Part 2: How and Why SPC Works

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P art 1 in this series introduced Statistical Process Control (SPC). In Part 2, our goal is to provide information to increase managers' understanding of and confidence in SPC as a profit-making tool. It is unreasonable to expect managers to commit to and support SPC training and implementation if they do not understand what SPC is and how and why it works. Specifically, this publication describes the importance of understanding and quantifying process variation, and how that makes SPC work.

Part 3 in this series describes how to use check sheets and Pareto analysis to decide where to begin quality improvement efforts. Later publications in the series present additional tools such as flowcharts, cause-and-effect diagrams, designed experiments, control charts, and process capability analysis.

Beginning in Part 3, SPC tools and techniques are presented in the context of an example case study that follows a fictional wood products company's use of SPC to address an important quality problem.

For a glossary of common terms used in SPC, see Part 1.

Variation—it's everywhere

Variation is a fact of life. It is everywhere, and it is unavoidable. Even a brand new, state-of-the-art machine cannot hold perfectly to the target setting; there always is some fluctuation around the target. Attaining consistent product quality requires understanding, monitoring, and controlling process variability. Attaining optimal product quality requires a never-ending commitment to reducing variation.

Walter Shewhart, the man whose work laid the foundations for SPC, recognized that variability has two broad causes: **common causes** (also called chance, random, inherent, or unknown cause) and **special causes** (also called assignable cause).

Common causes are inherent in the process and can be thought of as the "natural rhythm of the process." Common causes result in a stable, repeating pattern of variation. Real quality improvement requires a continual focus on reducing common-cause variability.

It's difficult to give examples of common causes because what is typical for one process may not be typical for another. However, common causes might include things like normal tool wear; differences in wood density or moisture content; and normal, gradual changes in ambient temperature and humidity throughout the day.

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Just because a factor is a common cause does not mean it is an acceptable or unavoidable cause. For example, a company may find that moisture content of their raw materials ranges from 2% to 16%. If the product is consistently within this range, the variability will be consistent as well. But this doesn't mean that the company shouldn't do something to reduce the variability. The main point is that variability will be consistent, regardless of whether it is determined to be acceptable or too high.

Special causes are a signal that something has changed in the process. They disrupt the stable, repeating pattern of variation. Special causes result in inconsistent and unpredictable process performance and must be identified and removed before taking other steps to improve quality.

Examples of special causes might include changes in operating procedures (e.g., equipment operators on different shifts using differing procedures); damage to a cutting tool; a sudden, abrupt change in ambient temperature or humidity; and a faulty measuring device.

Why is it important to distinguish between these two types of variability? Because the remedies are completely different. Understanding the difference helps manufacturers select appropriate quality improvement efforts and thereby avoid wasted effort and expense.

SPC in a nutshell

Montgomery (2013) defines SPC as "...a powerful collection of problem-solving tools useful in achieving process stability and improving capability through the reduction of variability." Control charts and process capability analysis are the two primary tools of SPC. Other tools such as histograms, flowcharts, cause-and-effect diagrams, check sheets, and Pareto diagrams also are useful in quality and process improvement.

In the following pages, we describe several concepts that show how and why SPC works:

- We show how histograms help us understand the **distribution of the process output** and estimate the limits within which the process operates under "normal" conditions.

- We use **control charts** to determine whether the process is stable and for ongoing **process monitoring and control**.

- We use **process capability analysis** to compare process performance to specifications.

- We discuss **continuous process improvement**.

Each of these concepts is covered in more detail in later publications in this series.

Distribution of the process output

In SPC, distribution of the process output refers to collected data that describe the process—such as data on widths of pieces coming out of a woodworking machine—and the way those data are distributed when plotted on a chart or graph.

Describing the distribution of process output is like asking, "How's your aim?" Are you accurate (on target)? Is your aim precise, or are results distributed all over the pace? We can illustrate these ideas with a marksmanship example (Figure 1). In manufacturing, the questions are:

- Is the process on or off target? If the latter, by how much is it off target?
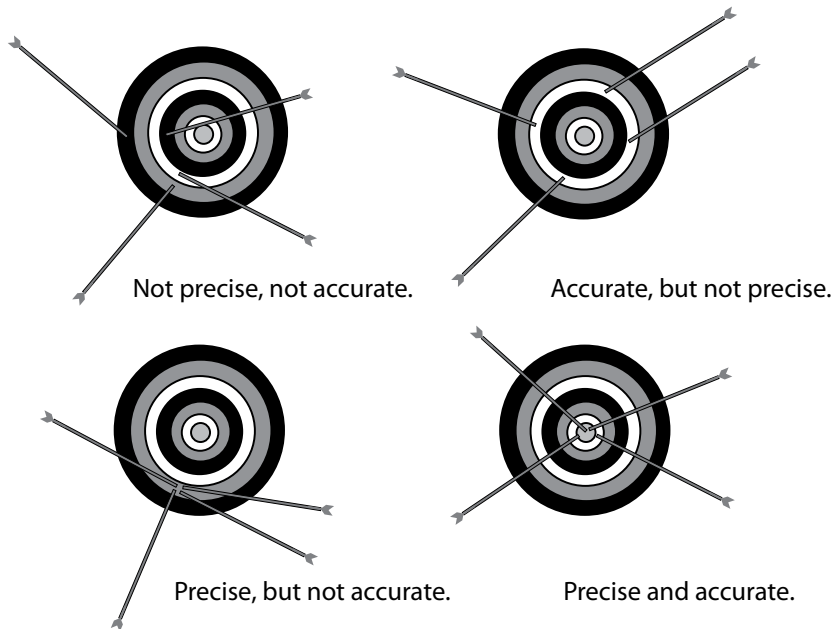- Where is the process centered? How much does the process fluctuate about the center?

Not precise, not accurate. Accurate, but not precise.

Precise, but not accurate. Precise and accurate.

Figure 1. Precision and accuracy.

Histograms are visual tools to examine distributions. A histogram is a bar graph that shows how frequently data fall within specific ranges of values. Histograms make it relatively simple to estimate where the process is centered and how much fluctuation there is about the center.

Table 1 shows measurements of widths (in inches) of 125 parts produced by a woodworking machine. Twenty-five samples of five items were collected and measured every 30 minutes for a period of 12 hours.

We must have data to know how a process is performing. However, it is difficult to derive much information from data as presented in Table 1. These data would be more useful if they were grouped, organized, and displayed graphically. A histogram does just that.

Creating a histogram involves developing and plotting a frequency distribution. A frequency distribution is a tally of measurements within specific ranges of values. For example, in Table 1 there are 15 measurements in the range of 2.5395 to 2.5404 inches, 21 measurements between 2.5405 and 2.5414, and so on. The frequency distribution is shown in Table 2, and the histogram is shown in Figure 2.

Table 1. Sample data

Sample	Individual measurements				
1	2.541	2.540	2.542	2.541	2.543
2	2.543	2.541	2.541	2.543	2.543
3	2.541	2.541	2.542	2.544	2.542
4	2.541	2.537	2.538	2.540	2.541
5	2.541	2.543	2.542	2.542	2.541
6	2.539	2.541	2.544	2.542	2.543
7	2.542	2.544	2.543	2.543	2.543
8	2.540	2.542	2.540	2.543	2.544
9	2.541	2.541	2.542	2.543	2.540
10	2.543	2.540	2.540	2.543	2.542
11	2.543	2.544	2.540	2.541	2.541
12	2.543	2.543	2.543	2.542	2.542
13	2.544	2.540	2.543	2.543	2.542
14	2.541	2.541	2.541	2.542	2.542
15	2.543	2.542	2.539	2.545	2.543
16	2.542	2.542	2.545	2.542	2.542
17	2.544	2.545	2.539	2.542	2.542
18	2.543	2.543	2.546	2.542	2.545
19	2.540	2.542	2.540	2.541	2.542
20	2.542	2.545	2.540	2.543	2.542
21	2.543	2.543	2.542	2.542	2.542
22	2.540	2.543	2.544	2.543	2.543
23	2.540	2.542	2.544	2.543	2.540
24	2.539	2.542	2.542	2.542	2.542
25	2.543	2.541	2.544	2.543	2.541

Table 2. Frequency distribution for data in Table 1

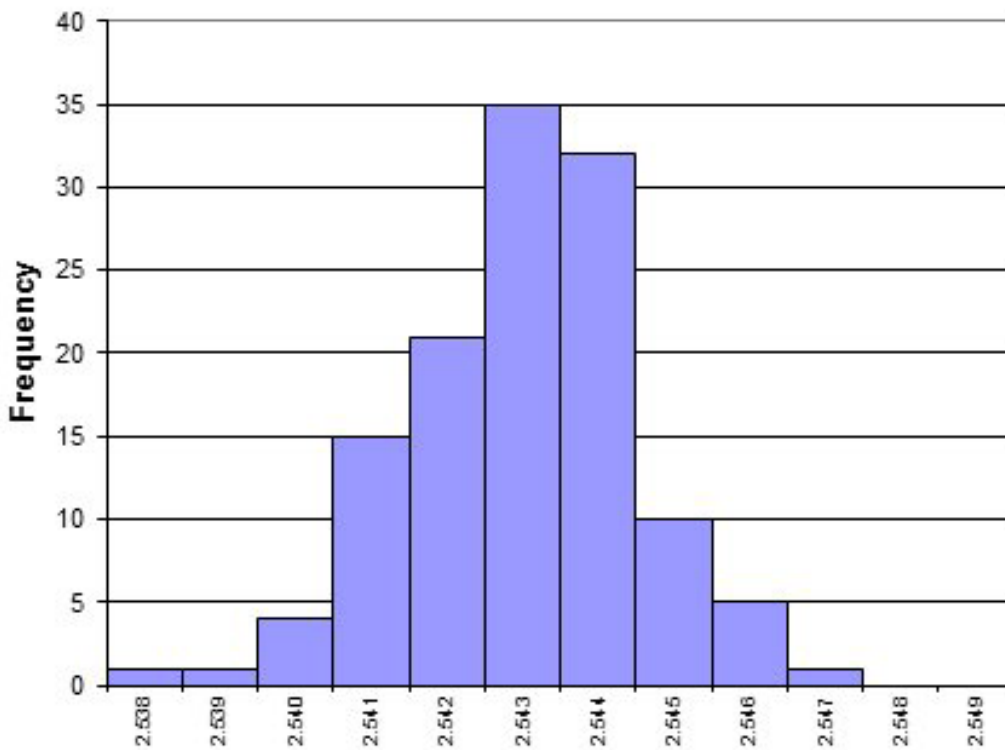| Range boundaries	Midpoint	Frequency
2.5365–2.5374	2.537	1
2.5375–2.5384	2.538	1
2.5385–2.5394	2.539	4
2.5395–2.5404	2.540	15
2.5405–2.5414	2.541	21
2.5415–2.5424	2.542	35
2.5425–2.5434	2.543	32
2.5435–2.5444	2.544	10
2.5455–5.5454	2.545	5
2.5455–2.5464	2.546	1

Figure 2. Histogram for data in Table 2.

What does this histogram tell us? First, we can easily estimate where the process is **centered** and the amount of **spread** about the center. The center of this distribution is approximately 2.543 inches. The majority of the measurements are between 2.541 and 2.544 inches.

Knowing the specifications allows us to get more information from the histogram. For example, if we know the specifications are 2.542 inches ± 0.008 inch, we can say the process is performing quite well. But if the specifications are 2.544 inches ± 0.002 inch, we can see from the histogram that a substantial amount of material is being produced below the lower specification and thus is defective.

A histogram is a snapshot of the process. It is useful for examining the status (centering and spread) of the process at the time data were collected and for examining the general shape (number of peaks and symmetry) of the distribution.

A single histogram, however, does not allow us to evaluate process performance through time or determine whether the process was stable (consistent and predictable) when data were collected. Also, histograms require a lot of data (mathematicians suggest 50 to 100 data points per histogram). It takes time to collect this much data, and data collection can become overwhelming if it has to be done manually every day.

For practical, day-to-day process control, we need a system in which relatively small samples allow us to decide whether the process is okay and should be left alone, or whether problems are beginning to arise and we should take action. SPC provides such a system through the use of control charts.

A histogram

is a useful snapshot of the process, but it doesn't let us evaluate the process over time or determine whether the process is stable.

Control charts

Control charts are the primary SPC tool. They are used to monitor and control processes. There are charts for **variables data** (measurement data such as length, width, thickness, and moisture content) and charts for **attributes data** (count data such as number of defective units in a sample or number of errors on an invoice). Variables and attributes control charts are described in Parts 7 and 8, respectively.

In general, control charts are used as follows:

- Take samples from the process (collect data).
- Calculate statistics (e.g., average and range), and plot on charts.
- Interpret the results according to process limits. In SPC, these are known as control limits.

Control limits are the limits within which the process operates under normal conditions. They tell us how far we can expect sample values to stray from the average given the inherent (common cause) variability of the process. Data points beyond the control limits or other unusual patterns indicate special causes of variability.

See Parts 7 and 8 for details on how to calculate control limits. For now, simply know that the statistical probability of obtaining a value (a result) beyond the control limits is very small unless the process changes significantly. Therefore, control limits minimize false alarms and prevent us from searching for problems when none exist. Searching for problems is often expensive because it involves time, effort, and often equipment downtime. Minimizing false alarms and the associated expenses is a key benefit of SPC and is the primary reason the first book on SPC was titled *Economic Control of Quality of Manufactured Product* (Shewhart, 1931).

Figure 3 shows a control chart for the data in Table 1. The chart shows the average width (the red squares) for each of the 25 samples, the overall average (the middle line), and the upper and lower control limits.

What can we learn from the chart in Figure 3? Our primary interest is determining whether the process is stable and predictable with respect to its centering (the average) and variability. In SPC, we ask, "Is the process in statistical control?" Or more simply, "Is it in control?"

In common usage, the phrase "in control" generally describes a desirable situation, and it has the same meaning in SPC. On the other hand, the phrase "out of control" brings forth images of mayhem—machines on fire or nuts and bolts flying through the air. An out-of-control process in SPC is not quite so dramatic.
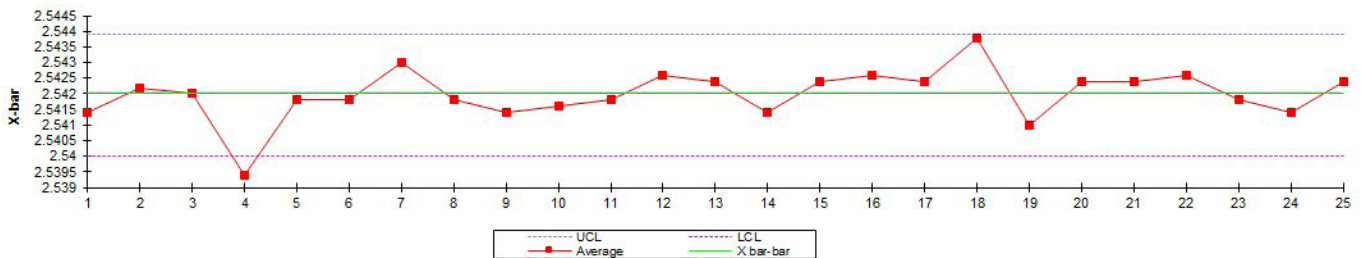

Figure 3. Example control chart for wood moisture content (data from Table 1).

A process that is **in control** is stable and predictable. A process that is **out of control** is not predictable and under the influence of special causes of variability. Statistically rare occurrences are signals that a process is out of control. When a process is out of control, we should investigate to find and eliminate the special causes to bring the process back in control and thereby improve product quality and consistency.

What can we learn about the process from Figure 3? Remember that points outside the control limits or unusual patterns indicate the process is out of control. Sample 4 indicates the process is out of control, and Sample 18 is questionable because it is on the upper control limit.

If these data were collected and plotted as the process was operating, we would have looked for a source of trouble immediately after we plotted the average of Sample 4. Because these data are historical, we are now using the data only to determine if the process is in control.

Figure 3 indicates the process was out of control when the data were collected. What's next?

- Now, we identify the problems that led to the low value in Sample 4 and the high value in Sample 18.

- After identifying and correcting these problems, we continue to remove out-of-control samples from the data and recalculate the centerline and control limits.

- Then we redraw the chart and examine it to see whether the process is in control now that out-of-control points have been removed.

- We continue this process until all data points are in control, and then use the resulting limits as trial limits for future production.

This process is described in more detail in Part 7. If the initial control chart showed that the process was in control, the initial control limits would serve as trial control limits for future production.

Process monitoring and control

For day-to-day process monitoring, we will collect samples and plot the results on a control chart using the trial centerline and control limits. Data points beyond the limits and unusual patterns will continue to signal that the process has changed and we must search for special causes of variability and take corrective action.

In reality, manufacturing is a fast-paced process and it is common for long periods to elapse between sample collection and control chart analysis. If an out-of-control process is identified, it is likely that defective product was produced between the time the problem occurred and when it was detected. The longer this period, the more defective product is produced.

For control charts to be effective, quality control teams should analyze, plot, and interpret data and take corrective action as soon as possible. Ideally, control charts should be constructed and interpreted in real time by workers involved in the process, not later by managers in the office.

Finally, because control limits change along with process variability, they should be revised periodically and when they provide evidence that process variability has been reduced.

Statistically rare occurrences

are signals that a process is out of control.

Once we know what the process can do and we are confident it is stable (in control), then, and only then, can we shift our attention to considering what we want the process to do. Next, we need to consider how the process compares to the specifications. This is the purpose of process capability analysis.

Process capability analysis

Many people new to SPC are surprised to discover that there's no direct connection between an in-control process and meeting specifications. Isn't a stable process a guarantee that we will meet customer expectations? Unfortunately, the answer is no. An in-control process can produce defective product if the process is off-target or if the common-cause variability is too high.

Process capability analysis compares the variability of a process to specifications. The results are reported as ratios. For example, if the specifications for the process shown in Figure 3 are 2.54 inches ± 0.005 inches, our specifications are 2.535 to 2.545 and the total specification width is 0.010 inches. If our process is operating with a total spread of 0.012 inches, our process capability index (C_p) would be:

$$C_p = 0.010 \div 0.012 = 0.83$$

The higher the number, the better. Values below 1.0, as in this example, indicate that we are currently unable to meet the specifications and are producing defective products.

For this example, we have simply assumed the process is on target. C_p has little meaning if the process is significantly off target. There is another process capability index known as C_{pk} that also accounts for centering.

This is a simple overview. There is some complexity involved in estimating the total spread of a process. For example, where did that 0.012 value come from? Part 9 in this series explains in detail how to calculate total spread of the process as well as how to calculate and use process capability indices.

In short, process capability analysis allows us to develop simple ratios from which we can compare the performance of our process with specifications. Always keep in mind that we must constantly strive to reduce product variation in our efforts to improve quality. Continuous process improvement is focused on keeping processes on target and reducing process variability.

Continuous process improvement

Real quality improvement requires a continual focus on reducing common-cause variability. This is possible only after the process has been brought into control. Continuous process improvement (which leads to quality improvement) requires a systematic and structured approach. Companywide quality improvement requires:

- Determining customer needs
- Setting quality goals
- Developing an improvement strategy
- Providing necessary training and resources
- Establishing organizational infrastructure (e.g., quality teams)
- Reviewing progress
- Revising reward systems

For these reasons, quality improvement requires the commitment and involvement of upper management. Years of experience have shown that "delegating quality" is ineffective. Juran (1989) provides a thorough treatment of management's role in quality planning, control, and improvement.

Summary

The bottom line: SPC helps manufacturers increase competitiveness and profitability.

In this publication, we walked through the basics of how and why SPC works to help build understanding of and confidence in SPC as a profit-making tool. We hope this publication has convinced you that implementing SPC will make your company money, and we hope you will commit to training your personnel to use SPC. To begin the training process, see Part 3 in this series, *Pareto Analysis and Check Sheets*.

For more information

Brown, T.D. 2000. *Lumber Size Control-Part 1: Measurement Methods*. EM 8730. Corvallis, OR: Oregon State University Extension Service.

Brown, T.D. 2000. *Lumber Size Control-Part 2: Size Analysis Considerations*. EM 8731. Corvallis, OR: Oregon State University Extension Service.

Brown, T.D. 1979. Determining lumber target sizes and monitoring sawing accuracy. *Forest Products Journal*, 29(4):48–54.

Brown, T.D. 1982. *Quality Control in Lumber Manufacturing*. San Francisco, CA: Miller Freeman.

Cassens, D.L., J.L. Bankston, and J.S. Friday. 1994. Statistical process control of hardwood lumber target sizes: Is it time? *Forest Products Journal*, 44(1):48–50.

Cook, D.F. 1992. Statistical process control for continuous forest products manufacturing operations. *Forest Products Journal*, 42(7/8):47–53.

Deming, W.E. 1982. *Out of the Crisis*. Cambridge, MA: Massachusetts Institute of Technology Center for Advanced Engineering Study.

Deming, W.E. 1993. *The New Economics: For Industry, Government, Education*. Cambridge, MA: Massachusetts Institute of Technology Center for Advanced Engineering Study.

Duncan, A.J. 1986. *Quality Control and Industrial Statistics*, 5th ed. Homewood, IL: Irwin.

Grant, E.L., and R.S. Leavenworth. 1988. *Statistical Quality Control*, 6th ed. New York, NY: McGraw Hill.

Juran, J.M. 1989. *Juran on Leadership for Quality: An Executive Handbook*. New York, NY: Macmillan, The Free Press.

Leicester, R.H. 1995. Statistical control for stress graded lumber. In: *Proceedings No. 7307, Statistical Process Control Technologies: State of the Art for the Forest Products Industry*. Madison, WI: Forest Products Society.

Montgomery, D.C. 2013. *An Introduction to Statistical Quality Control*, 7th ed. New York, NY: John Wiley & Sons.

Patterson, D.W., and R.B. Anderson. 1996. Use of statistical process control in the furniture and cabinet industries. *Forest Products Journal*, 46(1):36–38.

Peck, J., and R. Myers. 1995. SPC in action: Reduction in variation keys customer satisfaction. In: *Proceedings No. 7307, Statistical Process Control Technologies: State of the Art for the Forest Products Industry*. Madison, WI: Forest Products Society.

Shewhart, W.A. 1931. *Economic Control of Quality of Manufactured Product*. Milwaukee, WI: Quality Press.

Walton, M. 1986. *The Deming Management Method*. New York, NY: Putnam.

Warren, W.G. 1973. *How to Calculate Target Thickness for Green Lumber*. Information Report VP-X-112. Vancouver, British Columbia: Department of the Environment, Canadian Forestry Service, Western Forest Products Laboratory.

Western Electric Company Inc. 1956. *Statistical Quality Control Handbook*. Milwaukee, WI: Quality Press.

Young, T.M., and P.M. Winistorfer. 1999. Statistical process control and the forest products industry. *Forest Products Journal*, 49(3):10–17.

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