

Using Statistical Analysis for Industry Specific ISO 9000 Applications

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OVERVIEW

SPC can be defined as the use of statistical techniques to depict, in real time, how a process is performing through the use of graphical tools. Many engineers have heard about the Shewhart control charts, now being called process behavior charts, which were first developed in the late 1920's. However, there are many other tools available that we will briefly review in this chapter with references to where more information can be found if needed. It is recommended that the manufacturing engineer use this as an overview of the topic of SPC, which should not be confused with SPD – Statistical Process Display. Many organizations get into the habit of posting graphs around the organization without the benefits of using what the graphs are intended to tell the operator and supervisors. Thus SPC is a real time graphical tool process that gives insight into the process behavior that is being studied.

The tools are listed alphabetically to allow for ease of finding the reference quickly. This should in no way be taken to indicate a sequence or importance of use. All of these tools are useful for their intended usage and the manufacturing engineer is encouraged to become aware of as many of these as possible. This will prevent the old adage of everything starting to look like a nail if you only have a hammer in your toolbox.

Tip: In this section, you will note a number of “Tips” listed after the discussion of the various tools. These are listed to give additional insight into the use of the SPC tools. To ensure that SPC works within your organization, you MUST ensure that the

gages are performing properly. Use of Measurement System Analysis (MSA) or Gage Repeatability and Reproducibility (GR&R) Studies are strongly recommended.

THEORY

Variation is the basic law of nature that no two things are exactly alike.

There are usually many reasons for things not being constant. We have procedures for how to do the work, but small things can and will change causing the output of the process to be different. A common way to describe this today is with the formula: $Y = f(x)$ and called out as Y equals the function of the x's.

Graphically this is most easily seen when using the cause-and-effect diagram.

The effect is the Y of the formula and the causes are the x's (see figure 1).

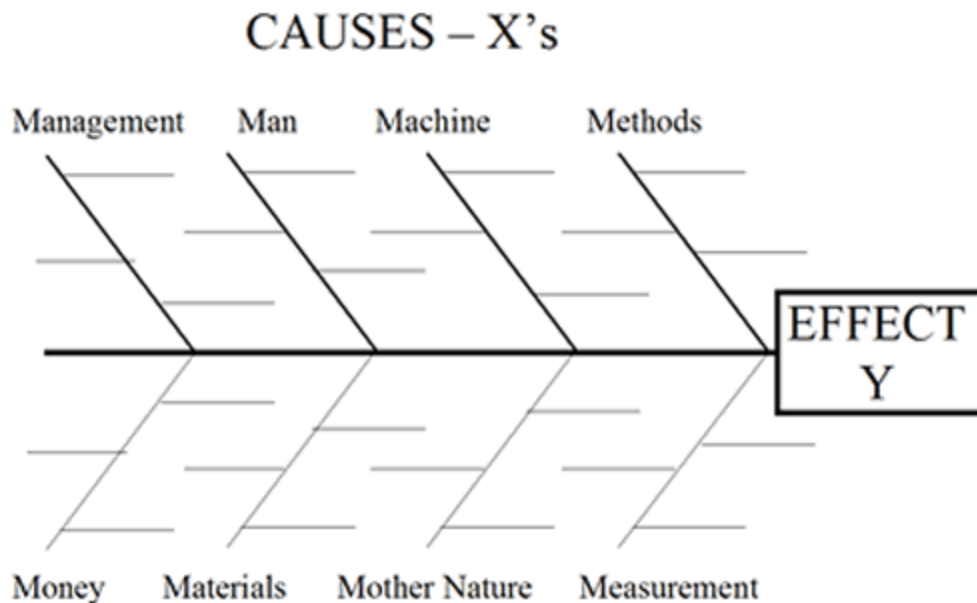


Figure 1

The traditional view of quality (sometimes called the goal post mentality) depicts that some parts are clearly made within specifications while others are outside of specifications (see figure 2).

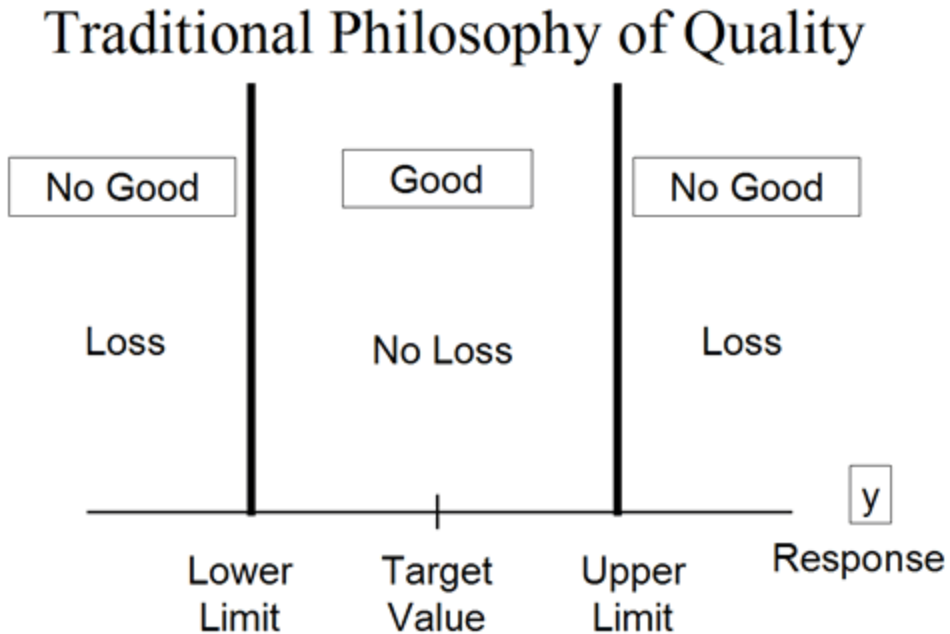


Figure 2

There is no relationship called out for $Y = f(x)$, but the question that should be asked here is what is the "real" difference between parts if one is just inside the spec and another is just outside the spec (see figure 3)? Put together, these two parts are very close and will probably function equally well, or poorly, when used by the customer. That is one of the reasons that people who use this traditional model will tend to ship the part at the spec limit (even if just outside the spec limits) because they think they can get a few more sales to the customer

that will not be noticed. This usually happened at the end of the shipping periods (e.g.: the end of each month).

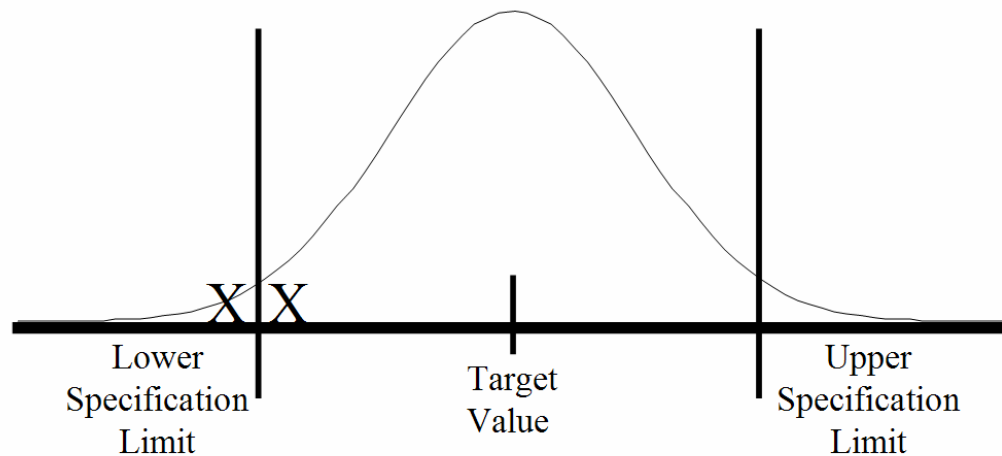


Figure 3

The change in view that is/has occurred (called the Taguchi Loss Function) states that all characteristics, which are measured by the "x's", should be aimed for a target value that is aimed at the middle of the specification limits (see figure 4). In this case, parts that are just in or out of specification have nearly the same "loss" to the customer and will not be accepted very well. As parts move away from the target value, the cost to the customer, and thus society, increases as issues or problems with the use of those parts increase. The goal today is that we need to reduce variation (both common cause and special cause)

so that the customer sees more parts that are closer to the target value of what they want - not what we can produce.

Quality Loss Function Philosophy

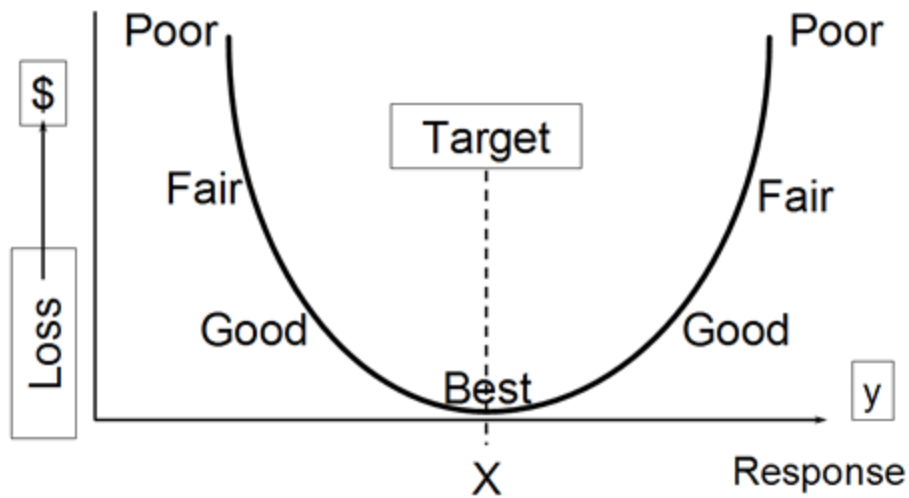


Figure 4

BASIC METHODOLOGY

The eight most commonly used tools in SPC include: Cause and Effect Diagrams, Checksheets, Flow Charts, Histograms, Pareto Diagrams, Process Behavior Charts, Run Charts and Scatter Diagrams. Each of these tools is designed to show a different view of the process variation and to assist the manufacturing engineering in identifying the common and special causes of the variation. Generally (Deming 1992), you will find that to reduce common cause variation, capital investment and other factor requirement upper management support will be needed. While workers and local

managers can usually handle the special cause variation on the shop floor (see references by Munro on Six Sigma for more discussion of other tools).

TOOLS

The remainder of this section will discuss the use of some of the common SPC tools found in manufacturing operations today:

Cause and Effects Diagram (CE Diagram)

Also called the Ishikawa Diagram or the Fishbone Diagram, this tool was first developed in Japan to help improve quality by studying the causes (factors) and effects of a process in greater detail to illustrate their relationships on a diagram and make them more useful to production. “CE Diagrams are drawn to clearly illustrate the various causes affecting product quality by sorting out and relating the causes (see figure 5). Therefore a good CE Diagram is one that fits the purpose, and there is no one definite for” (Ishikawa 1971).

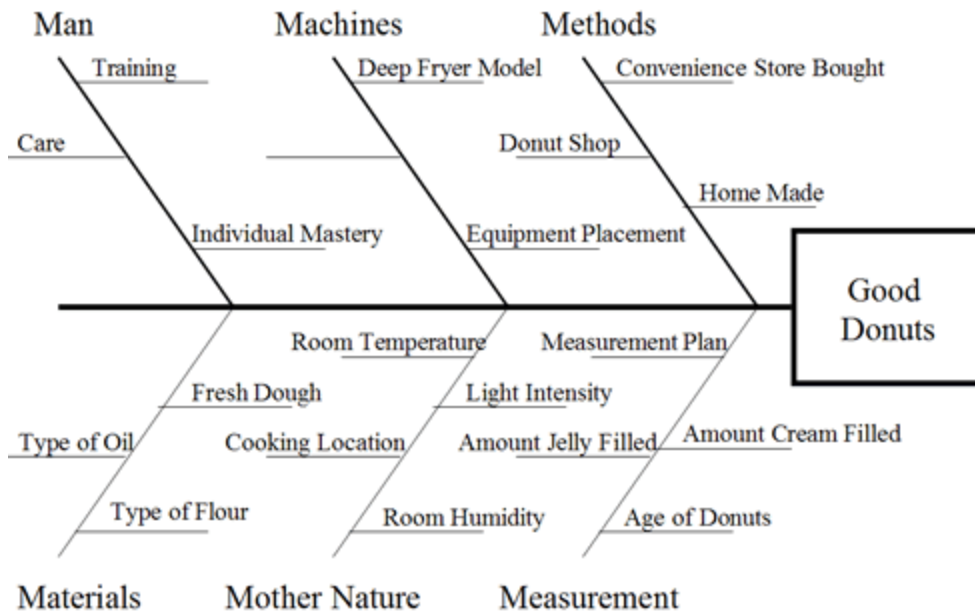


Figure 5

Tips: Remember to ask the five W's and H (what, why, when, where, who, how) when identifying the causes to be used in the diagram. The cause can be any outcome of the process, sometimes a positive situation (think prevention versus detection). The people doing the work should be involved with creating the diagram. The causes should include topics in the basic five M's (man, machine, methods, materials, mother nature, measurement, money or management). Note that the five M's really have eight items and that they are generic and no offense is meant toward women. Use appropriate language for your organization.

Sample: The author once used a CE Diagram to help a group of academics visualize a problem statement that they had struggle with for many hours. Using the basic frame of the diagram, he was able to focus the group's attention on each of the

stems to develop a single picture, in less than thirty minutes, of the factors in play that would eventually lead to their solution.

Check Sheets

A check sheet can be any set of words, tally lists, or graphics designed to assist in conducting a planned review or observation of a process (see figure 6). They are commonly used in many areas of our society to help ensure that something is done in a certain sequence (air plane pilots use checksheet to take off and land aircraft) or to tally information in a sequence that become useful in real time information (incoming inspection). As noted, check sheets can take on a number of forms from simple word lists to pictures that show the process.

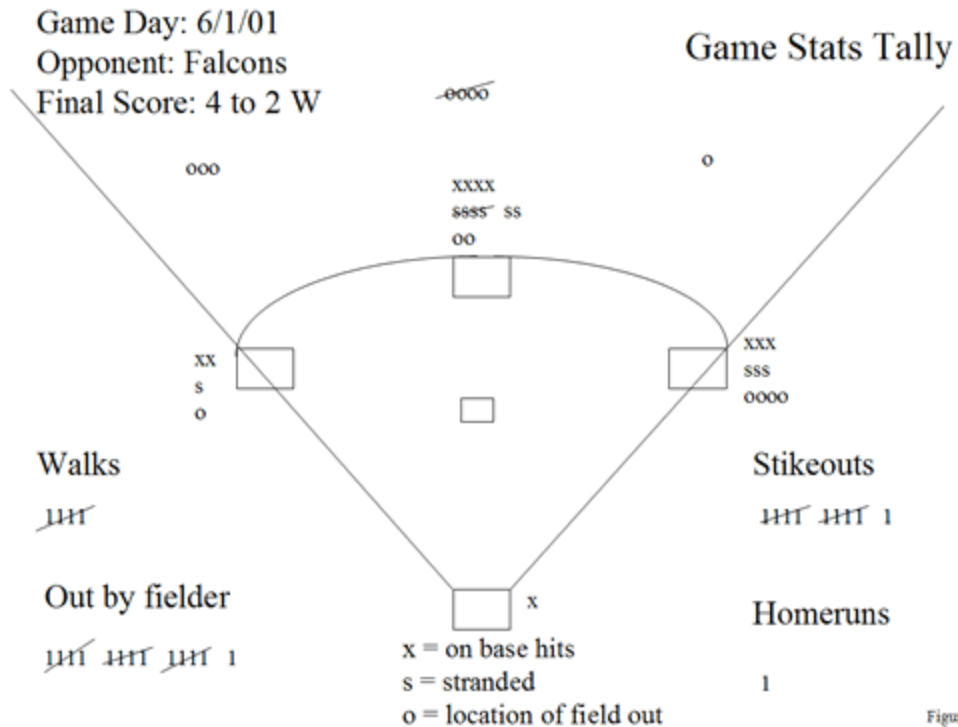


Figure 6

Tips: Pretest a check sheets before full use to ensure that it collects the desired information and that users understand how the information is to be displayed. Using pictures of the product and allow operations to make a mark on the picture whenever something is not according to specifications make for a very simple collection technique.

Sample: In one plant the author worked with, we created a profile of the product and taped a copy of the paper to each unit going down the line. After working with the operators, each person marked on the each unit anything they noted that was not exactly the way it should have been. At the end of the line, inspectors collected the paper and keep a single page showing all the issues for that day's production. The inspectors actually created a pictorial Pareto Diagram from the individual pictorial check sheets.

Flow Charts

Flow charts (a.k.a.: process maps, flow maps, process flow diagrams) are a pictorial representation of the process flow or sequence of events of the operation (see figure 7). You are creating a representation of the steps in a process or system as it actually operates or is supposed to operate. Many software programs are available to assist the manufacturing engineer in creating the flow charts.

Versions of Flow Charting a Process

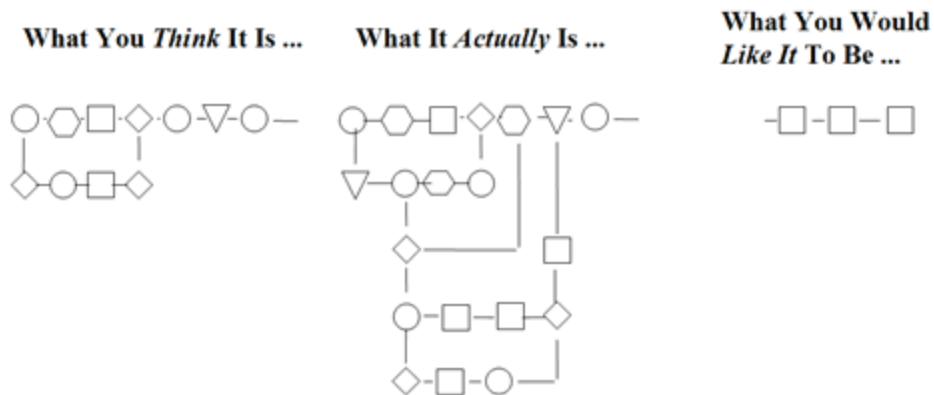


Figure 7

Tips: These are very common in many organizations and the primary challenge is to use similar figures and symbols to represent the same items throughout the organization. The two common ways to produce these is either by working with the various people in the system to identify the actual process or to create a “should be” flow map of what the process should do. The common challenge with asking people in the process is that the odds are that you will get vary different views of what is happening by the different functions within the organization. Thus time is needed to work out the differences.

Sample: The author has seen many “As Is”, “Should Be”, “Could Be”, and “What If” process flow map used in any number of situations from the boardroom to the

front line. This tool is very useful in getting common agreement with a group of people of what is or is suppose to be happening in a process.

Histogram

A histogram is a frequency distribution (usually shown horizontally) that graphically displays the measurements taken from a process and shows how those data points are distributed and centered over a measurement scale (see figure 8). Histograms give a picture of what the process is producing over a specified period of time, although not sequentially (see run charts or process behavior charts). A clear picture of the process variation for the specified time frame become evident and comparisons can be made against the expected process output versus the actual production.

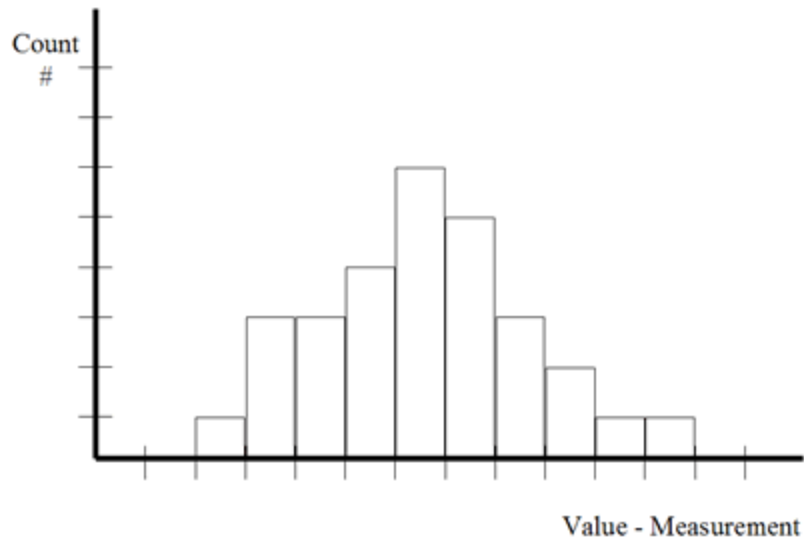


Figure 8

Tip: Whenever measurements are being made, ensure that you can trust those measurements through GR&R studies. Sometimes drawing a bell shaped curve (many software programs do this automatically) can help show how normal the process is behaving. Watch for bi-modal and multi-modal distributions, which could be a sign that the various machines, shifts, or people are operating slightly differently.

Sample: A bimodal distribution indicates that that something in the process is not quite the same. If two machines and two operators are involved, have the operators switch machines and compare the before and after results. Is it the machines or is it the people causing the bimodal distribution. Many times you find that it is one of the machines (maintenance hates this as many times the machine that is not the same is the one that they just rebuild or refurbished). This test is called the “old switcheroo”!

Pareto Diagram

The Pareto Principle basically state that 80 percent of the effect is caused by 20 percent of the causes (commonly called the 80/20 rule). The Pareto Chart organizes data to show which items or issues have the biggest impact on the process or system (see figure 9). Then on the chart, we stratify the data to show the groups, starting with the largest and working down to the lowest number of items in each group. The idea is that by organizing the data in this format, we can develop a plan to work on problems that will give us the biggest return for our process improvement efforts.

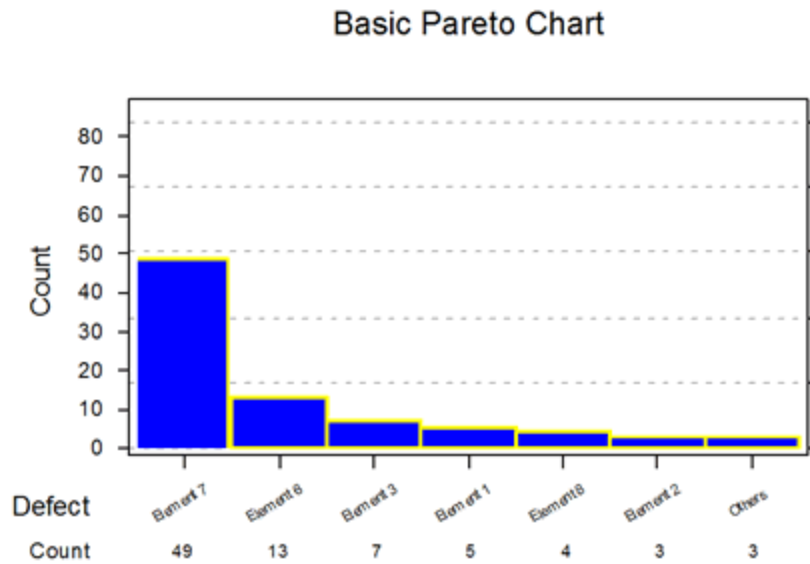


Figure 9

Tip: Pick a specific time frame to collect the attribute data for the chart. Ensure that the operators and/or inspectors are viewing the process in a similar manner to allow for consistency in data collection. A Pareto Chart is easy to develop by hand; however, use of computers makes for easier manipulation of the data as things change.

Sample: A group of executives once scoffed at this basic concept of 80/20. They challenged the author to prove that this concept worked and how it might relate to them. Having received information about the company ahead of the engagement, the author was able to point out to them that 80% of their total sales volume was directly related to 20% of their customer base!

Process Behavior Charts (Control Charts)

The Process Behavior Charts developed by Walter Shewhart were used primarily for long production runs of similar parts (Shewhart 1931). The 30 plus different charts that are available today were originally called Control Charts (many books still use this term) or Statistical Process Control (limiting SPC to only the basic Process Behavior Charts). In this section we will focus on only the six most commonly used charts, they are: Xbar and R (or s); Individual and Moving Range; p; np; c; and u (see figure 10). The primary distinguisher is the type of data measurements that are collected. Variable data is information collected from continuous measurement devices (e.g.: length, weight, volume, roughness, etc.) Attribute data is ordinal information (e.g.: go/no go, good/bad, blemishes, scratches, counts, etc.).

| Chart Name | Data Type | Measure* | Description |
|-------------------------|-----------|-------------------------------------|---|
| Xbar and R | variable | Averages of variable data | Subtract the smallest sample value from the largest to identify the range |
| Xbar and s | variable | Averages of variable data | Use a computer to identify the standard deviation |
| Individual Moving Range | variable | Individual variable data | Used when averages are not available |
| p | attribute | Fraction of nonconforming units | percentage of all units checked |
| np | attribute | Number of total nonconforming units | number of units found to have issues |
| c | attribute | Number of nonconforming | number of issues found |
| u | attribute | Number of nonconforming per unit | average number of issues found per the number of units checked |

Figure 10

The basic rules of the Process Behavior Charts work with all of the charts. The primary function of the chart is to demonstrate the stability of a process. Note that this may be in conflict with continual (continuous) improvement, but you must have a starting point (benchmark) to ensure that you have made improvements. Without a stable process behavior chart, you are unable to calculate capability of the process and you will be forever guessing on what factors are causing variation within your system. The Charts will distinguish the differences between special (assignable) and common (random) cause variation and give the manufacturing engineer the evidence needed to make process improvements.

X-bar and R

The X-bar and R (sometime sigma is used instead of the range, thus transforming the chart into the X-bar and S chart) was the first chart developed (see figure 11). It was used extensively through WWII because it is easy for operators to use without the need of a calculator or computer. If sample size five is chosen; then simply add up the five numbers, double the value, and move the theoretical decimal point one place to the left! You now have the mathematical average of the five numbers. This only works with sample size of five and this is why many textbooks suggest five for the sample size.

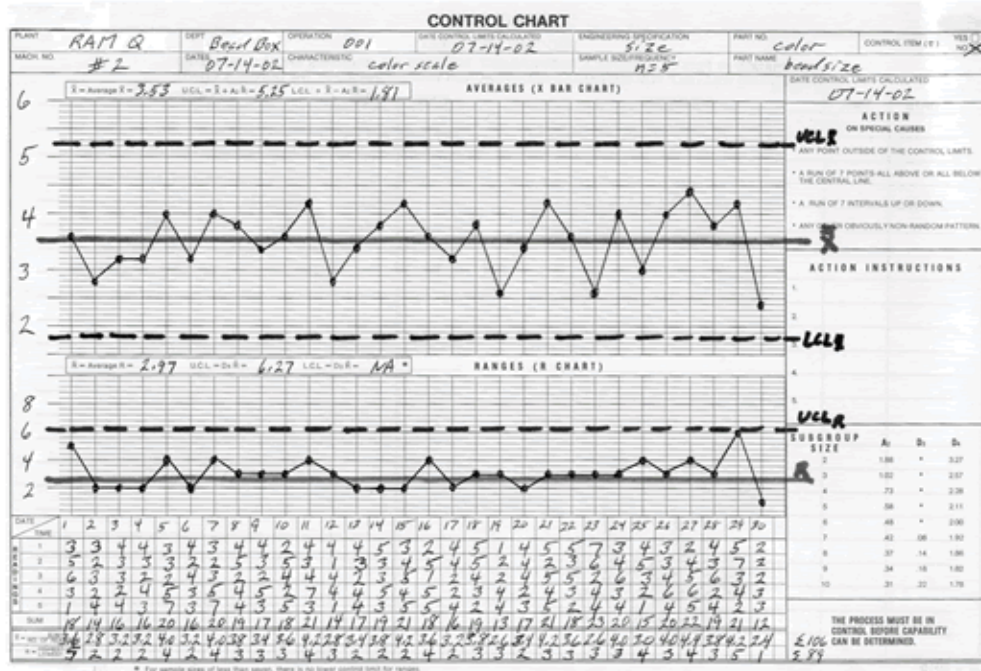


Figure 11

Individual and Moving Range (IMR)

When destructive testing or high cost measurement is involved, it is usually impractical to test more than one part or process parameter (see figure 12). Thus an Individuals chart can be used to monitor the process behavior for patterns, trends, or runs. As in all variables charts, start by observing the range chart for stability and then study the actual measurements.

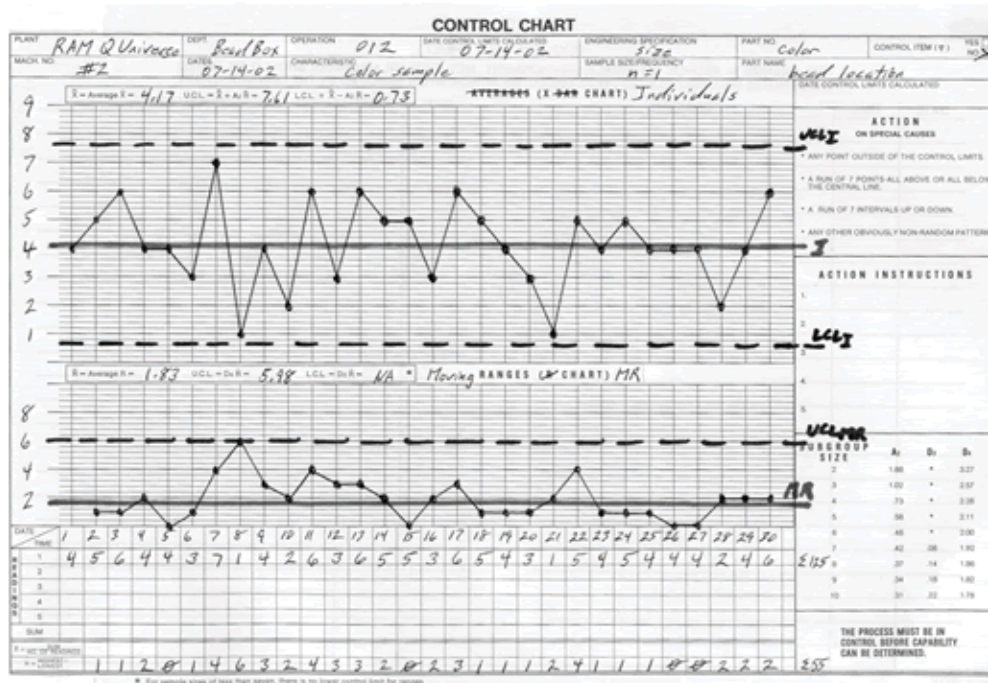


Figure 12

Attribute charts (p, np, c and u)

The attribute charts are not usually considered a robust as the variables charts but are still highly prized for their ability to monitor a process and show stability when variable data is not available (see figures 13, 14, 15 and 16). One note here for the manufacturing engineer is that as the process improvements are made in the process, larger and larger sample sizes will be needed to detect nonconforming rates and patterns in the process. The need for very large sample sizes is one of the primary reasons that many textbooks strongly suggest finding a variable measure in the process to monitor.

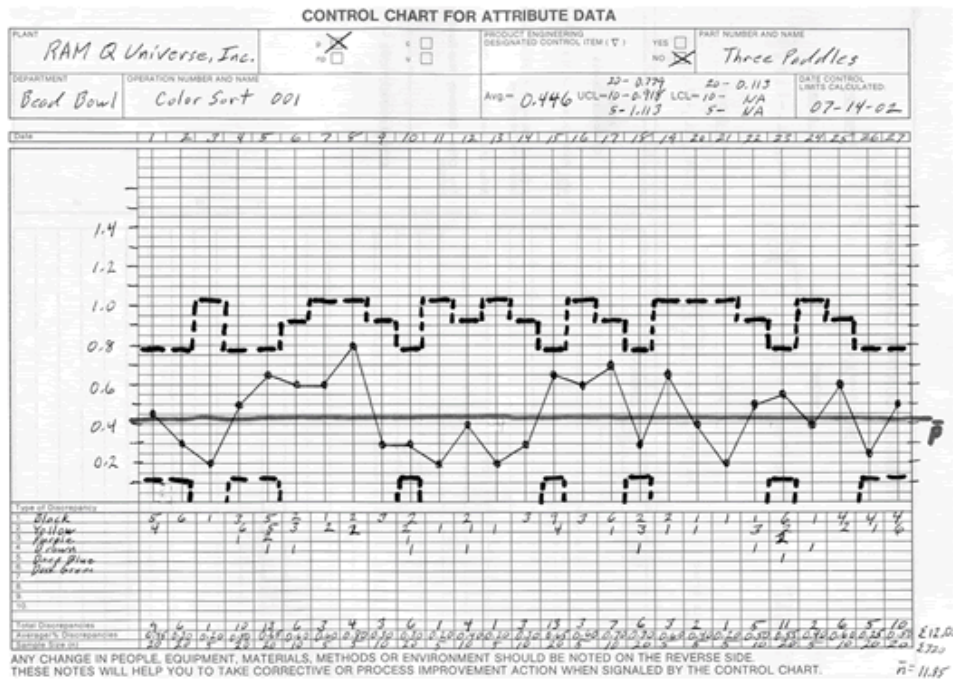


Figure 13

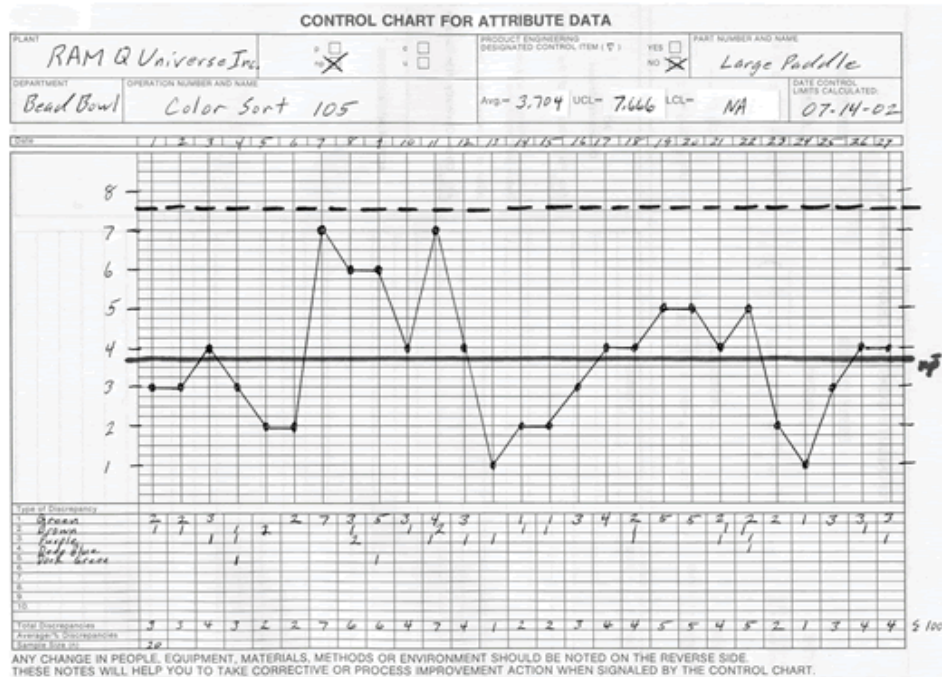


Figure 14

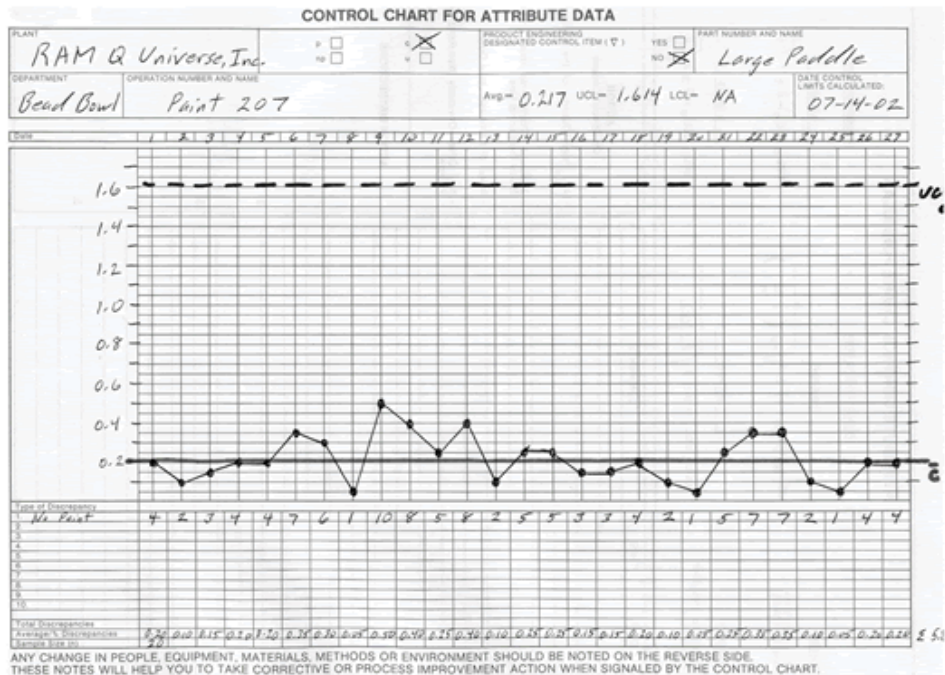


Figure 15

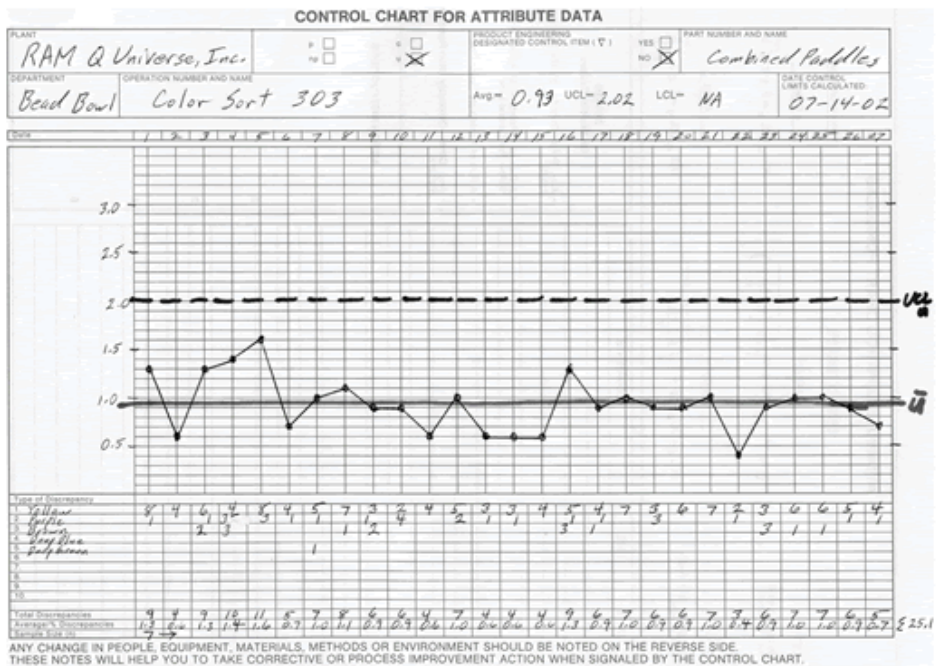


Figure 16

Tip: There is far too much material here to cover in a couple of pages, thus the list in the reference section. These books (Ishikawa, Juran, Munro, Stamatis, Wheeler and AT&T) have a wealth of information on the application and use of these and other charts. In manufacturing settings, you may also want to discuss the use of these charts with the quality office in your organization as they may have other applications in the company that you will be able to get ideas from. In office settings, the most common charts are the IMR and the attribute charts.

Sample: The author's first use of one of these charts was the Individual and Moving Range used on a late 1970's model vehicle to monitor gas mileage (this was before computer controls). By using the chart as a prevention tool, the author saved over a thousand dollars over a three-year period on maintenance and other costs related to the use of the car.

Run Charts

A Run Chart is a line graph that shows measurements from a process, system or machine in relationship to time (see figure 17). Virtually no calculations are required for this chart and it is very useful in monitoring process variation for patterns, trends, and shifts. The Run Chart (a.k.a.: trend chart or line graph) can be used almost anywhere is attribute or variable data.

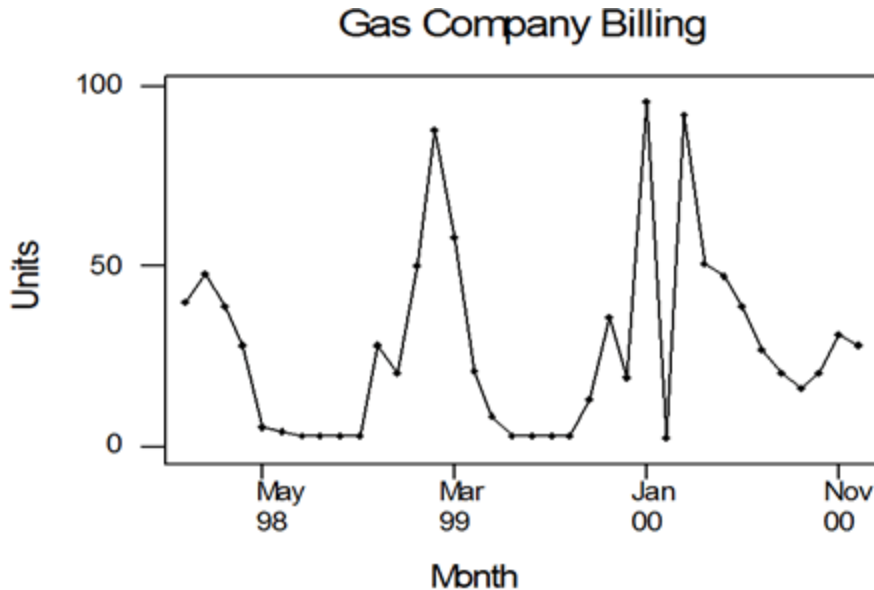


Figure 17

Tip: Very simple chart to construct by hand, however, when comparing charts, ensure that the scales are the same! Many times computers will change the scale to make the chart fit the available space without notifying the user. Many false readings or interpretations have resulted from not watching the scale shift.

Sample: As with many of these tools, the Run Chart can be used at home as well as in the production process. The author has monitored home utility usage of water, gas and electric to look for ways of energy conservation and to monitor the processes.

Scatter Diagram

Scatter Diagrams (a.k.a.: correlation charts, regression plots) are pictorial ways of showing the relationships between two factors (see figures 18, 19, 20, and 21). The base diagram lists each factor on one of the axes of the graph and plots the paired measured information. Patterns in the data plots can show how much, if any, relationship there is and the strength of the relationship.

No Correlation

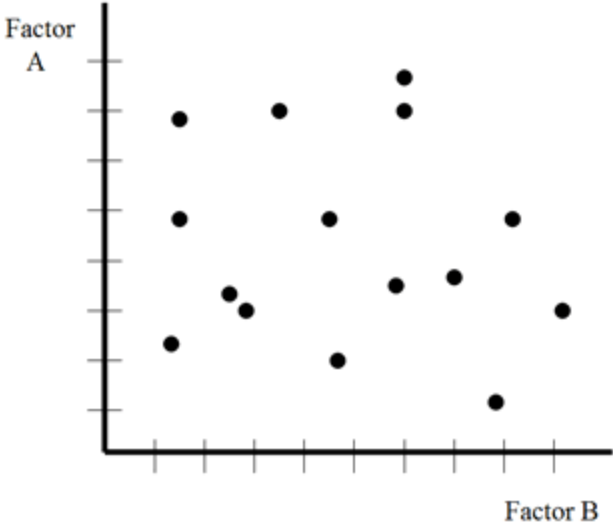


Figure 18

Positive Correlation

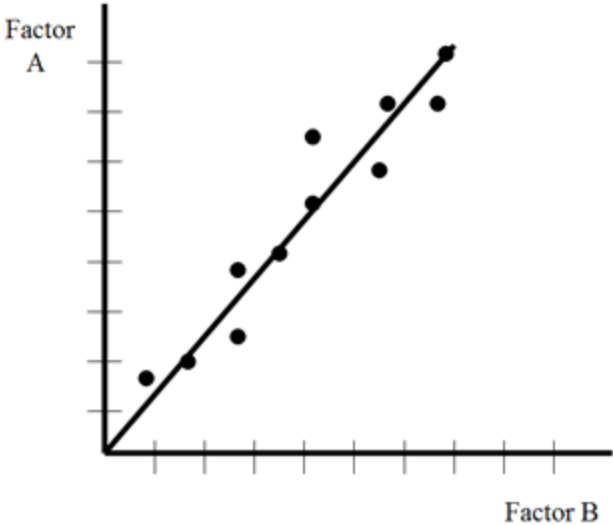


Figure 19

Negative Correlation

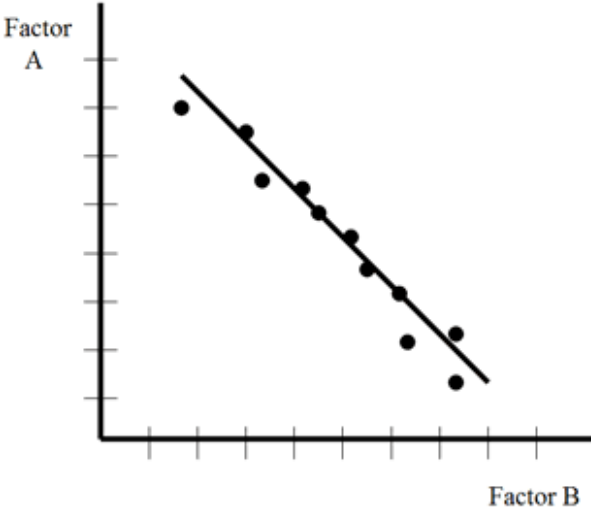


Figure 20

Linearity Correlation

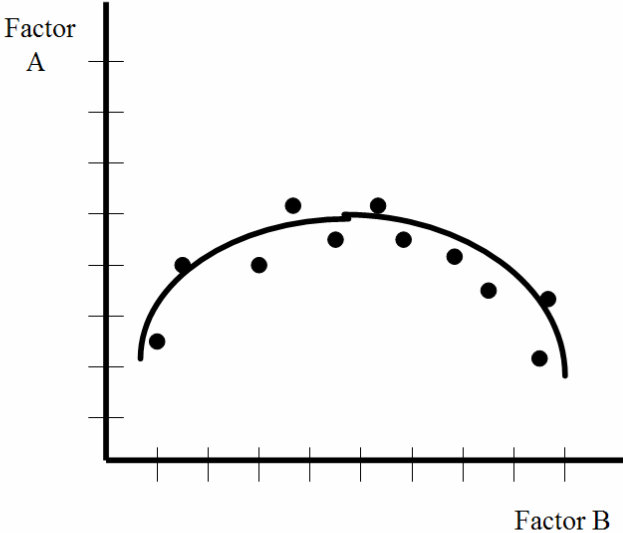


Figure 21

Tip: Sometimes things may seem to be related, however, a third factor is actually the controlling element. (e.g.: You can prove with a scatter diagram that ice cream causes drowning! As ice cream sales go up, so do swimming accidents. The hidden factor is that it is summer.) Look for the causality of the factors that you are planning to study.

Sample: The author used this tool on one study to look at relationships between air temperature and liquid volume in a large chemical storage tank. Management had supposed that the operators were overusing the chemical when in reality; the temperature of the outside air variation caused the variation of usage. No one had taken this into consideration when the chemical mixing process was developed.

Short Run SPC

The Short Run SPC technique has been developed to use the same Process Behavior Charts when frequent changeovers occur or short production runs are the norm. All of the same rules and charts apply with the one exception of how the data is plotted. Instead of plotting the actual measured data, a conversion of the data is made from the target value or nominal value for that specific process. Because of the need to add and subtract from the target value, operators will have to be able to handle a little more math and feel comfortable working with negative numbers.

Tip: Note that we are plotting the process behavior and not specific part measurements. This allows the Short Run SPC technique to work exceptionally well in a number of applications where changeover occurs frequently and or normal production

consists of relatively short production runs (e.g.: a machine shop, mold building, low volume industry as aerospace, etc.).

Sample: An injection machine with a large cavity low cycle time mold is able to produce a high number of parts with a short period of time. After studying the mold to ensure that each cavity is statistically capable, the engineer identified a cavity that is nearest the nominal value for each mold that is typically used in this machine. As each mold is set up for that days run, that one cavity is plotted on an Xbar and R chart using four consecutive shots of the same cavity once every 45 minutes of production time. This frequency and sample size were determined by the manufacturing engineer given past history of the speed of the system and how often the process can change.

Other Tools

Other tools (Munro 2002) that could be used on the production floor include: Advance Quality Planning (AQP), Benchmarking, Brainstorming, Control Plan, Cost of Quality (Cost of Poor Quality), Employee Involvement, Failure Mode and Effects Analysis (FMEA), Five S's, Lean Manufacturing, Measurement System Analysis (MSA), Process Capability, Plan-Do-Study-Act (PDSA), Sampling Plan, and Standardize-Do-Check-Act (SDCA).

SUMMARY

As we have seen in this white paper that SPC is far more than just the tradition Process Behavior Charts that are referenced in some books and articles. There are a number of statistical tools that can be grouped under the umbrella of SPC. Many of these tools have been used very successfully for many decades in production operations to help monitor and improve the process and parts in the plant. These are the same tools that are

used in the Six Sigma Methodology (see figure 22) and many other quality programs that have been toughed over the years. These tools work very well and are only limited by your imagination.

| Cpk | Six Sigma | DPMO | Yield |
|------|-----------|--------|----------|
| 2.00 | 6.0 | 3.4 | 99.99966 |
| 1.67 | 5.0 | 230 | 99.977 |
| 1.33 | 4.0 | 6210 | 99.379 |
| 1.00 | 3.0 | 66800 | 93.329 |
| 0.67 | 2.0 | 308000 | 69.2 |
| 0.33 | 1.0 | 690000 | 31 |

Figure 22

REFERENCES

- Deming, W. E. (1992). *Quality, Productivity, And Competitive Position*. MIT, Boston, MA.
- Ishikawa, K. (1971). *Guide to Quality Control*. Asian Productively Organization: Kraus International Publications, White Plains, NY
- Juran, J. M. (1999). *Juran's Quality Control Handbook Fifth Edition*. McGraw Hill, New York, NY.
- Munro, R. A. (2003). *Six Sigma for the Front Office: A Pocket Guide*. American Society for Quality, Milwaukee, WI.
- Munro, R. A. (2002). *Six Sigma for the Shop Floor: A Pocket Guide*. American Society for Quality, Milwaukee, WI.
- Shewhart, W.A. (1932). *Economic Control Of Quality Of Manufactured Product*. Van Nostrand Company, New York, NY.
- Stamatis, D. H. (1995). *Failure Mode And Effect Analysis: FMEA From Theory To Execution*. American Society for Quality, Milwaukee, WI.
- Stamatis, D. H. (1997). *TQM Engineering Handbook*. Marcel Dekker, New York, NY.
- Wheeler, D. J. and Poling, S. R. (2001). *Building Continual Improvement: SPC for the Service Sector, Second Edition*. SPC Press: Knoxville, TN.
- (1956). *Statistical Quality Control Handbook*. AT&T Technologies, Indianapolis, IN.