Process & Performance Capability

If I asked you . . . . . How capable is your process of producing parts that meet your customers' needs?

Would you know how to respond?

One question you may ask is . . . .

How do I conclude that a process is "capable" of producing a product?

This is where the concept of **Process Capability Analysis** comes into play.

This chapter is dedicated to this topic and has 6 major sections:

Section 1 - **What is Process Capability Analysis & Why It Matters**

Section 2 - Understanding the **Prerequisites of** a **process capability study**

Section 3 - How to calculate the **4 major process capability indices** including C_p, C_{pk}, C_{pm} & C_r .

Section 4 - Understanding the **2 major process performance indices** including P_p, P_{pk}.

Section 5 - How to **interpret the results** & the **5 Reactions** to your process capability study.

Section 6 - **4 pro tips to optimize your process capability analysis** and have confidence in the results.

What is Process Capability Analysis & Why It Matters

According to process validation principles, *we should demonstrate that our processes are capable of repeatedly producing product that meets specifications*.

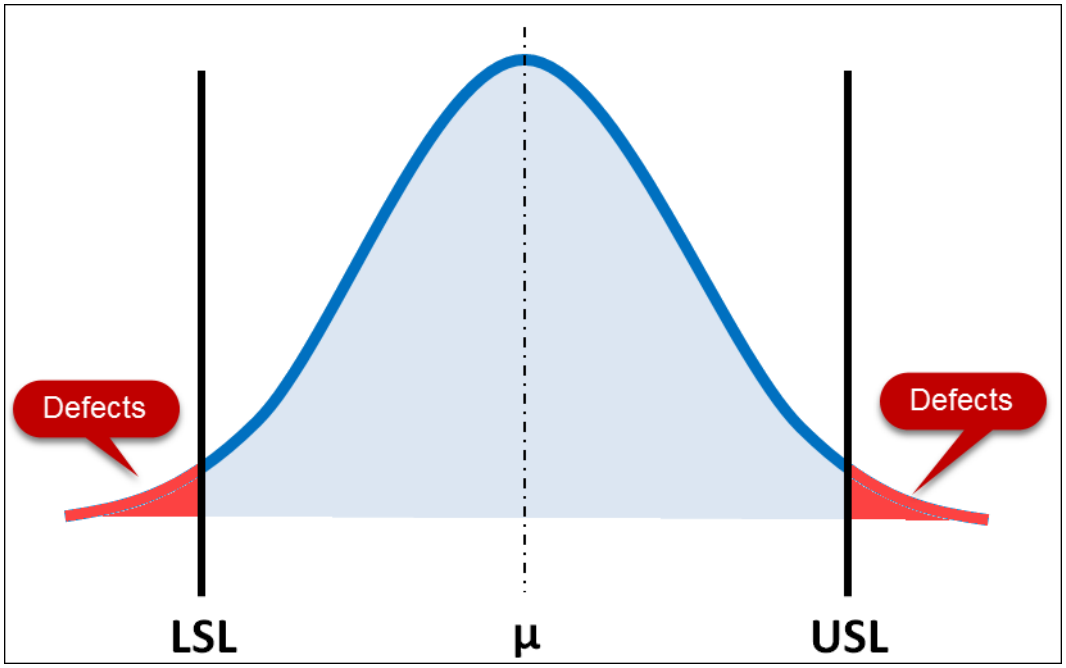
The problem with this statement is that it is somewhat nebulous. How can we quantify "repeatedly"?

How often do we have to build good product before a process can be confirmed as being "capable"?

To answer this question, Statisticians & Quality Professionals have developed the **Process Capability Analysis Tool**.

Process Capability Analysis allows us to quantify the capability of our process to produce product that meets the design specifications.

More specifically, this tool can be used to predict what portion of the overall population of product produced will fall outside of the customers specification limits - and thus ***result in a defect***.



This ability to make predictions is an extremely powerful one and is the primary benefit of Process Capability Analysis.

Process Capability Analysis can also be used in other instances as well.

For example, *Process Capability Analysis can be the starting point of a continuous improvement project*.

In this way, The Process Capability Analysis can establish the baseline for your process; and as you'll learn below, it can help guide you in how your process needs to be improved.

Process Capability Analysis can also be used on the back end of a project to measure the effect of a change on a process.

We will talk more below about the relationship between process variation and process capability and I'll comment quickly that the idea of six standard deviations (sigma) of capability was the foundation of the **Six-Sigma** concept.

Understanding the Difference Between Process Specifications & Process Performance

Process Capability can be described as a comparison of your **process performance** against its **process specifications** using various *capability indices*.

To better understand these concepts, I've broken this section down into 2 sub-sections.

In the first section we will define **Process Performance** & **Process Specifications**.

Then the second section explains their relationship with **Process Capability Analysis,** which at the end of the day looks like this:

$$\textbf{\textit{Process Capability Analysis}} = \frac{\textbf{\textit{Process Specification}}}{\textbf{\textit{Process Performance}}}$$

Process Performance

Process Performance is the natural ***variability*** associated with your **stable** process.

Remember a "stable" process cannot be experiencing any special cause variation; only normal cause variation.

Below I'm showing a control chart from a process that's only experiencing natural variability and thus is "in control".

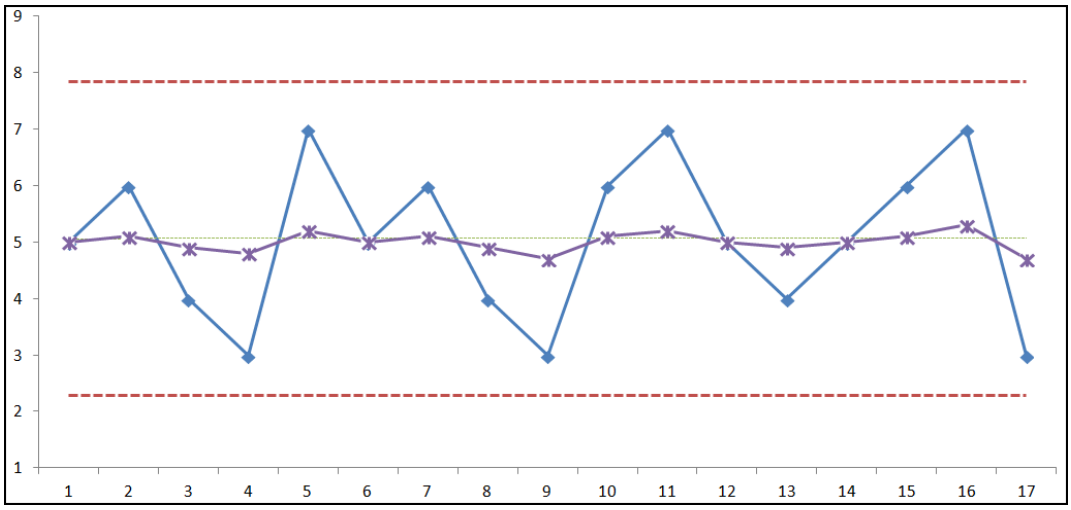
It should be understood that *it is possible to have a process that is in control and also producing bad product* - which is where process capability analysis comes into play.

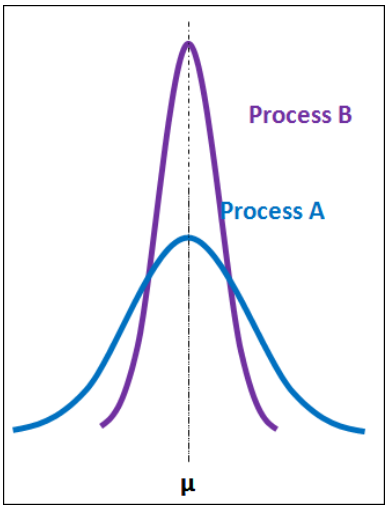
The width of this process is considered the process performance.

This process width is a reflection of the natural variation associated with the process.

A process with less variability could be described as having have higher performance and a low performance process has high variability.

Of the two processes shown below, can you spot the one with higher performance (less variability)?





The histograms on the right represent the natural variation of each process above.

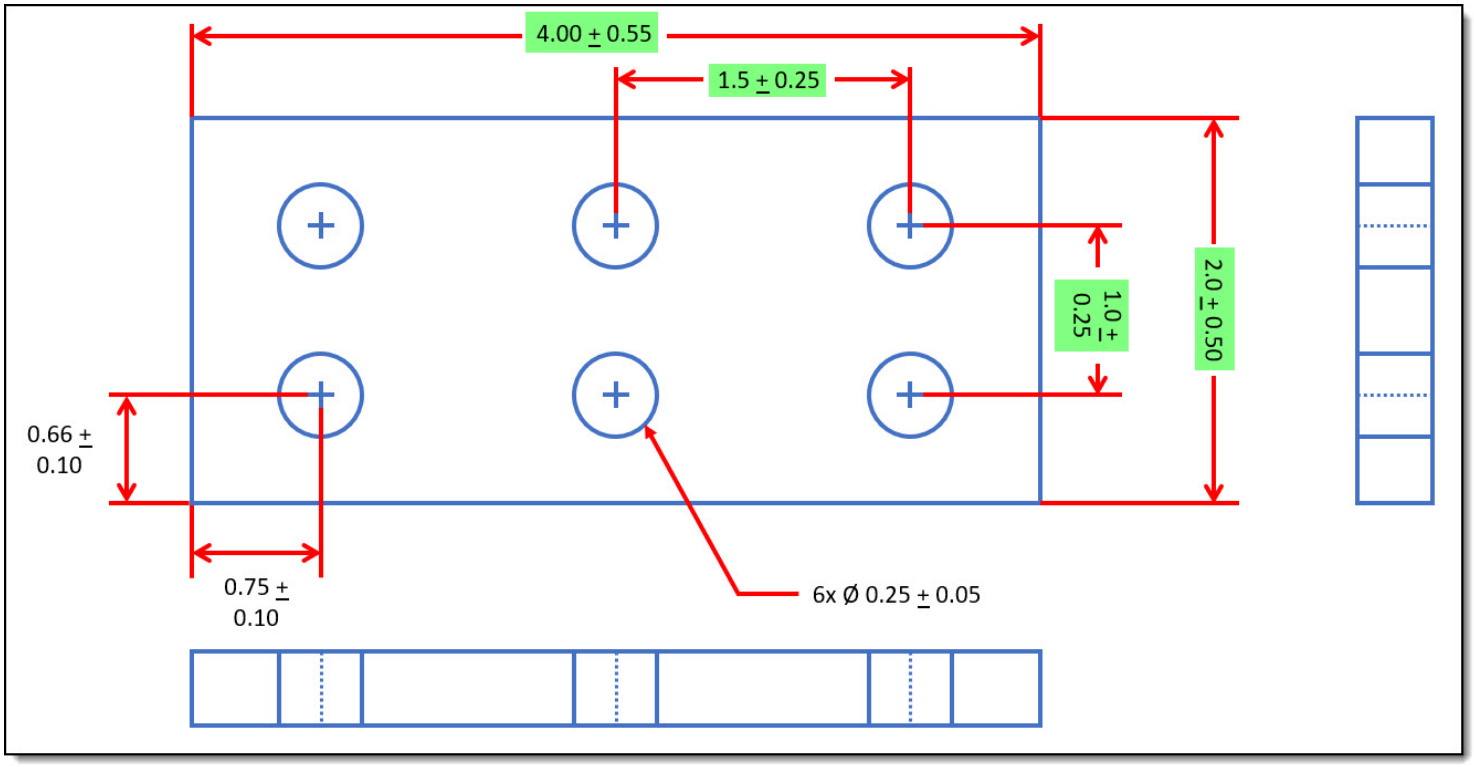
Notice how **Process A** has more variation (spread) than **Process B**?

Process Specifications

Process Specifications are the ***pre-defined specifications*** associated with the product that's produced by your process.

For example, if you're building a widget (example below) that has critical features (highlighted), you would expect to find that critical feature on the product drawing with a dimension and tolerance.

That dimension & tolerance can be considered the product specification and is usually determined by R&D or your customer directly:



Because this is a critical feature of the product it generally has some relationship with the functionality of the product and therefore, whenever a product is built outside of those tolerance the product will not function as intended.

Also, this tolerance implies that the design can tolerate that level of variability before functionality is affected.

Some Quality experts like Taguchi would argue here that the moment your process if off-center from the Target/Nominal dimension, you begin to experience some amount of "quality loss".

Below you'll see two examples how why the center of your process matters a lot for process capability.

Within the context of this chapter the Process Specification is generally defined by the **Lower Specification Limit (LSL)** and the **Upper Specification Limit (USL),** of your product.

In the example, the first feature which is the dimension of the through hole has an Upper Specification Limit (USL) of .500 & a Lower Specification Limit (LSL) of .498.

The second feature, which is the overall diameter of the base has a USL of 2.000 & a LSL of 1.997.

Make sense?

Understanding the Prerequisites of a Process Capability Study - 5 Steps

Ok - this section is dedicated to the prerequisites of your process capability analysis and breaks them down into a 5-step checklist.

Step 1 - Identify the critical features that you want to study

It isn't unusual for a product to have hundreds of features that are dimensioned & toleranced.

This usually makes it is impossible to calculate process capability on all of these features.

So, you must start by identifying the critical to quality product features and assess the process capability for only those features.

This is usually a critical feature that has a strong relationship to the **performance of your product**, or the **safety of your product**.

Step 2 - Ensure your process is operating in a state of control

For your process capability analysis to be valid, you must be analyzing a process that is "in control" and stable.

Remember, the overall goal of process capability analysis is to be able to make predictions about future products produces using that process and if *the process is not in control, those predictions are meaningless*.

If you think back to the chapter on SPC (Statistical Process Control), the most frequently used tool to ensure process control is a **Control Chart**.

The good news is that *the same data that is used to create a control chart can also be used to calculate Process Capability* - and in fact this is often the case.

		Capable?	
		Y	N
In Control?	Y	✓ (Yes!!!)	Reduce Normal Cause Variation
	N	Eliminate Special Cause Variation	

Step 3 - Ensure your data is normally distributed

This is the 2nd major requirement that must be verified before performing process capability analysis.

Your data must be normally distributed for the analysis to work out correctly.

To confirm normality, you can use a *Normal Probability Plot, or a Histogram or a Goodness Of Fit test*.

Now, if you're already a Pro at Process Capability Analysis you might be saying to yourself. . . non-normal data can still be used. This is true. But for now, let's assume the data must be normally distributed.

Step 4 - Understand How Your Variability is Calculated

Ok, so this is the first time we're going to cover this topic, but it's a super important one.

Below we're going to cover both C_p & P_p separately, but I'll show both equations here to make my point:

$$P_p = \frac{USL - LSL}{6s} \qquad\qquad C_p = \frac{USL - LSL}{6s}$$

Do these equations look similar??? YES!!

The one distinction between these two equations is the way the Process Performance (s - Sample Standard Deviation) is calculated.

C_p only considered the process variation within a sub-group while P_p is calculated using the overall variation.

One quick note here - in the bottom half of the equation above I'm showing "s" as the sample standard deviation, as opposed to the more common sigma (σ), which is the population standard deviation.

Let's look at this calculation in a bit more detail for C_p.

When you're using data from your control chart (Step 2), you're calculating the sample standard deviation using the following equation.

$$\boldsymbol{s_{c_p}} = \frac{\boldsymbol{R}}{\boldsymbol{d_2}} \; (if\ using\ an\ \bar{X} - \ R\ Chart) \qquad or \qquad \boldsymbol{s_{c_p}} = \frac{\boldsymbol{s}}{\boldsymbol{c_4}} \; (if\ using\ an\ \bar{X} - \ S\ Chart)$$

This variation is sometimes considered the "short term" variation because it only considers "within Sub-group" variation & ignores the "between sub-group" variation that can be experienced by a process.

P_p & P_{pk} use a different standard deviation calculation that also takes into consideration the between-lot variation.

These indices calculate the sample standard deviation using the common root mean square calculation we learned in the collecting & summarizing data chapter, shown below.

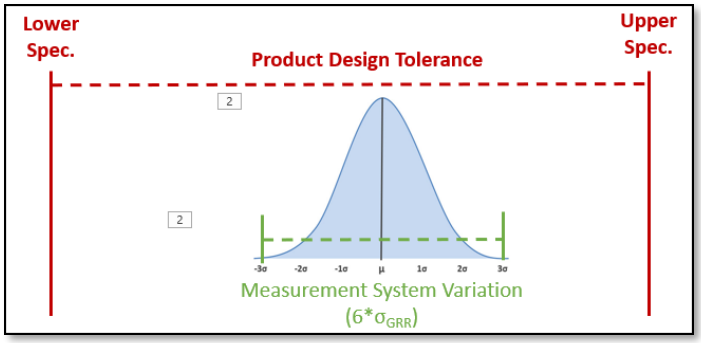
$$\mathbf{s_{p_p}} = \sqrt{\frac{\sum(\mathbf{x} - \bar{\mathbf{x}})^2}{\mathbf{n} - \mathbf{1}}}$$

So, I say all of this to let you know that you must be cognizant of how you're calculating your standard deviation and what impact that has on your process capability analysis.

Step 5 – Make sure Your Measurement System is Capable!

Remember, a capability study is all about measuring variation, and if your measurement system is introducing a lot of variation, then it'll negatively impact your capability analysis!

So before you measure anything, make sure your measurement system is capable!



Capability Compares Process Performance v. Specifications

Now let's bring it all together to understand how your **process specifications** & **process performance** are used to calculate **Process Capability**.

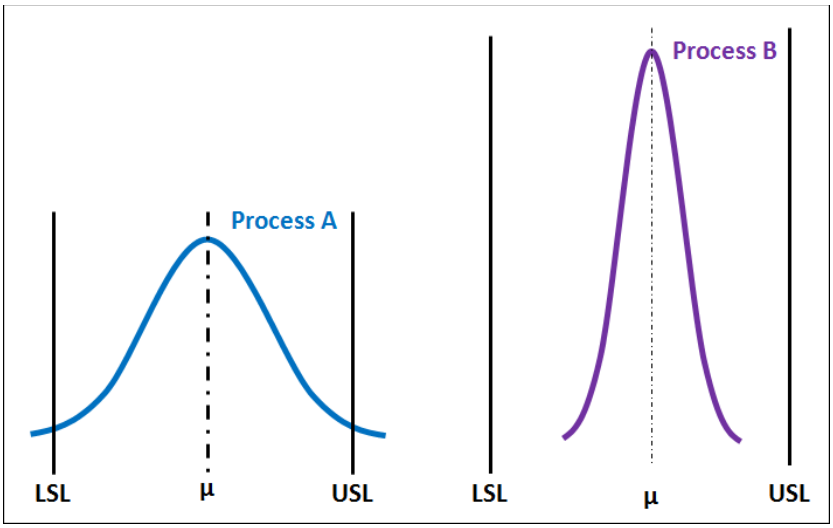
The concept of Process Capability can be summed up in the equation below:

$$Process\ Capability = \frac{Process\ Specification}{Process\ Performance} = \frac{Product\ Design\ Tolerance}{Natural\ Process\ Variation}$$

Example of Process Capability

So, if we take our histograms from the process above and add some fake specification limits to them, we can find out of process capability.

Note - These specifications *are not the same* as the control limits shown on the control chart above.



Remember, the histogram represents the natural variation of the process and the process specifications are shown as the Lower Specification Limit (LSL) & Upper Specification Limit (USL).

So, let's say, in this example that the Lower Specification Limit is 2, and the Upper Specification Limit is 14, and the standard deviation of **Process A** is 3, and the standard deviation of **Process B** is 1.

$$Process\ Capability\ of\ \boldsymbol{Process\ A} = C_p = \frac{Process\ Specification}{Process\ Performance} = \frac{\boldsymbol{USL - LSL}}{\boldsymbol{6\sigma}} = \frac{\boldsymbol{14 - 2}}{6 * \boldsymbol{3}} = \frac{12}{\boldsymbol{18}} = 0.66$$

$$Process\ Capability\ of\ \boldsymbol{Process\ B} = C_p = \frac{Process\ Specification}{Process\ Performance} = \frac{\boldsymbol{USL - LSL}}{\boldsymbol{6\sigma}} = \frac{\boldsymbol{14 - 2}}{6 * \boldsymbol{1}} = \frac{12}{\boldsymbol{6}} = 2.00$$

Notice that in both of these calculations the **Process Specification** is identical (14 - 2 = 12).

What does change is the **Process Performance**, where Process A has 3 times the variation as Process B, and thus has less Capability.

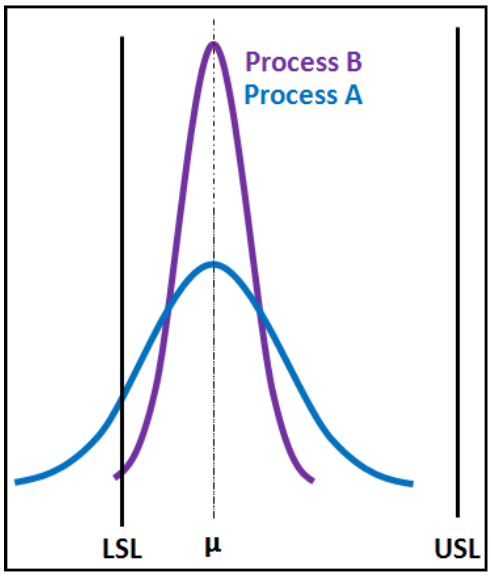
This is a reflection of the image above, where the tails of Process A pass beyond this specification limits.

Another Example C_p Calculation - Shifted Limits

Let's now take a look at what happens to the process capability when the process specifications are shifted.

So, the new **LSL is 4** and the new **USL is 16**.

You can see what that looks like on the histogram below, and the percentage of the population that is now out of specification (the tail of the distribution that's now past the LSL).



Now that the limits have shifted, we can calculate Process Capability.

$$Process\ Capability\ of\ \textbf{\textit{Process A}} = C_p = \frac{Process\ Specification}{Process\ Performance} = \frac{\boldsymbol{USL - LSL}}{\boldsymbol{6\sigma}} = \frac{16-4}{6*3} = \frac{12}{18} = 0.66$$

You'll notice here that C_p does not change with this shift.

This is because C_p does not take into account the center of your process.

I wanted to point this out before jumping into the details to let you know that the "Center" of your process becomes important when it comes to process capability.

It's one of the reasons that we have so many different Indices that can be used to calculate process capability.

I'll cover all of this in the next lecture along with how to interpret your results.