STRATEGIES FOR IMPROVEMENT OF PROCESS CONTROL

by

Michael V. Petrovich
Senior Staff Associate
Luftig & Warren International

SUMMARY

This paper provides a new perspective on process control that takes the reader beyond the present SPC paradigm, leading to new thinking in control strategies.

INTRODUCTION

During the past 20 years there has been resurgence in the use of statistical tools applied in the field of process control. The work of Walter Shewhart and W. Edwards Deming resurfaced around 1980 as a new emphasis on quality was born. Shewhart and Deming's work came to the attention of managers throughout the world, particularly in the United States. The term SPC, for Statistical Process Control, became fashionable and defined for many the direction of their process control efforts.

Process control became statistical process control with the use of control charts as the primary tool employed. A dichotomous view of control emerged: a process was either "in-control" or "out-of-control." The term "control" was used to describe the through-time stability of a process as demonstrated by a process control chart.

Because of the predominance of the use of statistical process control methods during the 1980s, many people began to associate process control with statistical process control and assumed all control strategies must include the use of on-line control charts. Control plans tended to emphasize the use of control charts. A broader range of control methods was often overlooked.

How "control" is defined affects the strategies employed. This paper reexamines the definition of control and provides an alternative definition. Redefining control changes the "process control" paradigm. With a new way to look at control, new methods of process evaluation and control strategies emerge.

THE CASE OF THE BALL ROLLERS

As an example of typical process control efforts, let's look a fictional story of Ball Rollers.

Four operators are responsible for rolling four-inch spherical balls across the floor. The intent is to strike a vertical mark located on the wall, about 12 feet from the operator rolling position. The customer requirements permit a specification range of one inch on each side of the vertical mark, for a total specification range of two inches. Unfortunately, the operators are not capable of consistently rolling balls which strike the wall within this range. They call in Skippy, a top-notch quality facilitator to assist them. Each of the operators is given introductory SPC training.

First, the operators are formed into a team. Skippy has them begin with a study of their measurement system. Calipers are used to measure deviation from the vertical mark on the wall. Each operator is trained on the use of the calipers. Skippy has the team participate in a measurement system study. Assessments of measurement error due to repeatability and reproducibility are made. The measurements from operator Moe are found to be statistically different from the other operators. Additional training is commenced. The operator differences are then eliminated.

Next, a process potential study is conducted. Skippy has each operator roll 50 balls against the wall and measures the deviation of the impacts from the target mark. Strikes to the left of the mark are recorded as negative values, strikes to the right are recorded as positive values, and striking the mark yields a value of zero.

Skippy analyzes the distributions of scores for each of the operators, and finds that the distributions may be approximated by a normal distribution. A Levene test is conducted to assess homogeneity of variances. This is followed up by a Oneway Analysis of Variance with an appropriate post-hoc procedure. Operator Curly is found to possess lower variation than the other three. Larry is found to have a positive mean deviation. In other words, Larry has a slight bias to the right.

Learning from the slight differences in individual operator techniques, the standard operating procedures are then updated. Further training is conducted and slight improvements are seen in follow-up process potential studies.

A mean and range chart is then put in place, with samples of size five taken each hour. This is tracked over a few weeks. A few out-of-control signals are observed on both the mean and range chart. Changes are sometimes seen during morning startups and in the late afternoon. A ball design change, affecting the surface texture, also produces a change seen on the control chart. Excellent documentation is made of any process changes and is noted on the charts.

Skippy calls a team meeting to review their progress. He invites Mary from the maintenance department to the meeting to gain a cross-functional perspective. Mary is responsible for floor maintenance and ensures the balls are kept in top condition.

Skippy reports to the team the results of a full process capability study that he has conducted. Unfortunately, the process variation exceeds the specification range. The observed natural tolerance is three inches. Curly expresses his disappointment. The team is stumped.

Mary was unable to attend the SPC training, and so she asks what the team what they are trying to do. Larry explains they are trying to meet and then exceed their customer requirements by consistently striking the wall as close to target as possible.

Mary says, “OK, I’ll have it fixed tomorrow!”

The next day, Mary places a 12 foot long, two-inch wide channel iron, with the open channel facing up, on the floor stretching from the operator position to the mark on the wall, and centered on the mark. Mary demonstrates rolling the ball. She places the ball in the channel and gives it a shove. The ball rolls down the channel iron and strikes the mark on the wall dead on. She repeats this demonstration several times. Each time, her deviation from target is not even measurable.

That day, Moe turns in the calipers and gives the control charts back to Skippy. The customers remark on the vast improvement in quality received.

A funny story? Unfortunately, this scenario is frequently encountered in practice. A very limited understanding of possible control methods is the cause.

QUALITY GOALS

It is well understood that customer requirements must be translated into design specifications for products and services. The ability of products and services to meet these requirements is known as “design quality.” Specifications include design optimums or targets, as well as limits which define the minimum or maximum of given characteristics that a company wishes to deliver to its customers. The ability to conform to targets and specifications is known as “conformance quality.”

In the early 1960s, Taguchi popularized a loss function that quantifies the losses due to manufacturing variation. (See Taguchi 1986.) This loss function states that economic losses will increase as product characteristics depart from their design targets. Assuming the validity of the Taguchi loss function, it becomes necessary to not just meet specifications, but to seek minimum variation around the design optimums.

Beyond providing assurance that designs meet the intended needs of customers, the goals of the quality practitioner are to eliminate nonconformance and minimize variation around appropriate targets, at minimum cost. The purpose of process control strategies is the achievement of these goals.

PROCESS VARIATION

Processes vary. To understand process control, an understanding of product and process variation and the causal mechanisms that create that variation is needed. Assume Y is a product or process characteristic. Y is a function of a number of variables, and may be expressed, academically, in the following equation.

$$Y = f\,(X_1, X_2, X_3, X_4, \ldots X_n)$$

A number of observations is appropriate for this equation. Each X_a represents a random variable. The number of variables, *n*, is a large number. The function probably cannot be exactly defined. The variables could be continuous or discrete, vary in terms of how they change through time, vary in terms of their importance or effect on *Y*, combine additively or interactively, or influence *Y* directly or indirectly.

The number of variables affecting a process could extend to infinity, although in practice, the contribution of the variables will follow a Pareto function, with a small number of variables contributing the most to the variation in *Y*.

Continuous variables may vary in magnitude anywhere along the number line. For example, continuous variables affecting a process could be length, height, weight, temperature, pressure, fatigue, or speed.

Discrete variables affecting the process could be dichotomous such as present or absent, for example, with or without coolant. They may also be categorical, such as material type, supplier, operator, or setup method. Discrete variables could also be count variables such as the number of bearings or inserts used.

Process control is concerned with how these variables change over time. Changes in these variables may affect the process in the short term as seen in piece-to-piece variation of a machined part or short-term fluctuations in flow rate. Other changes, such as machine and tool wear, will occur over a longer period of time, from a few hours to months. Ambient temperature or humidity in a plant can change throughout the day. Variables may change gradually as previously described, or abruptly, as in a step change resulting from the presence or absence of a condition.

In almost all industrial processes, the variation observed in *Y* will be bounded. With adequate controls, the bounds will be acceptable. If unacceptable bounds are observed, improvements in control methods are needed.

To achieve the quality goals mentioned previously, process control efforts must counteract these sources of variation to stabilize *Y* to prevent nonconformance and minimize variation.

DEFINING PROCESS CONTROL

Walter Shewhart (1931) wrote, "...a phenomenon will be said to be controlled when, through the use of past experience, we can predict, at least within limits, how the phenomenon may be expected to vary in the future." Shewhart stressed the ability to probabilistically define the chance a phenomenon will fall within given limits.

Traditional SPC has defined a process as either being "in-control" or "out-of-control" based on the observed patterns on a control chart. This is an operational extension of Shewhart's work. This has led to the dichotomous view of process control, as found in statistical process control.

Thinking back to Mary, is Mary's process in a state of statistical control? Does it really matter? Probably not.

In Random House Webster's dictionary (1992), definitions for the word "control" include the following:

1. to exercise restraint or direction over; dominate, regulate, or command;
2. to hold in check; curb: to control one's emotions;
3. to prevent the flourishing or spread of: to control a forest fire;
4. check or restraint: My anger was under control; and
5. prevention of the flourishing or spread of something undesirable: rodent control.

A new definition of process control may be more closely aligned with traditional meanings of control outside the quality field, and more closely match Webster's definitions. Here is one possible definition: Process control is the ability to constrain variation and prevent nonconformance over time.

Control is really a continuous characteristic, rather than a dichotomous one as viewed in traditional SPC. The "level of control" is the degree to which nonconformance is eliminated and variation constrained. The level of control is demonstrated through the evaluation of Process Performance over long periods of time. (See Petrovich 1998.) This view of control is more closely aligned with traditional definitions of capability and performance. Statistical control is not the goal. Achieving conformance and minimal variation through time is the goal.

"Control strategies" are the methods employed to achieve a given level of control. Optimal control strategies deliver a desired level of control at a minimum cost.

With these new definitions, control improvement is seen through the implementation of system changes that improve the level of control. These system changes will be countermeasures against sources of variation.

CONTROL METHODS

A number of methods can be employed to control processes. In the past, when people wanted to learn how to control processes, they took SPC. Numerous other tools and strategies are also available.

Although it is not well understood, Statistical Process Control charts are not really a process CONTROL tool, they are a process RESEARCH tool. A similar on-line technique is an "adjustment chart." (See Box & Luceno 1997, Ishikawa 1990.) An adjustment chart is a paper feedback-and-control system that alerts an operator when to make an adjustment. This is not the purpose of a control chart. Although they look similar, the construction of an adjustment chart is not necessarily the same as a control chart. For example, plus-or-minus three standard errors is probably not appropriate. These concepts are often not taught in traditional SPC, even though a large number of "control chart" applications are for adjustment.

Control charts provide value in process research by identifying when process changes occur at specific points in time. Knowing when process changes occur allows investigators to determine the source of those changes and implement countermeasures against those sources of change. Eliminating the sources of process change generally results in improved stability and reduced variability of the output. These are the typical benefits of traditional SPC approach. However, in the new paradigm, this is not always the most effective means of obtaining the desired end. Some other approaches for consideration follow.

Robust product and process design involves designing products and processes that prevent or minimize the effects of process variation and environmental conditions. Robust design is the ideal method of control. In essence, the robust product and process design assures a level of control of various characteristics, with human intervention or investigation never required. When variability is addressed by design, it never has a chance to cause problems later. Mary's solution to the Ball Rolling problem is an example of robust process design.

One example of robust product design occurred at a company manufacturing a seal that was molded into a plastic housing. A high proportion of nonconforming seals was observed. Two types of nonconformities were observed: air-bubbles and voids. Each of these nonconformities threatened seal integrity. Multiple experiments were conducted, and process conditions were optimized. Unfortunately, no process settings, or process modifications were found that could completely eliminate both conditions. The company was forced to have one or the other nonconformity. They also tried to minimize the level of nonconformities by operating the process within a tight window. The product design department changed the radius in the seal, which completely eliminated these nonconformities. The tight window of operation was no longer needed.

What is often not known is that process changes may also influence the short-term variation of a process. Changes in temperatures or speeds could result in a lower inherent process variability. Developing optimum operational conditions is another example of a robust process design.

Mistake-proofing, called "poka-yoke" in Japan, is a collection of methods and strategies used to prevent or reduce chances of error. Mistake-proofing may involve physical methods to catch and prevent human error or methods to provide attention to errors. One example of a mistake-proofing method is a fixture that allows a part to be inserted into a holder in only the correct way. An electrical outlet that allows a plug to be inserted only one way, is a similar example.

Autonomous control includes a variety of methods which can be used to automatically stop a machine whenever a nonconforming item is produced. Following a stoppage, an alarm is activated, calling the operating personnel to investigate.

Feedback and feed-forward control systems can provide a means of electronically monitoring and adjusting processes on a continuous basis. Many types of these systems are used in industry. The thermostat in your home which controls room temperature or the cruise control in your car which controls speed are simple examples of feedback systems.

Standardizing operations and developing standardized procedures or work instructions reduce process variability. Standard operating procedures describe a state of consensus among operating personnel on documented methods for the operation of a process. The main purpose of standard operating procedures is to minimize variation from operator to operator, achieve minimal variation within operator, and consistently employ optimal operational methods.

Reliability methods include a large set of tools, techniques, and strategies. Process reliability methods contribute to process control through the prevention of failures that may ultimately result in product nonconformance or excess variability.

The previous discussion summarizes several control methods, that in many cases are superior to the paper and pencil, or even computer generated control chart methods characterized by traditional SPC. Remember the goals are the minimization of variability and elimination of nonconformance at minimal cost.

DEVELOPING CONTROL METHODS

The following is a sequence of steps that can be employed to develop control methods. Similarities to Control Plans, Process Failure Mode and Effects Analysis, and Root Cause Analysis will be seen.

1) Construct a high level process flow diagram which identifies the major process operations. These major process operations are referred to as process blocks.

2) For each of the process blocks identify the product output characteristics. These characteristics will be either discrete or continuous in nature. Label each characteristic in terms of a deficiency: either a negative attribute or excess variation is present.

This list is "collectively exhaustive." This means anything that can go wrong in the process should be captured on this list. If this list is complete, no customer complaint or scrapped product should occur for something that is not on this list. If items are found that are not on this list, the list will need updating.

3) Identify which items on the list are end-of-line characteristics. Some characteristics will be in-process characteristics and others will be the characteristics of the final product as seen by the customer.

4) For each characteristic identify its contribution to customer complaints, outgoing nonconforming levels, and scrap. This contribution may be used as a means of prioritization.

5) For each of the output characteristics determine the principle causes in a causal chain. Capture 3-5 levels in depth in the causal variable chain. For a first pass, three levels may be sufficient for most variables, but for an intense focus on particular problems, deeper levels may be required. Example: mold flash can be caused by pellet placement error, which can be caused by a timing error, which can be caused by a worn pulley. There may exist several items under each level for a particular characteristic.

6) Identify the frequency of the problem causes. Initially this may be done on a low/medium/high scale. Check sheets may be created for actual data collection and analysis.

7) Identify detection methods used to detect the problem. This is important for problems that cannot be prevented. Detection methods may detect bad product or detect undesirable machine characteristics or process conditions. Control charts may be considered detection methods. Reaction methods are concerned with what happens when problem detection occurs. In some cases, the detection may be a machine or process failure, with the reaction being to repair/replace on failure. Generally repair/replace on failure is acceptable only for rare or low frequency failures.

8) Identify the prevention methods used to prevent causes. These are the means used to prevent, minimize the occurrence, or reduce the effect of the causes. Prevention method categories may include: product design, process design, tooling design, operating parameters, SOPs, and preventive maintenance.

9) Identify the subjective effectiveness and execution of the current countermeasures using a Low, Medium, High scale. Data collection will yield objective data. Effectiveness refers to how well the prevention or detection methods work. Execution refers to how well the methods are carried out.

10) List potential countermeasures. Capture any ideas for possible improvement.

11) Review items to identify improvement actions. Document who will do what and when.

As the above strategy is conducted, a number of options will surface to control a given process. When prevention is sought, control charts will not be among the highest proportion of the control methods used. However, control charts may prove valuable in the assessment of the control methods selected.

Control methods will do one of the following.

1) Prevent a problem or process change from occurring,
2) Reduce the chance that problem or process change will occur, or
3) Minimize the effect of a problem or process change.

Prevention is always the most desirable, where economically and technologically feasible. In some cases a negative effect cannot be eliminated, but the frequency of the problem may be substantially reduced. In other cases, a problem may still occur, but conditions may be created where little or no harm is created. For example, material flatness could be compensated for by the process equipment. Detection methods also fall into this category. Detecting a change provides the opportunity to react and minimize negative consequences.

CONCLUSION

The definition of process control one uses will affect control strategies employed. This paper has presented the idea that we must look beyond the definitions of statistical control and consider the ultimate purpose of conformance quality, which is the elimination of nonconformance and minimization of variation around appropriate targets, at minimal cost. Multiple control strategies were presented to increase the awareness of techniques beyond the SPC paradigm. Some concluding guidelines were given for the development of appropriate control methods. Rethinking the present control paradigm may yield improvement in the effectiveness of control strategies used today.

REFERENCES

Box, George & Luceno, Alberto 1997. Statistical Control by Monitoring and Feedback Adjustment. New York, N.Y.: John Wiley & Sons, Inc.

Ishikawa, Kaoru 1990. Introduction to Quality Control. Tokyo, Japan: 3A Corporation.

Petrovich, Michael V. 1998. Performance Analysis for Process Improvement. Proceedings of ASQ's 52nd AQC: 697-707.

Random House Webster's Electronic Dictionary and Thesaurus, College Edition, Version 1.0, 1992. Reference Software International.

Taguchi, G. 1986. Introduction to Quality Engineering. Tokyo, Japan: Asian Productivity Organization.

Shewhart, Walter A. 1931. Economic Control of Quality of Manufactured Product. New York, N.Y.: D. Van Nostrand Company, Inc.