Visiting Old Friends

Statistical Concepts That Work For You

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Many problems found in the design, production and delivery of products and services can be prevented by applying basic statistical concepts to extract and analyze process and test data. Analysis of statistical data permits decisions to be made proactively which eliminates causes and reduces variation. When results are predictable and variation is minimized; quality improves, costs are reduced and customer satisfaction increases.

- Many problems can be prevented once you can see the variation
- Sampling and Histograms show the extent of variation
- Process Control Charts and Capability Metrics show you what the customer will see, and help prevent customer dissatisfaction

Variation is the Enemy

Variation in any repetitive process is harmful. Consider the great American sport of football. If a team's kicker always was able to punt the ball exactly in the center of the goal post, that team would have a competitive advantage. Other kickers might have more variation. This might be more exciting, but potentially costly if the score is close and the kick was, well, not close enough. Other examples of the danger of variation include a pilot landing a jet on a landing strip, the taste of your French fries at McDonalds or the dependability of your high-speed internet connection. Sometimes even very small variation can be a big problem.

Variation in any repetitive process is harmful because it causes waste, disruptions and customer dissatisfaction. We sometimes think that products produced with dimensions that exceed customer specifications are wasteful, but that is only the tip of the iceberg. Parts that fall out of specification are physically obvious because it is usually detected before being shipped to the customer and classified as scrap or rework. But imagine when many parts with minimal variation are assembled together and the length of each of those components happens to fall on the low end of its tolerance. When stacked together, by chance, those variations add up to a short part … and in fact, much shorter than possibly another assembly composed of several parts that are on the high end of the allowable tolerance.

In certain manufacturing processes, variation might be perceived in the performance of the part. Consider the functionality of a brake pad. When a driver applies the brake, there are several contributing factors to the 'feel' of the braking system. In some vehicles, applying the brake may feel firm … in others it might feel squishy. With today's discriminating customers, even that variation can be the cause of customer complaints, warranty claims and possibly even lost market share.

As customers become more discriminating, and global competition offers consumers more alternatives, reduction of variation becomes very important to a

Overview

- Commonly used statistical concepts critical to management of product quality
- Explores linkages between operations management, measurement, analysis and corrective action
- Importance of Control Charts, Cpk and reduction of special and common causes in order to achieve quality goals

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company's survival. Customers don't just want product that works well, they want product that looks great, operates smoothly; product that sounds and feels like it is well engineered. The requirement placed on the producer is no longer just making parts in specification, or holding processes within a range. More than ever the requirement is to reduce variation within the specification, and target performance in a way that maximizes customer satisfaction. World-class manufacturing requires that processes be capable of producing product which satisfies customer requirements.

Seeing Variation

Statistical concepts allow us to evaluate and monitor variation. If the length of parts within a sample were measured, we would see that while the parts were close to some value, some measurements will be higher and some lower than that average length. A histogram could be used to visualize the extent of the variation and provide a visual of the central tendency, or average length. In a histogram, the measured values are on the x-axis and the height of the bars above each value represents the number (or percent) of observed occurrences for that value. See Figure 1.

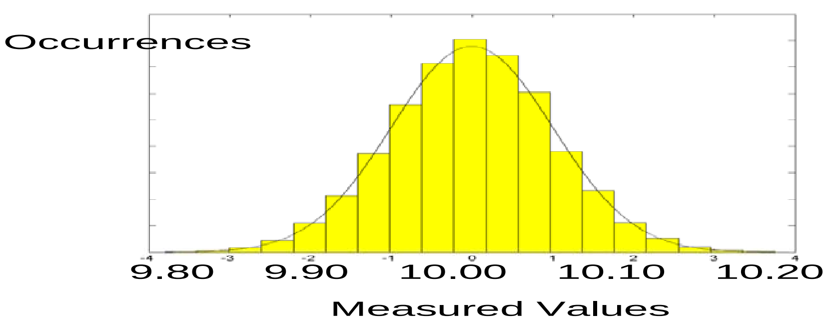

Figure 1: A Histogram Is a Visual Representation of Probabilities and Variation

The shape of the distribution of values in a histogram indicates the expected results. Where the curve is highest, there is a greater likelihood of the corresponding value. Where the curve is closer to the x-axis, there is a very low probability of observing the corresponding value.

While a histogram is one tool to understand variation after it occurs, there are other statistical tools that allow us to proactively evaluate and manage variation and capability.

Consequences of Variation

If not well managed, we might 'see' the consequences of variation. Skids of scrapped parts, re-inspection and sorting of parts, are indicators of unwanted variation. Reduced production yields due to product failing final test is a gross indicator. Warranty recall programs and lost market share are among the costliest consequences of variation. The bottom line is that if we don't meet customer requirements at the first opportunity, we will incur costs that could have been prevented.

Responding to increased scrutiny from customers and the need to focus on waste reduction or elimination, many companies are abandoning conventional metrics for quality. Measures such as Parts Per Million defective (ppm) and Customer Concerns or Customer Incidents are being replaced with barometers of operational productivity and process yield. More companies are using, or considering, metrics such as First Time Quality (FTQ) and Overall Equipment Effectiveness (OEE). Both FTQ and OEE recognize that quality and efficiency go hand in hand.

Once a company commits to taking steps to reduce variation, consideration has to be given to the appropriate strategy to do that. Considerations for the appropriate strategy might trade-off effort, cost and effectiveness. There are costly ways to reduce variation, such as investing heavily in precision automation, robots and high tolerance CNC equipment, and redesigning product and processes to prevent errors. But there are other creative and less costly ways to control variation.

Measuring Variation

Many problems can be prevented if you see the variation early. Gaging parts at the point of fabrication is better than checking parts at final assembly. Similarly, understanding and controlling the sources of variation is better than measuring the resulting effects. For example, if the sharpness/dullness of a drill was known to affect the diameter of a high tolerance hole, monitoring tool wear could prevent parts from ever having non-conforming hole diameters. By monitoring and controlling the sources of variation, a manufacturer can save effort, save time and save money – and the natural byproduct is increased customer satisfaction.

Since a histogram shows the extent of variation and relative likelihood of possible outcomes, we can apply that concept to view the variation in a given process. Let's consider a drilling operation, when the hole diameter tends to be around 10mm, but has been known to range from 9.8mm to 10.2mm. After sampling parts, we can construct a histogram that illustrates the distribution of measured diameters. We can sort the parts by size, count how many of each size occurred and create a bar chart akin to a histogram. If the sample is representative of all parts coming off the manufacturing line, we can fit a curve on top of the bars to represent diameters that could occur between and beyond the diameter of the sampled parts. We call this a Process Distribution Curve. See Figure 2.

The Process Distribution Curve tells you a lot about the historical performance of a process. In addition to the visual interpretation, statistical concepts and formulas can be applied to the raw data to calculate the central tendency (mean, median and mode) and the extent of dispersion in the sample (range and standard deviation). Using these process distribution metrics, processes can be monitored over time or compared to target values. For example, there may be a need to reduce variation so that it is less likely that

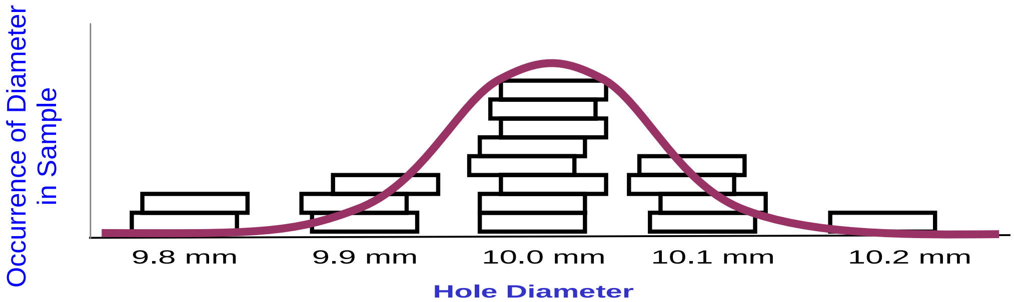

Figure 2: A Process Distribution Curve is a build-up of the individual measured values

a diameter would fall outside (above or below) the customer specifications, usually referred to as the Lower Specification Limit (LSL) and the Upper Specification Limit (USL). Or, there may be a need to shift the distribution, so that the average is equal to some defined process optimum.

Six Sigma programs have gained in popularity largely because their focus is improving process performance, so the process distribution curve is well inside of customer specifications. Six Sigma performance implies the results from the process when shown as a curve are well within the customer specifications; in fact, 99.99966% or more of the output satisfies the customer's requirements. See Figure 3. That very high percentage of conforming parts is not "zero defects", but 3.4 defects per million. Close to perfection, but at Six Sigma performance, defects can still be produced; albeit with a low occurrence.

Sigma Level and ppm

Process Long-Term Yield	Waste	Long-Term Sigma (Cpk)	Short-Term Sigma	Defects per 1,000,000	Defects per 1,000
99.99966%	0.0%	4.5	6.0 ←	3.4	0.0034
99.99700%	0.0%	4.0	5.5	30	0.03
99.97700%	0.0%	3.5	5.0	230	0.23
99.86500%	0.1%	3.0	4.5	1,350	1.35
99.37900%	0.6%	2.5	4.0	6,210	6.21
97.73000%	2.3%	2.0	3.5	22,700	22.7
94.52000%	5.5%	1.6	3.1	54,800	54.8
93.32000%	6.7%	1.5	3.0	66,800	66.80
84.20000%	15.8%	1.0	2.5	158,000	158.00
69.20000%	30.8%	0.5	2.0	308,000	308.00

From Six Sigma Fundamentals, by D. H. Stamatis.
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Figure 3: Process Yield Percentages and Correspondence with Sigma Values

Problems Can Be Prevented

While a Process Distribution Curve provides some good information, it has two key weaknesses. First, since it is constructed from sample data, it doesn't show you how bad performance might be. The worst performance might be from parts produced before or after samples were taken. Second, since the curve represents a sample within a given period of time, it doesn't show you if the process is getting better or worse, or is actually stable. Since our objective is to prevent problems rather than react to them when they occur, it is essential that we find a way to look for trends in the data.

Another statistical tool for evaluating process performance is called a Run Chart. A Run Chart plots measured values at prescribed time frames. Therefore a Run Chart shows a chronology of performance, enabling you to see trends and patterns which occur over time. "Eye balling" a Run Chart, you might observe that values are trending upward, or downward; that variation is increasing, or that performance has shifted from one central tendency to another. All these might be indicative of a problem. See Figure 4.

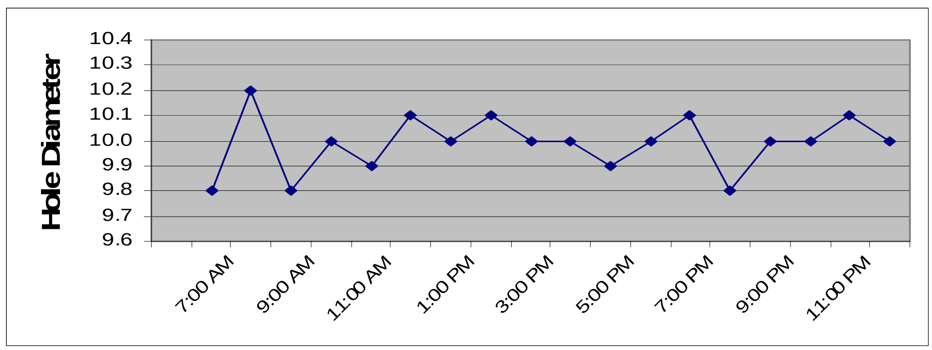

Figure 4: A Process Run Chart Shows Trends and Patterns in the Process

If we can establish how much variation is expected and normal, vs. a true detrimental change in the underlying process, we could prevent problems. We could detect a change in the process early if we could identify a trend. One way to do this is to establish control limits or early warning 'alarms' so that when results fall too far from the average value, we get a 'signal' that some intervention is needed to prevent production of any nonconforming parts.

Process Control Limits can be calculated to define boundaries within which variation of the process is expected. Very different than customer specification limits, which are provided by the customer, the Process Control Limits are calculated based on where most of the process results fall. Mathematically, Process Control Limits are calculated using two key process statistics: mean (the sample average) and standard deviation (the square root of average squared deviations of each number from the mean). The boundaries where most of the process variation is expected is three standard deviations above and three standard deviations below the process mean. Control limits are calculated by the following formulas:

Lower Control Limit (LCL) = (mean) - (3 x (Standard Deviation))

Upper Control Limit (UCL) = (mean) + (3 x (Standard Deviation))

It's convenient to understand the concept of Process Control Limits by seeing where they lie on a Process Distribution Curve. Note in the chart below, that a small percentage of process results will fall outside the calculated Control Limits. It's important to understand that the Control Limits are established purely by the past behavior of the process, regardless of how well the results fall within or outside customer requirements. When we monitor results against Process Control Limits, we're only checking to see if there is a change in the process. See Figure 5.

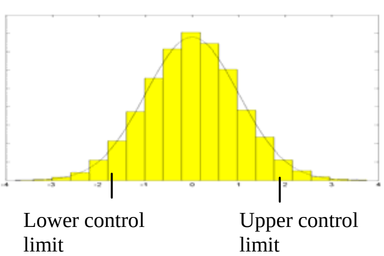

Figure 5: Control Limits are Calculated from the Process Data

In other words, Process Control Limits identify the natural maximum variation of the process. If there is a lot of variation in process results, the Process Control Limits will be wide. If the distribution of process results is very tight, the Process Control Limits will be tight. All this is completely independent of where process results fall within the customer specifications. Sometimes, Process Control Limits are called the "Voice of the Process" because they are used to indicate how the process has behaved.

Regardless of how wide or how narrow the limits, Process Control Limits establish the alarm points – to warn us about a change in the process. Some change from one sample to the next is to be expected due to random variation. But when there's a trend – when observed data is no longer bouncing within the Process Controls Limits – or when a data point is found outside the Process Control Limits, we know that something in the process has changed, which might be problematic.

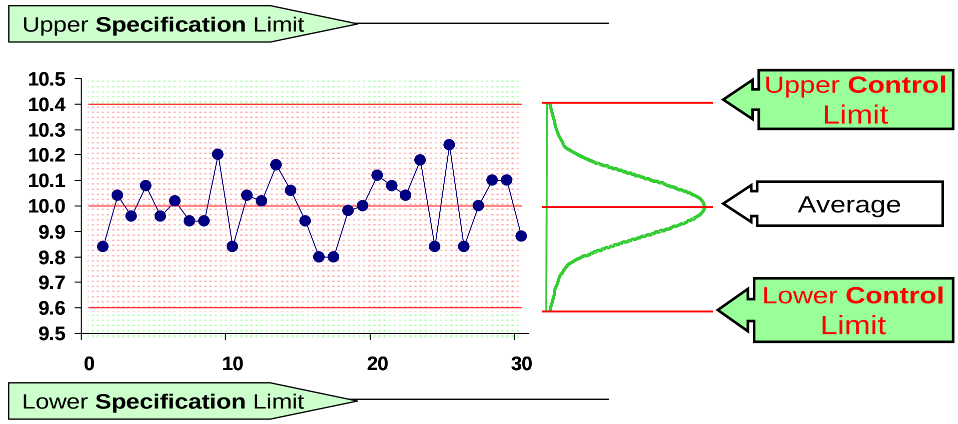

Figure 6: Process Control Charts Show Patterns and Trends Relative to the Control Limit Alarm Points

If data from the process continues to fall within the Process Control Limits, and the data have an expected amount of variation, or bounce, within the Limits, we can say with confidence that the process is "Under Control" or "Stable." This means that under the current process settings, we don't expect that parts will be manufactured which fall beyond the Process Control Limits.

After Control Limits are calculated from historical data, a Process Control Chart can be drawn to monitor current performance and determine if a change is impacting performance. Process Control Charts are sometimes called "Statistical Process Control (SPC) Charts." A Process Control Chart monitors performance chronologically, like a Run Chart, but will put alarm points in place to trigger preventive action when a detrimental pattern or unstabilizing trend occurs. See Figure 6.

When operating a process, we want to control the mean and the variability of the output, or even of the controllable process inputs. We can use a Process Control Chart to monitor the mean and variation of process input or outputs.

A Process Control Chart indicates that a process is out-of-control when one or more points fall beyond the control limits, or when plotted points exhibit some non-random pattern. A non-random pattern is a symptom of outside factors affecting the process. The following are common indicators for out-of-control situations:

Point(s) outside the Control Limits - An outside influence (special cause) is impacting the process – (e.g., machine adjustment, tool breakage, change in raw materials, change in the measuring device).

Run of 7 consecutive points upward or downward (Trend) - A slow change in the process resulting from slippage of a setting, omitted preventive maintenance or unanticipated wear of fixtures or tools. Seven consecutive points moving in one direction indicates a non-random drift in the process. If the points move from near a Control Limit toward the mean, it could indicate desirable setting adjustments or an improvement in operator technique.

7 consecutive points above or below the mean - A shift in the process – (e.g., change in machine setting, change of methods). Though the values may still be random (bouncing up and down), seven consecutive points indicates a low probably of a value on the other side of the mean; therefore the process has shifted.

Sudden Level Shift - A sudden change in the process – (e.g., a change in machine setting, change of methods or tool breakage). Though the values may still be random (bouncing up and down), a sudden shift in the mean shows a change in the central tendency or level of the data.

Stratification - Points are within but too close to both the LCL and the UCL. This indicates that different samples (high vs. low) are affected by different factors; e.g., two different machines (one running on the high side and the other on the low side) or two different operators.

Hugging the Mean - Since the control limits were set by the 'voice of the process' a change in the process has resulted in less variability than expected. While less variation is good; something not yet identified has occurred. If the change can be identified and controlled, then the process might be permanently improved.

Cyclical pattern - A recurring change; e.g., process changes related to start of shift or activity prior to breaks, regular rotation of equipment or staffing, changes in output due to scheduled changes of tools, a problem in one out of many positions in a dial-type machine.

Same value - No variation when limited inherent variation is expected – might be created by a measurement problem.

Making the Right Proactive Decisions

If a process is not targeted or if variation of the process is greater than variation tolerated by the customer, then you could still have excellent process control (stable and predictable process), but the product produced may not satisfy the customer specifications. To fix the situation, you'd need to reduce variation and/or shift the mean to fall within the customer specifications.

If the process is not stable (i.e., an out-of-control pattern is observed) but observed parts happen to fall within the LSL and the USL, the customer won't see a problem in the parts produced. Still, that situation should be fixed so that process results are random but predictable within the Control Limits – otherwise you might not be capable of processing conforming product all the time.
When we have controls on the process to prevent disruptions and the process is targeted within the LSL and USL provided by the customer, we are capable of producing conforming product all the time. In this situation, we only need to monitor the process, using Process Control Charts which will alarm us of any change in process stability.

Conclusion

Problems can be prevented and money can be saved by applying the Statistical Concepts of Process Control; and by monitoring results using Process Control Charts. If a process can be designed to hold a tight tolerance and stay targeted well within customer specifications, then you can make the occurrence of an error virtually impossible.

Computer applications are available to automate the data collection, calculations and plotting of the resultant statistical values. Some of these computer applications also automatically alarm the operator of out of control situations. While these software solutions are helpful, their usage deteriorates over time if the people using them do not have a sound understanding of the underlying statistical concepts.

When you cannot prevent harmful variation but that variation can be detected, Process Control Charts should be used to detect and correct the process problem before non-conforming parts are produced. While Distribution Charts and Capability Indices (Cp and Cpk) might be used periodically to assess the health of the process, Process Control Charts monitor the stability of a process on an ongoing basis.

By understanding these statistical concepts, efficient action can be taken to achieve lasting process improvement and prevent problems before they actually occur.

Bibliography

Bolton, 1VI. (1987). *The Road to 6 Sigma and Beyond: Statistical Process Control.*

Bothe, D.R. (March 1985). The group control chart, *Quality*, 24(3), pp. 53-54.

Clements, J.A. (September 1989). Process capability calculations for non-normal distributions, *Quality Progress*, 22(9), pp. 95-100.

Chrysler Corporation, Ford Motor Company, and General Motors Corporation, AIAG. (1992). *Statistical Process Control: Reference Manual*, Automotive Industry Action Group, Southfield, MI.

Deming, W .E. (1986). *Out of the Crisis*, Massachusetts Institute of Technology, Cambridge.

Flaig, J.J. (1996-1997). A new approach to process capability analysis, Quality Engineering, 9(2), pp. 205-211.

Hansen, Robert C. (2002). *Overall Equipment Effectiveness*. Industrial Press.

Minitab. (2001). Minitab Release 13, Minitab, Inc., State College, PA.

Mirabella, J. (August 1991). Determining which capability index to use, *Quality Progress*, 24(8), pp. 8-10.

Stamatis, D. H. (2003). *Six sigma and beyond: Statistical process control*. St. Lucie Press. Boca Raton. Fl.

Wheeler, D.J. (1993). *Understanding Variation: The Key to Managing Chaos*, SPC Press.

Zaciewski, R.D. (May 1995). Attribute control charts: opportunities for application, *Quality Digest*, 15(5), pp. 36-111.

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