Executive Summary

- Statistical process control (SPC) is a management philosophy that relies on straightforward statistical tools to identify and solve process problems.
- By systematically identifying potential problems in process control, managers can proactively make corrections before quality outcomes suffer.
- SPC methods are useful in helping managers to measure whether their processes and products conform to design specifications, and they also help organizations to improve productivity and reduce waste.
- SPC methods are used extensively in manufacturing settings but are also relevant in the service sector.

Introduction

Statistical process control (SPC) is an optimization philosophy centered on using a variety of statistical tools to enable continuous process improvement. Closely linked to the total quality management (TQM) philosophy, SPC helps firms to improve profitability by improving process and product quality. Although initially used in manufacturing, SPC tools and methods work equally well in a service environment.

SPC methods are used extensively by organizations to enable systematic learning. Using methods developed in the 1920s by Walter Shewhart and subsequently enhanced by quality consultants William Edwards Deming and Joseph Juran, organizations are able to use a set of straightforward statistics to find out whether or not their processes conform to expectations. Furthermore, the use of SPC methods can help to identify instances of process variation that may signal a problem in the process. By identifying process variation and potential nonconformance with design expectations early in the production or service environment, managers can proactively make corrections before the process variation negatively impacts quality and customer perceptions.

An Overview

Although SPC is enabled with statistical analysis, the management philosophy that underlies SPC is much broader than a set of statistics. To improve a process systematically, managers must first identify key processes and key variables of interest. Every organization has hundreds, if not thousands, of processes and variables that can affect product and service outcomes, and one challenge is to focus on the processes and variables that are of key concern. SPC tools can be useful in identifying areas that need attention, but managerial insight is needed to use the SPC tools strategically.

Managers can directly influence organizational performance using SPC practices. Their choice of key processes and performance variables creates a feed-forward signaling device to the organization about key performance indicators. This causes attention to be paid to these processes and variables. Feedback is then received through the SPC information, enabling evaluation of the data and an opportunity for corrective actions to be taken. Thus, SPC is not merely a set of statistical tools, but a management philosophy that helps organizations to improve performance through feed-forward and feed-back loops.

SPC Tools

The SPC toolkit contains a number of tools to help managers to evaluate processes. Many of the tools were first identified as essential to continuous quality improvement by Kaoru Ishikawa, a Japanese quality expert. This section describes a number of the tools that are commonly used by organizations to evaluate and improve quality performance. To learn more about how to construct each of these and other SPC tools, refer to the More Info section at the end of this article, where details and links are given.
Flowcharts

Flowcharts depict the progress of work through a series of defined steps. They can be used to communicate a process to employees who are being trained for the work, and management can use them to evaluate process flows, constraints, and gaps. The symbols used in flowcharting are standardized; some of the more commonly used are rectangles (activities and tasks), diamonds (decision points), rectangles with a wavy base (documents), cylinders (files), and arrows (linkages). The flowchart in Figure 1 demonstrates an order entry process.

![Flowchart for an order entry process](image)

Figure 1. Flowchart for an order entry process

Pareto Charts

Pareto charts are graphical demonstrations of occurrences, with the most frequently occurring event to the left and less frequent occurrences to the right. Pareto charts are named after Vilfredo Pareto, an Italian economist who identified that 80% of the wealth is held by a relatively small share of the population. This has been translated into the Pareto principle, which says that about 80% of outcomes are typically created by about 20% of causes. By constructing a Pareto chart, managers can quickly see what problems are most prevalent in their organizations.

The Pareto chart in Figure 2 shows the occurrences of accidents in a manufacturing organization. 58% of the accidents in the plant are falls, followed by broken bones at 21%. The managers can see that these two types of accident are the most prevalent, and they are perhaps related.
Ishikawa Cause-and-Effect or Fishbone Diagrams

These diagrams depict an array of potential causes of quality problems. The problem (the head of the fish) is displayed on the right, and the bones of the fish—representing the potential causes of the problem—are drawn to the left. Potential causes are often categorized as materials, equipment, people, environment, and management. Other categories may be included as appropriate. Useful in brainstorming the causes of problems (including potential problems) from multiple perspectives, these diagrams should include all possible reasons for a problem. When completed, further analysis is done to identify the root cause. Figure 3 is an Ishikawa diagram in an airline setting.

Run Charts

Run charts are graphical plots of a variable over time. These charts can be made for a single variable, but they are useful in detecting trends or relationships between variables when two are included on the same run chart.

In the example in Figure 4, the average wait time for a telephone customer service is plotted along with the number of lost calls—customers who hang up before a customer service person takes the call. As the run chart demonstrates, there is a relationship between average wait time and lost calls: as the wait time...
increases, customers are more likely to hang up. As the wait time decreases (samples 6 through 8), there are fewer lost calls. The widening gap between the lines shows that the problem of a customer hanging up decreases as the wait time diminishes.

![Run chart for telephone customer service](image)

**Figure 4.** Run chart for telephone customer service

**Control Charts**

Control charts combine expanded run chart information with statistical control data to help identify process variation over a period of time that is not likely due to random chance. Time can be defined as a production run, a series of batches, a day's activities, or any relevant time period that captures the process being evaluated. Useful in manufacturing, administrative, and service functions, control charts provide rapid feedback on key variables of interest. Control variables of interest might include those listed in Table 1.

**Table 1. Examples of control variables in different business sectors**

<table>
<thead>
<tr>
<th>Manufacturing environment</th>
<th>Service environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liters of liquid in a container</td>
<td>Wait time in a bank line Delivery time for packages</td>
</tr>
<tr>
<td>Thickness of a coating</td>
<td>Temperature of a restaurant entrée Time lag between a customer request and a service response</td>
</tr>
<tr>
<td>Tension in a coil</td>
<td>Infection rates in a medical setting Loan approval time</td>
</tr>
<tr>
<td>Direct labor time per unit</td>
<td>Loan approval time</td>
</tr>
<tr>
<td>Changeover time between batches</td>
<td></td>
</tr>
<tr>
<td>Defect rates</td>
<td></td>
</tr>
<tr>
<td>Overhead costs</td>
<td></td>
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</tbody>
</table>

Control charts are used to show when a process is in, or out of, statistical control. Statistical control does not imply zero variation—some degree of variation is normal and it is unrealistic to expect zero variation. However, the control chart is able to demonstrate data patterns that indicate that a process is out of control, and it is useful as a tool for making continuous improvement by reducing variability. The most commonly employed control charts are the mean chart and the range chart, often referred to as X-bar and R-charts.

**The Mean Chart**

The mean chart (X-bar chart) shows the variation in a process by plotting the actual mean values of a set of sample data. Each set of sample data consists of multiple observations of the process that’s being evaluated. These data are plotted against the background of the mean of all the samples taken and the upper and lower control limits for the data. These limiting bounds are each three-sigma limits, meaning that almost all (99.73%) of the variation in the process is expected to fall within a six-sigma limit. Sigma, represented by the greek symbol s, is the standard deviation of a distribution.

Signals from a mean chart that a process is out of control include the following:

- Data points that fall above the upper control limit or below the lower control limit.
- Eight or more consecutive data points that fall above or below the mean line.
- Two out of three consecutive points in the lower or upper third of the chart.
- Six or more consecutive data points that trend up or down within the chart, as this indicates a trend or drift of the variation in the process.
• Fourteen or more points that alternate in an up or down direction, indicating that there may be too much variation in the process.

Figure 5 is an example of a mean control chart, constructed for a month’s sample data. The chart shows that samples 2, 9, and 16 are all above the upper control limit, indicating a problem. Interestingly, each of these samples was taken on the same day of the week (each is seven days apart). Another problem highlighted by the chart is the set of daily sample means recorded after day 20. Starting on that day, a series of sample means falls below the mean for the set of data. Although these data points are all within the control limits, they indicate a potential problem in the process because more than eight consecutive points fall below the mean.

Figure 5. Mean control chart for a production process (y axis represents mean values)

The Range Chart

The range chart (R-chart) is similar to the mean chart in having upper and lower (three-sigma) control limits, but the data plotted for each sample are now the range between the largest and the smallest value in the sample. By plotting the range of values, variation within each sample is more apparent.

Signals from a range chart indicating that a process is out of control are similar to those for the mean chart and include the following:

• Data points that fall above the upper control limit or below the lower control limit.
• Eight or more data points in succession that fall above or below the mean.
• Six or more consecutive data points that trend up or down, as this indicates a trend or drift of variation in the process.
• Fourteen or more points that alternate in up and down directions, indicating that there may be too much variation in the process.

The range chart in Figure 6, which has been constructed for the same set of data as the mean chart, demonstrates that there is wide variation in the sample data. As in the mean chart, the three data points that fall outside of the upper control limit indicate a process that is not in control. The strong variability in consecutive data points also indicates potential problem in process control. As a general rule, although data points may fall within the control limits, variations from the norm can be pointers to performance problems, product returns, possible lawsuits, loss of customer loyalty, and loss of reputation. All of these risks can be costly for an organization.
Process Capability Analysis

Process capability analysis is a technique that is used to determine the ability of a process to meet product or service specifications. It is a useful tool to evaluate variation within a process and whether improvements can be made to process control. Although a process may be within control limits as determined by control chart data, capability analysis takes things a step further by evaluating the amount of variation in process outcomes (the product or service) compared to the capability of the process.

Capability analysis is based on measures of process capability (Cp) and process control (Cpk). These measures are based on the means and standard deviations of a process variable and are indicators of the aptitude, or capability, of the process to perform. Similarly, measures of actual process performance (Pp) and process control (Ppk) demonstrate how a process is actually performing. A comparison of the actual process control data (Ppk) with the process capability data (Cpk) helps managers to numerically evaluate how much variation there is in an in-control (within control limits) process, and whether modifications of the process will reduce variation. Refer to the isixsigma website for details of process capability calculations and uses.

Taguchi Loss Function

The Taguchi loss function is based on the assumption that all variation has a cost, even when the variation does not violate the data patterns defined by control charts. This concept is most useful where deviations from expectation are expected to be costly. Taguchi posited that all deviations from target values ultimately result in customer dissatisfaction. The Taguchi loss function enables organizations to calculate the financial consequence of process variability, making it useful in reaching design decisions.

Case Study

Graco Children’s Products

Graco Children’s Products, a US manufacturer of children’s equipment such as high chairs, baby swings, and car seats, set itself the goal of improving product quality in the design phase of operations. By identifying problems early in the design process, the firm expected to reap benefits in manufacturing performance, product quality, and customer satisfaction.

Using SPC tools, Graco managers were able to analyze multiple design options efficiently. For example, in the plastics injection molding area there were more than 30 variables of interest to evaluate. One analysis was done for a plastic grip handle on a child carrier seat. The handle had a problem with warping, which
caused too much curvature in the part, making later assembly of the carrier seat difficult. Eight machine variables were identified as potential causes of the problem. By using SPC analysis data, Graco determined that three variables—hold time, cure time, and material temperature—significantly impacted warping. By modifying these processes, the organization was able to correct the problem and reduce associated costs. The SPC analysis also showed that cooling temperatures did not significantly impact quality outcomes, which led to a decision not to invest in expensive cooling equipment. By using SPC tools to focus attention on process variables that could be controlled in the design phase of the product, Graco managers improved process and product quality, which resulted in savings for the organization.

Conclusion

Statistical process control benefits organizations by providing a systematic method for the monitoring and evaluation of process variation. Too often, managers do not notice changes and problems in processes until either the output is inspected or customers make complaints.

By proactively identifying potential process problems and using SPC tools to evaluate process outcomes and improve process control, organizations are able to direct their resources more efficiently and can focus management time and attention on the most pressing problems.

Making It Happen

SPC tools can be used in the following stages of process evaluation and improvement:

Identify the Problem

- Flowcharts identify and communicate information about the flow of a process, including constraints and gaps.
- Pareto analysis identifies the issues that are causing most of the problems.

Identify the Reasons for the Problem

- Use Ishikawa cause-and-effect diagrams to brainstorm the causes of a problem from a multidimensional perspective.

Analyze the Data

- Run charts show the variability in data over time and the potential relationships between multiple variables.
- Control charts identify process variation using a set of statistical tools, enabling the identification of out-of-control variation.
- Process capability analysis is used to show the amount of variation in an in-control process, and can be useful in improving a process.
- The Taguchi loss function assigns an economic value to variation, helping to make trade-off decisions in process and product design.

More Info

Books:

Websites:

- American Society for Quality (ASQ), a professional association dedicated to learning about quality and the improvement of quality in organizations. ASQ administers the prestigious Malcolm Baldrige National Quality Award. Membership is available to individuals or organizations: www.asq.org
- iSixSigma, an online forum and extensive statistical process control resources: www.isixsigma.com
- Management and Accounting Web (MAAW), dedicated to education, research, and the practice of management and accounting disciplines. Contains links to dozens of management and finance resources: www.maaaw.info
- Managers-Net, an archive of articles and examples of management topics. Click on “Contents” and then on “Index to the complete Technical Archive” for an alphabetical list of topics: managers-net.com
- Quality America, Inc., has resources for implementing SPC tools, including articles, an encyclopedia, technical references, and interpretation guides for SPC analysis: qualityamerica.com

Notes

1 Excerpted from Anon. “Graco uses SPC software to improve quality of products (statistical process control at Graco’s Children’s Products).” IIE Solutions (January 1, 1997).

See Also

Best Practice

- Profitability Analysis Using Activity-Based Costing
- Reducing Costs and Improving Efficiency by Outsourcing and Selecting Suppliers
- Reducing Costs through Change Management
- Reducing Costs through Production and Supply Chain Management
- Turning Around Financial Performance

Finance Library

- The Six Sigma Way: How GE, Motorola and Other Top Companies are Honing Their Performance

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