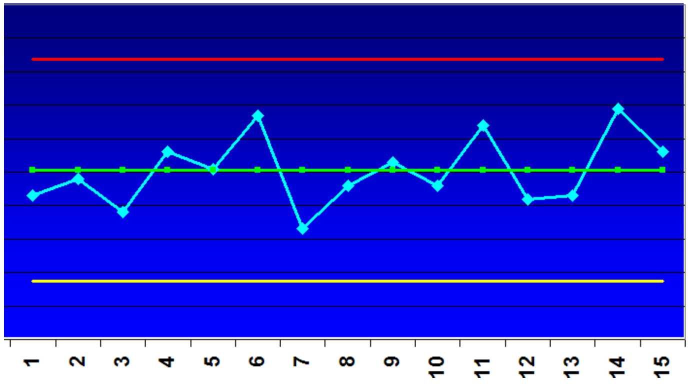
Statistical Process Control Basics



70 GLEN ROAD, CRANSTON, RI 02920 T: 401-461-1118 | F: 401-461-1119
www.tedco-inc.com

What is Statistical Process Control ?

- Statistical Process Control (SPC) is an industrystandard methodology for measuring and controlling quality during the manufacturing process. Attribute data (measurements) is collected from products as they are being produced. By establishing upper and lower control limits, variations in the process can be detected before they result in defective product, entirely eliminating the need for final inspection.

What is Statistical Process Control ?

- SPC performed during the manufacturing/assembly process not only eliminates the need for final inspection, but equally important significantly reduces and amount of material scrap along with direct & indirect labor waste. The result is a direct increase in bottomline profitability.

For those who feel they cannot afford to implement SPC, the reality is they cannot afford not to.

What is Statistical Process Control ?

- Collected data is plotted on a graph with predetermined control limits. Control limits are determined by the capability of the process, whereas specification limits are determined by the customer's needs.

What is Statistical Process Control ?

- Data that falls within the control limits indicates that everything is operating as expected. Any variation within the control limits is likely due to a common cause, the natural variation that is expected as part of the process.

What is Statistical Process Control ?

- If data falls outside of the control limits, this indicates that an assignable cause is likely the source of the product variation, and something within the process should be changed to fix the issue before defects occur.

What is Statistical Process Control ?

With real-time SPC you can:

1. Dramatically reduce variability and scrap
2. Scientifically improve productivity
3. Reduce costs
4. Uncover hidden process personalities
5. Instant reaction to process changes
6. Make real-time decisions on the shop floor

What is Statistical Process Control ?

To measure the ROI on your SPC investment, start by identifying the main areas of waste and inefficiency at your facility. Common areas of waste include:

● scrap ● rework ● over inspection

● inefficient data collection

● incapable machines and/or processes

● paper based quality systems

● inefficient production lines

What is Statistical Process Control ?

You can start to quantify the value of an SPC solution by asking the following questions:

- Are your quality costs really known?
- Can current data be used to improve your processes, or is it just data for the sake of data?
- Are the right kinds of data being collected in the right areas?

What is Statistical Process Control ?

- Are decisions being made based on true data?
- Can you easily determine the cause of quality issues?
- Do you know when to perform preventative maintenance on machines?
- Can you accurately predict yields and output results?

What is Statistical Process Control ?

- Dr. W. Edwards Deming claimed that the majority of variation in a process is due to operator over adjustment. SPC gives operators a tool to determine when a statistically significant change has taken place in the process or when an seemingly significant change is just due to chance causes.

Why do companies use SPC?

- There are a number of reasons why companies use SPC. Often an internal champion initiates the use of control charts and other SPC techniques to reduce variation and to improve manufacturing processes. Sometimes companies implement SPC to satisfy customer requirements or to meet certification requirements.

How can SPC help companies improve quality and productivity?

- SPC itself will not make improvements. Rather, SPC will give operating personnel a tool to identify when a special cause of variation has entered the process so that the special cause can be eliminated (if the special cause has a negative impact on the process) or built into the process (if the special cause has a positive impact on the process).

How can SPC help companies improve quality and productivity?

- With this tool, constant tweaking of the process is eliminated. In addition, SPC can be helpful in identifying opportunities for improvement that can lead to reduced variation and processes that are better aimed at their target.

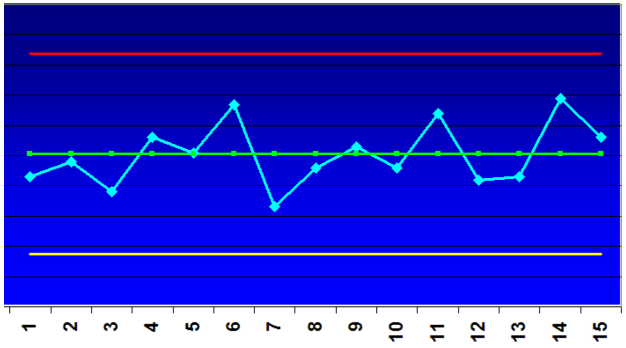
How does SPC work?

- The key tool of SPC is a control chart. While there are control charts for attribute data (data that must be counted, for example, in terms of number of defective items) and variable data (data that is take from a variable scale such as length, width, height), variable data control charts provide more valuable information and should be used wherever practical.

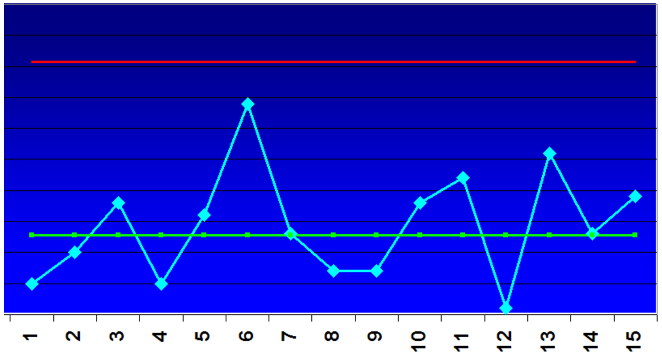
How does SPC work?

- Variable data control charts typically monitor the process target or mean and the process variation or range. There are a number of different types of variable data control charts but the most common chart is the x-bar and R chart.

x-bar chart



R chart



How does SPC work?

- A control chart has a centerline, an upper control limit and a lower control limit. The centerline for the x-bar chart is the process mean and the centerline for the R chart is the mean range. The control limits are set to represent plus and minus 3 standard deviations from the mean or where 99.73% of all data points should fall.

How does SPC work?

- Data is then collected from the process, typically in subgroups of 3 to 5 and the subgroup mean and range is plotted on the x-bar and R charts respectively. Once a point is plotted, the chart is interpreted to determine if the process is staying in-control or if the process is out-of-control.

How does SPC work?

- There are many different rules to select from and then follow when interpreting control charts. All of the rules are based on statistical probabilities of the pattern occurring due to random, common cause variation. The patterns a company uses depends on the variability of the process, the criticality of the process, and customer requirements.

How does SPC work?

The most common patterns to watch out for are:

- One point outside of the control limits
- Eight points in a row on either side of the centerline
- Eight points in a row trending in the same direction
- Cycles or recurring trends.

Common mistakes companies make when they use SPC

Here are the top reasons why SPC does not work:

1. Putting spec limits on control charts.
2. Using control charts only to satisfy customer needs.
3. Plotting data for a control chart in the QA lab, after the process has already been run. It is like driving your car using your rearview mirror.
4. Using the wrong type of control chart for the process resulting in false signals or muted signals.

Common mistakes companies make when they use SPC

5. Not reviewing control charts and how they are used on the shop floor with operators on a regular basis.
6. Thinking that if you use a computer program that generates control charts that you don't need to teach operators how to use SPC.
7. Not first conducting a process capability study.

Common mistakes companies make when they use SPC

8. Not taking random samples from the process or not using a sampling frequency or sample size that captures the variation in the process.
9. SPC is used to control product characteristics after a part is manufactured and the defect has been made rather than monitoring key process parameters that affect whether or not a defect is likely. That's why it is called statistical PROCESS control and not statistical PRODUCT control.

Control Points

SPC can easily be used to control anything that can be counted. Before initiating any SPC program, it is necessary to determine what to count. These are termed control points. Control points can be related to:

- Process
- Product
- Financials

The first hurdle to SPC is determining proper control points based ideally on 32 samplings.

The Average Chart

For process control, proper average charts consist
Of several pieces of related data:

1. 15 to 30 days of actual data.

2. A line showing the average of the most recent 15 to 30 days of data. This line should coincide with the specification aim.

The Average Chart

3. The Lower Control Limit line (LCL) A line showing the average minus three standard deviations of the most recent 15 to 30 days of data.
4. The Upper Control Limit line (UCL) A line showing the average plus three standard deviations of the most recent 15 to 30 days of data.
5. Relevant historical data, generally LCLs and UCLs for the past 30, 90, and 150 days.

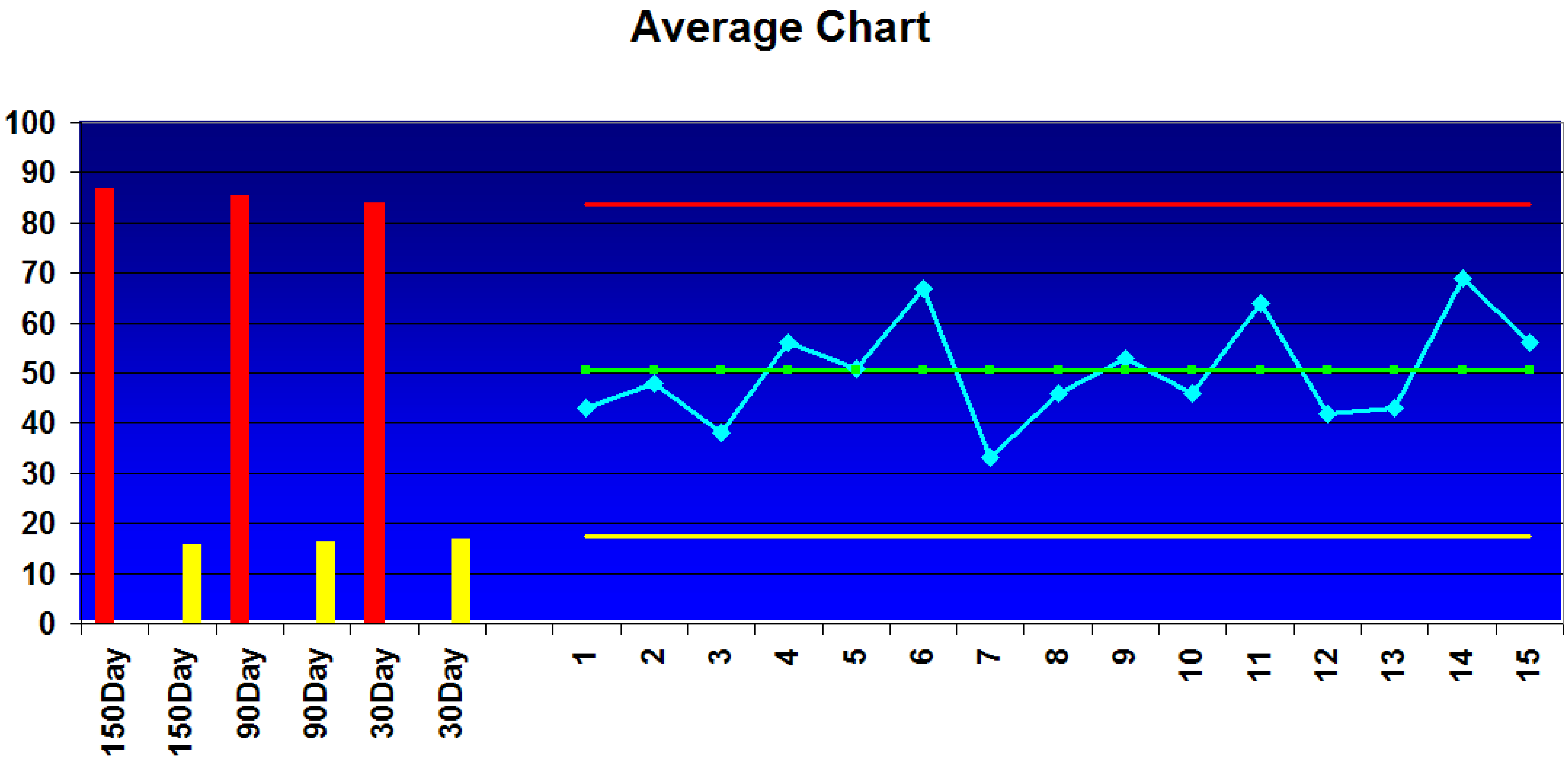
The Average Chart

Upper Control Limit (UCL)

Lower Control Limit (LCL)

Average

Actual Data

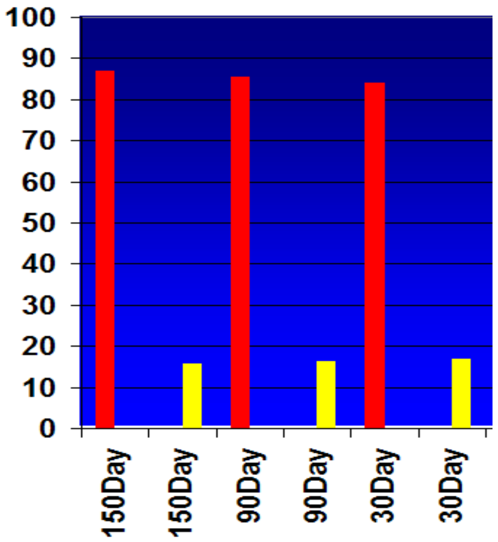


What this Average Chart shows

- The process is under statistical control (actual data are well within +/ three standard deviations).
- Over the past 60, 90 & 150 days the process has improved (the UCL has gotten smaller and the LCL has gotten bigger).

Note: the average line should coincide with the specification aim. If it does not, then generally more data should be included to determine the avg.

Note: although the process is in statistical control and improving, measures should be taken to help reduce variability, in a perfect world, all actual data points would coincide with the average line.



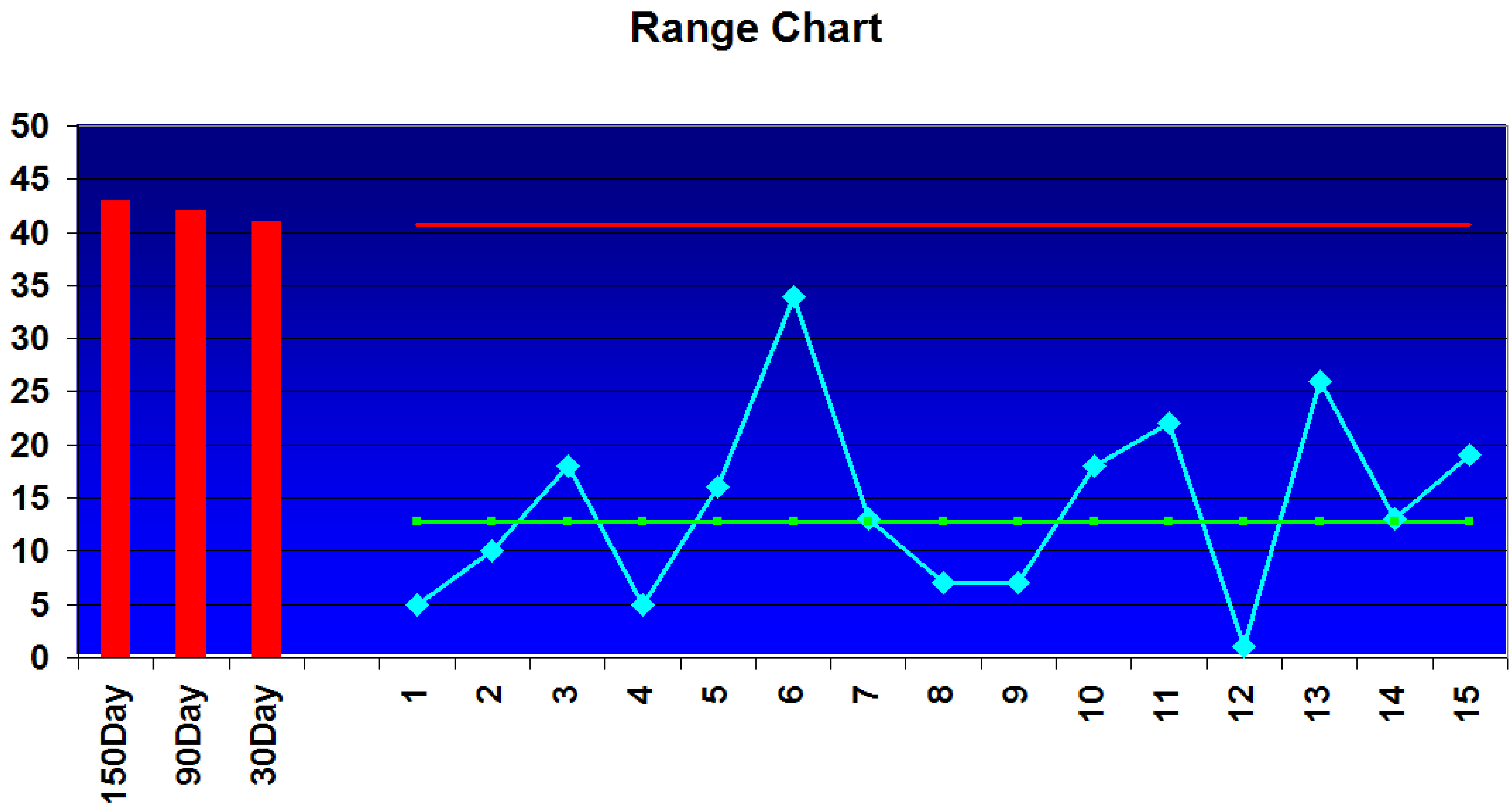
The Range Chart

For process control, proper range charts consist of several pieces of related data:

- 15 to 30 days of the range of actual data.
- A line showing the average range of the most recent 15 to 30 days of data.
- The Upper Control Limit line (UCLr) A line showing the average range plus three standard deviations of the average range of the most recent 15 to 30 days of data.
- Relevant historical data, generally UCLrs for the past 30, 90, and 150 days.

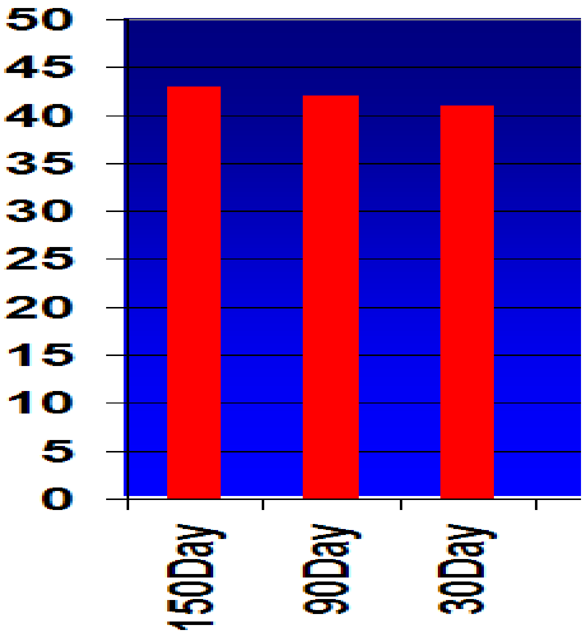
The Range Chart

Upper Control Limit (UCLr)
Average
Actual Data



What this Range Chart shows

- The process is under statistical control (actual data are well within + three standard deviations of the range).
- Over the past 60,90 & 150 days the process has improved (the UCLr has gotten smaller).
- Note: the average line should be a small number.
- Note: although the process is in statistical control and improving, measures should be taken to help reduce variability, in a perfect world, all actual data points would coincide the horizontal axis at zero.

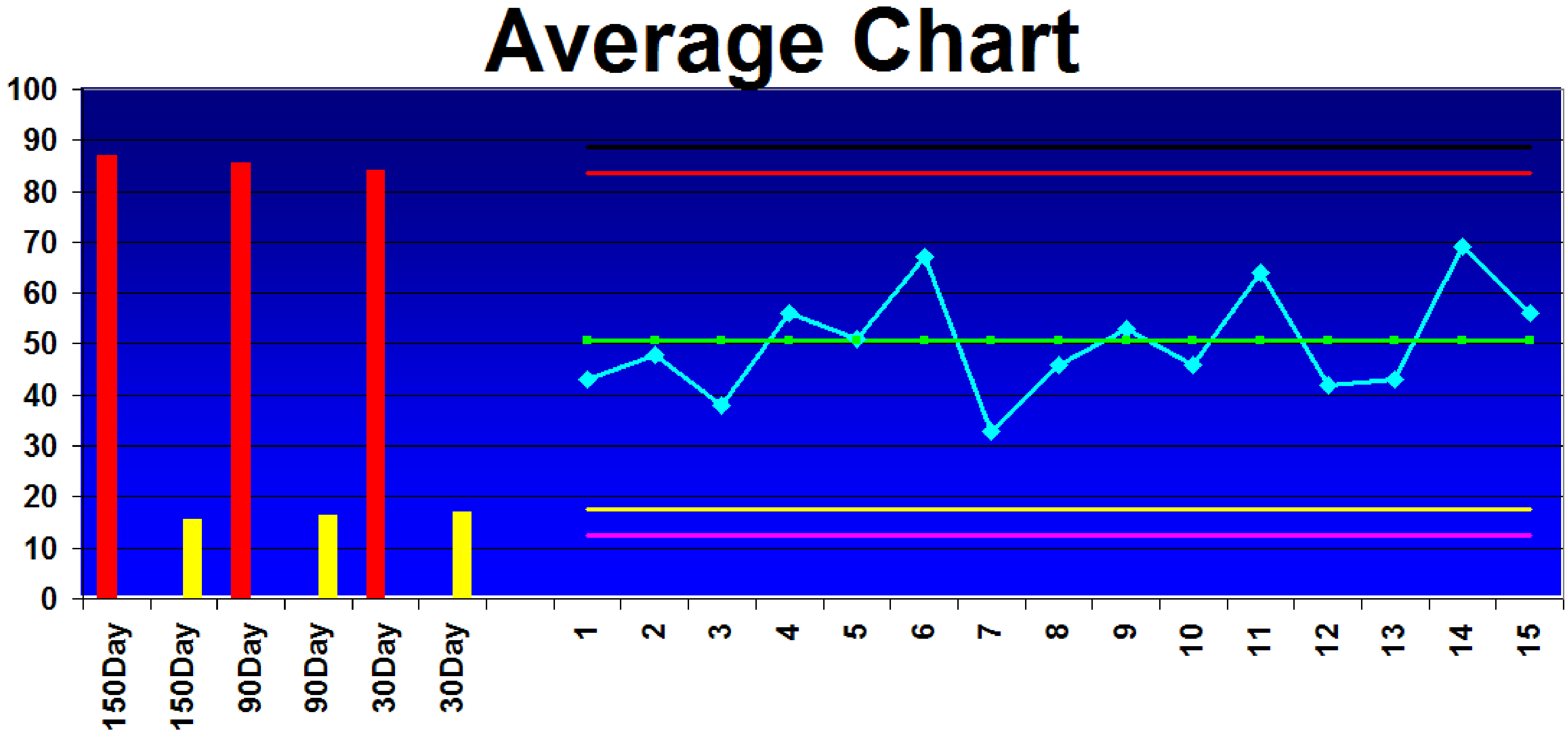


A Note About Statistical Control

- A process being in statistical control does not necessarily indicate that the process is "good enough" for manufacturing. A further condition is that the UCL and LCL on the Average Chart must be inside specification limits. For the final product, specification limits are generally dictated by the customer. For in-process material specification, limits should be determined for each control point. An Average Chart in statistical control and in specification control is shown as follows.

A Note About Statistical Control

Upper Control Limit (UCL)
Lower Control Limit (LCL)
Average
Actual Data
Lower Specification Limit
Upper Specification Limit



The "Seven Step Process"

The use of a Seven Step Process improves statistical process control. Proper application of SPC will improve process, product and financial results.

1. Investigation and benchmarking of current process,
2. Identification of appropriate measurable variables,
3. Estimation of available resources and project cost,
4. Estimation of project time line,
5. Application of appropriate statistical techniques,
6. Implementation of corrective action and
7. Statistical monitoring of identified variables.

Process Capability Indices

- We sometimes talk about Process Capability and define it as the “six sigma” (6**s**) spread. In such a context, we might say, “My process is capable of less than three thousandths of an inch.” We’re saying that the process spread is less than three thousandths of an inch, and presumably, that means our standard deviation is less than one sixth of that, or half a thousandths of an inch. But that number doesn’t mean much to us *until we put it in the context of the requirements*. If the tolerance spread is only one thousandths of an inch, our process isn’t so capable after all, is it?

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Process Capability Indices

- But if our tolerance spread is ten thousandths of an inch, then maybe it *is* capable. So, at least in the terms of Quality and Manufacturing, the term *"Process Capability" means the ability of the process spread to fit within the tolerance spread*. But how *well* does the 6**s** spread of the process fit within the tolerance spread? Which of two processes is better? For the comparison of two or more processes, we'll need some kind of *index* number to help us compare "apples to apples."

Basic Capability Indices

Pp = Process Performance. A simple and straightforward indicator of process performance.

Ppk = Process Performance Index. Adjustment of Pp for the effect of non-centered distribution.

Cp = Process Capability. A simple and straightforward indicator of process capability.

Cpk = Process Capability Index. Adjustment of Cp for the effect of non-centered distribution.

Basic Capability Indices — Pp/Ppk

- For the Pp index we take a sampling (30, 50, 100, 300, whatever your customer requires) from the process, measure the characteristic in question, and calculate the average and standard deviation using the standard formulas. If we review our basic understanding of the normal distribution, we'll remember that the average plus and minus three standard deviations will account for 99.73% of the entire population… as long as the population is normally distributed.

Basic Capability Indices — Pp/Ppk

- So, six standard deviations (the width of ±3s) will essentially represent all of the product. For the Pp index, we simply want to see how well this 6s spread could fit into the tolerance spread. Let’s suppose our tolerance is ±5 units and our s is 1 unit. (We’re keeping the math easy here!) The tolerance spread is thus 10 and the process spread is thus 6. So if we divide the tolerance by the process, 10÷6 we get 1.67 Pp.

Basic Capability Indices — Pp/Ppk

- Since the process spread is the denominator in this equation, we can easily see that any number greater than one is "good" and any number less than 1 is "poor." So a 1.67 says that our process fits into the tolerance one and two thirds times, which might make most of our customers quite happy. (Your customer may require an index greater than 1.00, 1.33, or 1.67 or even 2.00, so be sure to check with them to determine the requirements for your parts).

Basic Capability Indices — Pp/Ppk

- But is the process "centered" in the tolerance zone? Since there is more of the population closer to the average in the normal distribution, it is important to have the average in the middle of the tolerance to minimize potential discrepant measurements. The formula for the Pp index does not consider this in any way. In fact, in theory, you could have a good Pp and run 100% scrap. Think of this index as the "potential" capability of the process. This means that if we can center the process in the tolerance zone perfectly, it will achieve the quality represented by the Pp index.

Basic Capability Indices — Pp/Ppk

- The Ppk index is a little more complex than the Pp because of its need to evaluate centering of the process. The best way to think of it is to divide the normal distribution in half at the average, leaving you with one curve representing the 50% of the population above the average and another for the 50% below the average.

Basic Capability Indices — Pp/Ppk

- So each of these “halfcurves” is 3s wide and bounded on one side by the average. Now, we take that halfcurve and compare it to the limit of the tolerance with which it should be associated. In other words, the “bottom” half, or lower 50% halfcurve should be compared to the “bottom” limit or lower specification limit (LSL).

Basic Capability Indices — Pp/Ppk

- Let's look at this in detail. For our example, we'll go back to the case where the tolerance is a nominal value, say 10, with a ±5 tolerance, meaning the tolerance zone is from 5 to 15. The process has a standard deviation of 1. So 3s is equal to 3. But because we want to take into account how well our process is *centered*, we need to compare the average of our process to its location within our tolerance range.

Basic Capability Indices — Pp/Ppk

- The best way to do this is to find the distance our average is from the specification limit by subtracting the lower limit from the average. Thus, in our example, if the average is 10 (right on target), and the lower spec limit (LSL) is 5, then our tolerance width for comparison purposes is (10–5) = 5, and so our 5÷3 still equals 1.67 capability index. So in a "perfectly centered" process, the Ppk index will produce the same value as the Pp index.

Basic Capability Indices — Pp/Ppk

- But let's say the process drifts to where the average is now at 9 instead of 10. Our formula now becomes (9–5) = 4, so now 4÷3 = 1.33, and so our index number is reduced to reflect the non-centered process. If the average was 8, we'd get (8–5) = 3 and 3÷3 = 1.00 index, and if the average was 7, we'd get (7–5) = 2 and 2÷3 = 0.67 index, etc.

Basic Capability Indices — Pp/Ppk

- You might have noticed that the index will drop to zero when the average and the tolerance limit are the same. (So a Ppk of 0.00 essentially means 50% scrap.) It's also possible for the index value to go negative if and when the average is *outside* the tolerance zone.

Basic Capability Indices — Pp/Ppk

- And what about the upper half of our index? It works the same, but we subtract the actual average from the Upper Spec Limit (USL) this time and divide by 3 standard deviations. As the average gets lower, it moves farther away from the Upper Specification Limit, and thus the upper limit index would get larger with each shift while the lower limit index gets smaller.

Basic Capability Indices — Pp/Ppk

- Therefore, to keep our values consistent with the Pp values, we have to say we'll only use the *smallest* (or minimum) of these two indices for the Ppk value. And we have now arrived at our textbook formula for Ppk: Ppk = minimum of (USL – Avg)÷3s and (Avg – LSL)÷3s But in reality, we will know that we only have to do the calculation for the specification side closest to our average, so we only need to calculate one of these—the one we know will be the lesser.

The Cp and Cpk Indices

- But there is another thing about our process for which we have not yet taken into account: whether or not our process is stable. Obviously, if our process was stable, meaning it will *stay* at this same average and standard deviation for a reasonable period, then we can trust it to stay at the 1.67 capability index for a longer period of time. If it has been proven *extremely stable*, we might even be happy with a *lower* index number because we'd have greater confidence in it remaining good.

The Cp and Cpk Indices

- But remember how we got our data, we simply grabbed a bunch of parts and measured them. We only know that it represented the process *at that time*. We can think of the Pp/Ppk as a "snapshot" of the process capability at a given moment. Therefore, to think of the Pp and Ppk indices as the "short term" capability indices. They represents the capability of the process today, but we have *no idea* whether tomorrow's Ppk index will be the same as today's.

The Cp and Cpk Indices

- If we want to know the capability of a process over the *long term*, we'd like to know how stable that process is, right? And what is the "classic" test for stability? The Control Chart. So, if we have a control chart to encourage and demonstrate the stability of our process, and use the data from that control chart to determine our average and standard deviation, we will probably have an even better idea of the capability of our process over the "long haul."

The Cp and Cpk Indices

- We will also have the capability index Cp/Cpk instead of Pp/Ppk, but the calculation and meaning of the resulting number is the same. That is to say, the calculation of the index is the same. The *real* difference is how we calculate the *standard deviation*.

The Cp and Cpk Indices

- For Pp/Ppk, we calculated the standard deviation the old fashioned way, by finding the squares of the deviations from the average, summing them, then dividing by the samples size minus one, and finally finding the square root of the answer. In other words, the usual mathematical definition for the standard deviation.

The Cp and Cpk Indices

- But when you have Control Chart data, you use the average Range to estimate the standard deviation by dividing it by the “d2” constant factor. So *the only difference mathematically between the Cp/Cpk and the Pp/Ppk is how you estimate the standard deviation*, and since neither can be considered the "true" standard deviation, they might differ slightly from each other.

The Cp and Cpk Indices

- Many people consider the Pp and Cp indices the “potential” capability of the process and the Ppk and Cpk the “performance” capability indices. So the Pp would be the “short term, potential capability index” and the Cpk would be the “long term, performance capability index.” That being the case, why does anyone use the Ppk index anymore?

The Cp and Cpk Indices

- The answer is sometimes we simply do not have the time required to use the Cpk index. On a new production part, during the initial phases of production, you have yet to get the control chart established enough to enforce stability and you certainly don't have enough evidence to prove stability if you can claim it. Thus, the only choice you have is the Ppk index based upon the small sample you have at this time. In other words: *cost* is the reason to use Ppk.

The "ppmequivalent" Capability Index (Cp_{ppm})

- There are numerous other indices. One that is actually quite useful is the Cp_{ppm}, which is much more difficult to calculate, but which has the advantage of being comparable in application to the Cpk (or Ppk) index. The "ppm" superscript on that index stands for "parts per million" and is the key to understanding this index.

(Cp_{ppm})

- Take the classic example of a Cpk = 1.00 index. What does this represent in terms of parts per million rejected? If our process is producing a normally distributed value for the characteristic and if our process is stable, then we can easily figure this one out. A Cpk index of 1.00 means that the tolerance limits exactly matches the ±3s limits of the process.

(Cp_{ppm})

- And we know that the average plus and minus three standard deviations is equal to 99.73% of the population. So in a million parts, this would equal 997,300 parts, leaving 2,700 parts rejected. And that means that a Cpk of 1.00 = 2,700ppm rejected, so an *equivalent* Cpppm of 1.00 should have 2,700ppm rejected also.

(Cp$_{ppm}$)

- If we do a few calculations, we can see that a Cpk of 1.33 is the same as a process spread of ±4s being equal to the tolerance spread and thus results in 64ppm. Similarly, a Cpk of 1.67 is equal to a tolerance spread of ±5s and 0.6ppm; and a Cpk of 2.00 = ±6s = 0.002ppm. So we could say that a Cpk of 1.00 is equivalent to 2,700ppm defects, and Cpk 1.33 =176ppm, etc. So what does this mean for us? How is it useful? In a couple of ways:

(Cp_{ppm})

- First, suppose your customer wants a capability index Ppk/Cpk=1.33 but you only have attribute data. You've sorted 55,000 parts and found 3 parts defective. Can you tell your customer you are supplying parts at Cpk ^{3} 1.33? Well, now that we know that a Cpk of 1.33 is equal to 64ppm, we can answer that question: in 55,000 parts at a Cpk of 1.33, you should have found 3.52 defects.

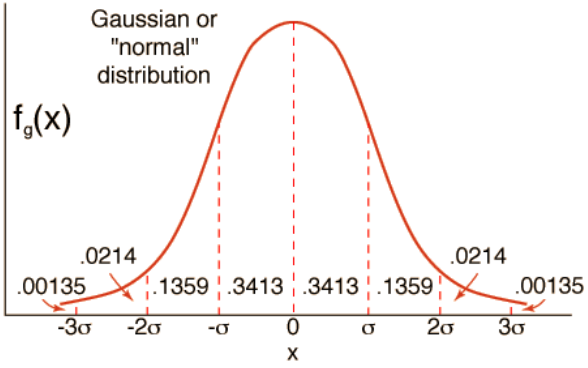
(Cp_{ppm})

- You only found 3, so it sounds like you are doing better than an equivalent Cpk of 1.33, and there is good basis for telling your customer so! That is probably the most common thought when one discusses the ppm equivalent capability, being able to give a capability index equivalent to the Ppk/Cpk index using only attribute data.

(Cp_{ppm})

- But there is yet another, even more powerful concept behind the ppm equivalent capability, and one which is needed more often than we'd like to admit. What do you do when your data is *not* normally distributed? All of the capability indices are based upon the probability curves based on the normal distribution, the "Gaussian Curve," and if your data isn't normal, then your capability is in doubt! Most textbooks on capability studies will tell you that your process *has to be* normally distributed and stable or else the capability index is meaningless.

  The implication is then, if is isn't normal and stable, then *get it normal* and stable!



(Cp_{ppm})

- Unfortunately, in the real world, there are sometimes legitimate non-normal distributions. Any time there is a “natural” barrier to the values of data, there is a potential for a skewed distribution. A “natural” barrier means a limit beyond which it is impossible for data to exist. For example, suppose we are collecting data on concentricity.

(Cp_{ppm})

- Perfect concentricity is zero, there can be no "negative" value for concentricity. (You'll find similar barriers in perpendicularity, run out, parallelism, flatness, surface finish, tensile strength, etc.). Any time your distribution approaches one of these natural barriers closely enough, it will become skewed.

(Cp_{ppm})

- A skewed distribution is one where the tail on one side is longer than the tail on the other, or you might say, a “lopsided” distribution. Obviously, as your average approaches a natural barrier, the distribution will start to tighten up to it on that side, and stretch out on the other. When you are sufficiently close to that barrier, the skewness becomes large enough to really mess up your Ppk/Cpk calculations! And now you have a process which gives you a *worse* capability index each time you *improve* the process; what some call a “*Contrary* process” because it just seems like pure stubbornness sometimes.

Capability from Multiple Process Streams

- This one is very common. You have a 4spindle, 7station indexing machine spitting out parts every few seconds. So, you would need 28 control charts *per characteristic* to effectively control this process, prove stability, and generate capability indices the way they should be done. Does anyone believe they can justify the time involved in simply shutting off the machine to measure this many features (or, alternately, paying someone to stand at the machine and measure parts all day long)?

Capability from Multiple Process Streams

- Out here in the "real world," it simply ain't gonna happen. Yet, the customer wants to see Capability Index numbers for these characteristics. So what do you do? Automated gauging and data collection might work, but suppose you don't have the budget for that. You find short cuts like combining these 28 different charts somehow into a manageable number of combination charts. But there are dangers to this.

Capability from Multiple Process Streams

- In general, combining two or more sets of data into one in order to generate Capability Indices will result in lesscapable indications. If you calculate the average and standard deviation of each group of data, then the average and standard deviation of the combined data, you'll find: The combined average will be what the average of the individual averages is (assuming equal sample sizes), but the standard deviation will be *larger* than the average of the individual standard deviations.

Capability from Multiple Process Streams

- A little further checking will show that predicting what the combined standard deviation will be is a risky business! The more then two (or however many there are) distributions of individual processes differ, the larger the standard deviation will become. In a worse case scenario, you'll get a bimodal distribution with a standard deviation that is very large, and the resulting capability index could be very bad even when each process by itself has a good capability.

Capability from Multiple Process Streams

- So what do you do? Are we faced with only these two choices (high cost of many charts vs. poor capability indices due to combining to reduce costs)? Not necessarily. Logical combinations could be made if you understand the machine. You might combine the stations, and end up with four charts (and capabilities), one for each spindle or maybe the other way around, and have seven charts, one for each station.

Capability from Multiple Process Streams

- The “ultimate combination” would be a single chart and capability that consists of all 28 spindle station combinations, but you’d probably still end up with some kind of staggered sampling plan because of the time and expense it would take to measure 28 parts. But before you apply any of these “shortcuts,” you should first check out what would happen to your capability index before you commit to it.

Capability from Multiple Process Streams

- The prudent thing to do is to perform a Ppk study on each combination (yes, 28 studies with at least 30 if not 50 pieces in each sample) for a baseline. Now, you can look at the results and determine the best tradeoff between cost and control effectiveness. You might get lucky and find that you can take some kind of reduced (and staggered) sampling plan that allows you to monitor the process effectively without measuring 28 parts each sample. But don't just *assume* you can combine these! Know that any combination will most likely make your Ppk/Cpk index worse than the individuals were.

Capability from Multiple Process Streams

- You may still be stuck with repeating the 28 part study every year anyway, and doing some kind of creative sampling trick in the meantime, but you won't know until you try. (Here's an interesting idea: Do 4 capability studies, one for each spindle by combining stations, followed by 7 capability studies, one for each station by combing spindles.

Capability from Multiple Process Streams

- Theoretically, you can now separate the influence of the spindle and the influence of the station to the total variation—by the same logic as a *Gage R&R Study separates Appraiser and Equipment variation—and you've only done 11 capability studies, not 28. (But see if your customer will buy this one first!)

*Gage repeatability and reproducibility

Capability from Multiple Process Streams

- So, let’s suppose we find out that we can combine all 28 combinations in one capability study. *Should* we? First, before you start any such “shortcut” system, consult with your customer and discuss the issues, the benefits and the risks with any alternative combination system. Then, as long as you (and your customer) understand the impact on your capability index, and if even so it is good enough to make your customer happy, why not if there’s are benefits to be gained?

Capability from Multiple Process Streams

- The one thing you can pretty much count on is the fact that your Ppk/Cpk index will only get worse by combining them. (It is theoretically *possible* for the index to improve, but *highly unlikely* in the real world.) So, my answer is the same in any such decision as the "should we?" question: *evaluate the risk against the benefits, consult with your customer and decide*. My guess is, no matter what shortcut you might choose, you'll still be required once a year (or whatever) to do a "real" capability study on each individual process.

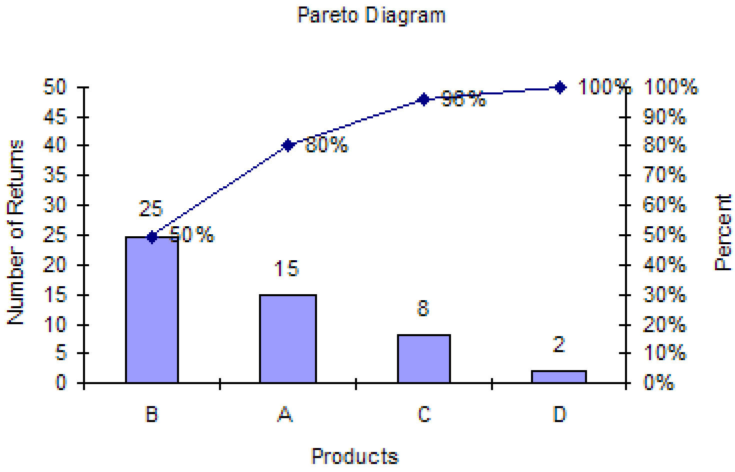
Capability from Multiple Process Streams

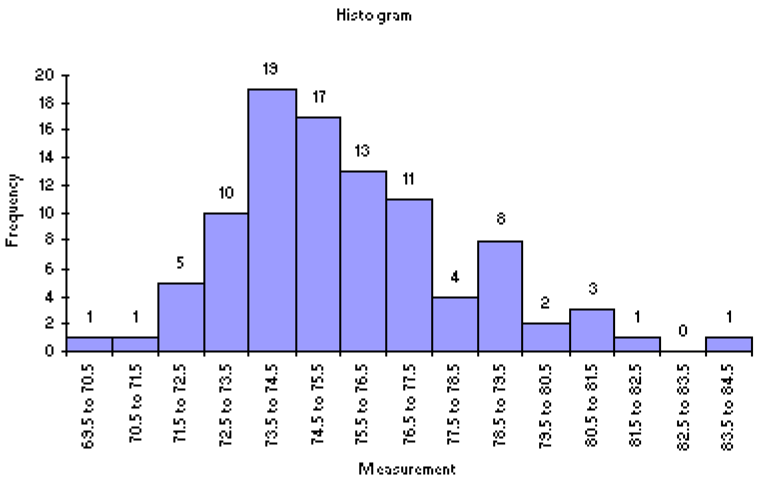
- Ford Motor Company at one time even promoted such a shortcut system designed for multiple cavity dies where you took a reasonable sample from them, calculated an overall standard deviation, and applied that in the ±3s to the average from each cavity to determine the capability. It is questionable if anyone at Ford advocates this method anymore, but it does illustrate that sometimes the shortcuts are acceptable to the customer.

SPC Software

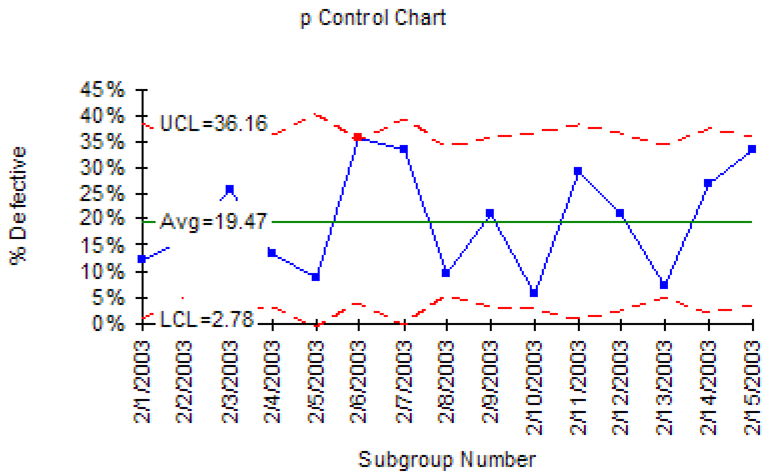
There are numerous SPC software programs available such as SPC for MS Excel, Minitab and SPC XL from Air Academy Associates.

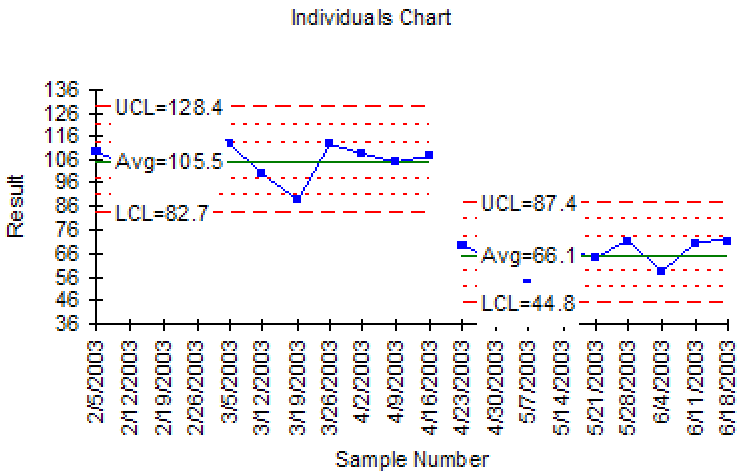
Examples of the output from SPC for MS Excel:

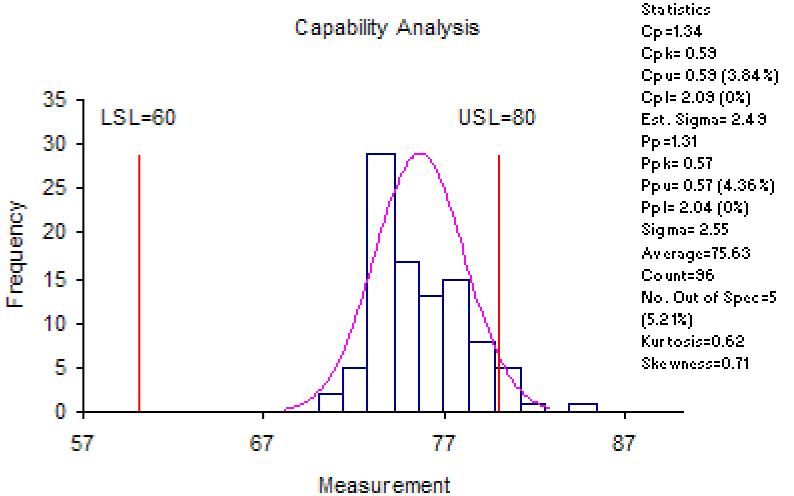




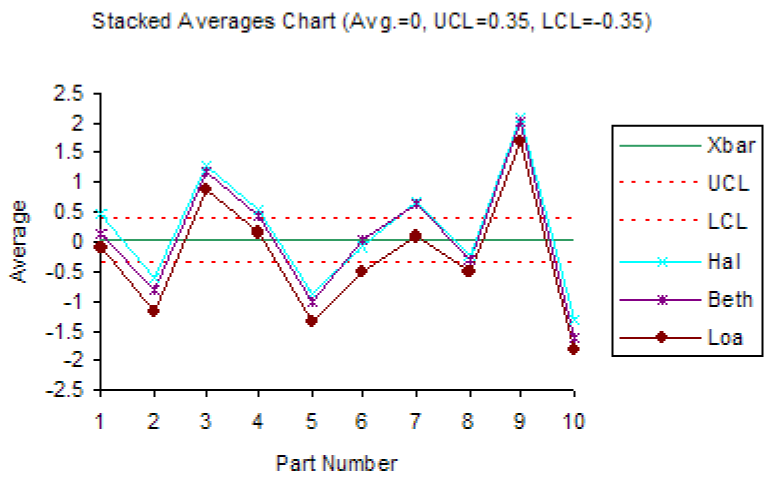
SPC Software

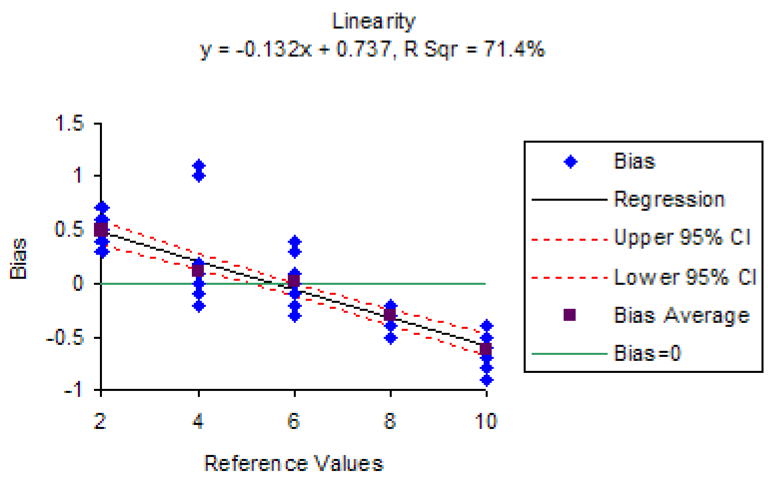


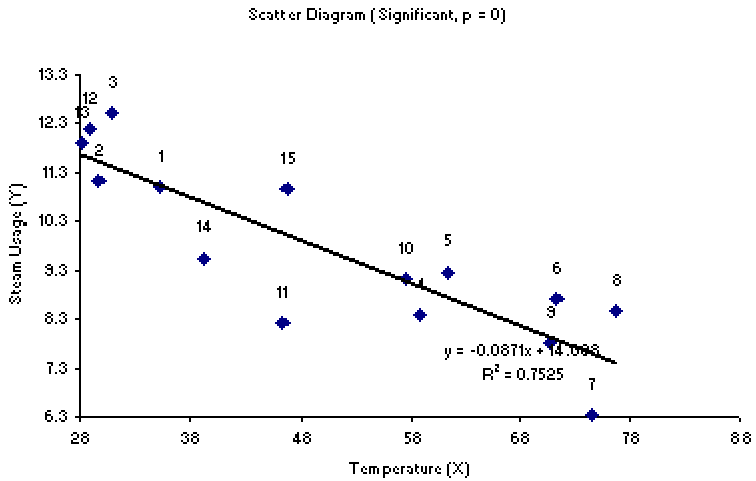




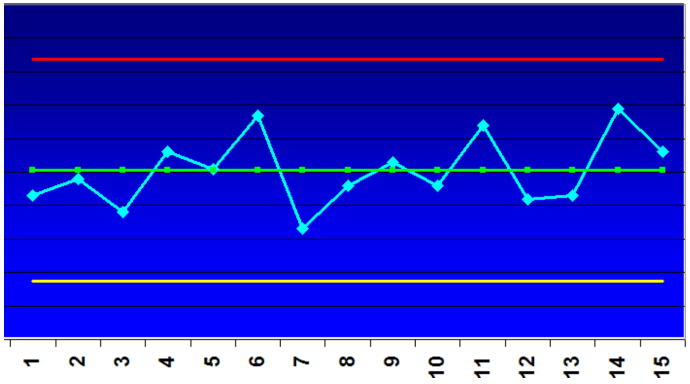
SPC Software







Statistical Process Control Basics



70 GLEN ROAD, CRANSTON, RI 02920 T: 401-461-1118 | F: 401-461-1119
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