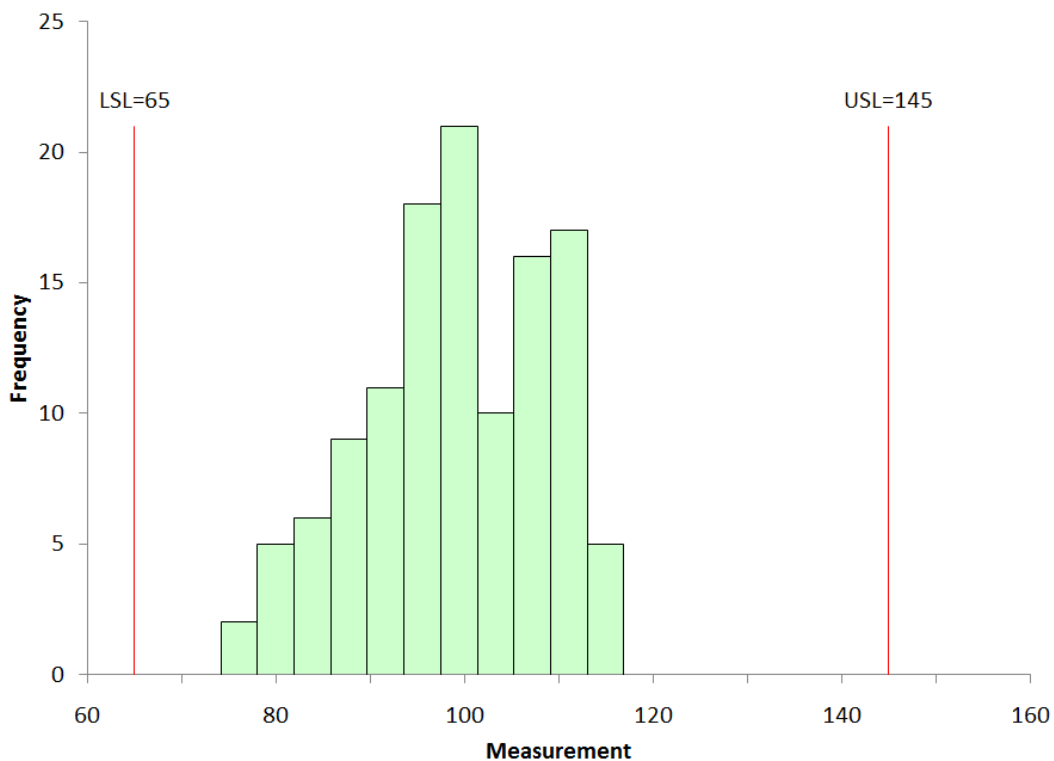
The histogram fits easily with the specification limits. Since the process is consistent and predictable, you would expect this to continue. Thus, it appears that your process is meeting specifications fairly easily.

Note that nothing has been said here about whether the data are normally distributed, needs to be transformed or fitted to a non-normal distribution. There is no need to that with this approach. If you have any points that are out of specification, you can easily determine the % out of specification by counting the number of out of specification points and dividing by the total number of points. The distribution issue comes into effect if you are calculating theoretical % out of specification.

In reality, the control chart and the histogram with specifications are all you need to show that your process is capable. The process is in statistical control. Nothing is anywhere near the specification limits. But, people still like to have the Cpk value. So, we will move on to step 3.

Step 3: Determine the Natural Variation of the Process

The natural variation of the process is the variation that you would expect in the individual data points when the process is in statistical control. Dr. Wheeler refers to these as the "Natural Process Limits." You determine the natural variation using the following:

$$\overline{\overline{X}} \pm 3\left(\frac{\overline{R}}{d_2}\right)$$

where $\overline{\overline{X}}$ is overall average, $\overline{R}$ is the average range and d_2 is a control chart constant that depends on subgroup size. The subgroup size for your process is 4. This corresponds to a d_2 value of 2.059. The natural variation in the process is then:

$$\overline{\overline{X}} \pm 3\left(\frac{\overline{R}}{d_2}\right) = 98.98 \pm 3\left(\frac{19.65}{2.059}\right) = 98.98 \pm 3(9.54) = 98.98 \pm 28.62 = 70.36 \text{ to } 127.6$$

The individual values range from 70.36 to 127.6. You would expect essentially all the data to fall within this range as long as the process stays in statistical control. Note that $\overline{R}$ divided by d_2 is the estimate of the standard deviation of the individual values. So, $\sigma = 9.54$.

Again, note that there is nothing about assuming there is a normal distribution. The fact is, that for just about any set of data, the vast majority of the data falls within +/- 3σ of the average.

Step 4: Calculate Cp and Cpk

Both these calculations were covered in last month's publication. The Cp calculation is given below. NT is the natural tolerance. It is the range calculated in step 3. ET is the engineering tolerance.

$$Cp = \frac{ET}{NT} = \frac{USL\text{-}LSL}{6\sigma} = \frac{145 - 65}{6(9.54)} = 1.40$$

Since Cp is greater than 1, the process is capable of meeting specifications. Another way to look at this number is that it defines how much "elbow room" (as Dr. Wheeler calls it) that your process has. Based on Cp, the process has about 40% elbow room. This means that the specification range is 40% larger than the natural process variation *if the process is centered*. This process is not centered so you will lose some of that elbow room when looking at individual specifications. This is shown through the Cpk calculation.

The Cpk calculations are given below.

$$Cpk = \text{Minimum (Cpu, Cpl)}$$

$$Cpu = \frac{USL\text{-}\overline{\overline{X}}}{3\sigma} = \frac{145 - 98.98}{3(9.54)} = 1.61$$

$$\text{Cpl} = \frac{\overline{\overline{X}}\text{-LSL}}{3\sigma} = \frac{98.98 - 65}{3(9.54)} = 1.19$$

Cpk in this case is 1.19. So, there is about 19% elbow room when you look at the lower specification. Since Cpk is greater than 1, the process is capable of meeting specifications.

Step 5: Combine All the Information When Summarizing Process Capability

So, what can we say about your process? The following is pretty powerful.

- The control chart shows that the process is consistent and predictable
- The histogram shows that the process variation fits easily within the specification range
- The value of Cp and Cpk confirm what the histogram shows
- This process is more than just consistent and predictable – it is capable of meeting specifications – just want you want!

This paints a true picture of the process capability – much more than a Cpk value by itself. You have confidence in this process – and so should your customer and leadership.

Summary

Just looking at a Cpk value does not tell the entire story. The first step – and the most important – is to demonstrate that the process is in statistical control. There is only way to do that and that is through the use of control charts – over an extended period of time. If the process is not in statistical control, you need to work on that and not worry about the process capability. Only when your process is consistent and predictable can you move to the next steps.

The next step is to demonstrate that the process variation fits within the specifications by constructing a histogram with the specifications. Finally, you are ready to calculate the process variation, Cp and Cpk. And the last step is to put it all together to fully describe the process capability.

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Thanks so much for reading our publication. We hope you find it informative and useful. Happy charting and may the data always support your position.

Sincerely,

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