Oregon State University Extension Service

Statistical Process Control: Part 3, Pareto Analysis and Check Sheets

Scott Leavengood and James E. Reeb

Summary

Describes how to use Pareto analysis to identify and prioritize quality control problems in a manufacturing environment. Includes how to identify nonconformities, their frequency, and their impacts.

Part of the Performance Excellence in the Wood Products Industry publication series.

Part 1 in this series introduced the reader to Statistical Process Control, and Part 2 provided an overview of how and why SPC works. Part 3 begins the step-by-step process of building the practical skills necessary for hands-on implementation of SPC. This report discusses Pareto analysis, a tool we can use to help decide how and where to begin using SPC. We also discuss check sheets, which are data collection tools that may be used in Pareto analysis.

Part 4 discusses flowcharts. Other publications in the series discuss case histories of wood products firms using SPC, providing real-world evidence of the benefits of SPC and examining pitfalls and successful approaches.

Where to begin an SPC program?

Most manufacturing processes are sufficiently complex that at first glance it may seem impossible to decide where to begin using SPC techniques. SPC programs that attempt to monitor too many process variables are quickly overwhelmed by the time and labor required to collect, analyze, plot and interpret the data. In such cases, SPC seems too time consuming and expensive to be of any benefit.

The life expectancy of SPC in a company depends heavily on the results of the first few projects undertaken. With this kind of pressure, how do you decide where to begin?

Obviously, we cannot measure everything. We must focus initially on the most important quality problems to get the “biggest bang for the buck.” This is especially true in the early stages of an SPC program when personnel are likely to be skeptical of SPC and hesitant to make the necessary changes.

Prioritizing quality problems for the company is a good first step. Then, determine which projects will have the highest return on investment and therefore should be the initial focus of quality improvement programs. Pareto analysis enables us to do all this.

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Pareto analysis

Pareto (pronounced "pah-RAY-toe") analysis uses the Pareto principle, also called the 80:20 rule, to analyze and display data. Vilfredo Pareto was a 19th-century Italian economist who studied the distribution of income in Italy. He found that about 20% of the population controlled about 80% of the wealth.

Quality expert J.M. Juran applied the principle to quality control and found that 80% of problems stem from 20% of the possible causes. The numbers 80 and 20 are not meant to be absolutes. The main point, as Juran stated, is that we should focus on the "vital few" problems (those in the 20% category) rather than on the "trivial many" to make the most significant improvements in product quality.

Pareto charts are the graphical tool used in Pareto analysis. A Pareto chart is a bar chart that displays the relative importance of problems in a format that is very easy to interpret. The most important problem (for example, the one highest in cost, frequency, or some other measurement) is represented by the tallest bar, the next most important problem is represented by the next tallest bar, and so on. A check sheet is a useful tool for collecting data for Pareto charts.

Nonconforming, not defective

A nonconforming product is one that fails to meet one or more specifications, and a nonconformity is a specific type of failure. A nonconforming product may be termed defective if it contains one or more defects that render it unfit or unsafe for use. Confusion of these terms has resulted in misunderstandings in product liability lawsuits. As a result, many companies have adjusted their internal terminology and now use the terms "nonconforming" and "nonconformity" in favor of "defect" and "defective."

Check sheets

Check sheets are relatively simple forms used to collect data. They include a list of nonconformities and a tally of nonconformities. Check sheets should also include the name of the project for which data is being collected, the shift when the items were produced, the names of persons collecting the data, dates of data collection and of production (if known), and the location of data collection (e.g., in-house or at a customer's).

Check sheets aren't mandatory to construct Pareto charts. However, because check sheets require you to standardize your list and definitions of nonconformities, they provide several benefits.

First, people often do not agree on the major categories of nonconformities. Therefore, developing a list of common nonconformities (i.e., quality problems) is not as easy as it sounds. A good way to develop this list is to brainstorm with production personnel, management, QC personnel, and, most important, your customers.

Second, people often do not agree on precisely what constitutes "nonconforming." In other words, how bad does it have to be to get thrown in the scrap or rework pile?

Last, different people often will put a given item in different categories. For example, one person may call an item with torn grain a machining defect, another might call it fuzzy grain, and another may call it reaction wood. Without standard terminology and definitions, it becomes very difficult to conduct a Pareto analysis.

To get an idea of the effect on your company of lack of standardized terminology and definitions for nonconformities, try a simple experiment. Select several items at random and ask different people to examine them and record nonconformities item by item.

One experiment at a secondary wood products manufacturer involved five quality inspectors. The inspectors did not agree on the number of items that should be rejected due to quality problems (the scrap/rework rate varied from 34% to 49%) nor did they agree on the reasons for rejecting the products. Had we looked only at data collected by inspectors 1, 2 and 3, we would have concluded that torn grain and blue stain were the biggest quality problems. Had we looked only at data collected by inspectors 4 and 5, we would have concluded that dents (handling damage) and reaction wood were the biggest quality problems. Do not underestimate the importance of developing a standard list of nonconformities and precise definitions for each.

The following example demonstrates how to construct and interpret check sheets and Pareto charts.

Example

The Quality Improvement Team at a manufacturer of wood components visited a customer and examined items in the scrap and rework bins. After looking at each item and talking with the customer, the team agreed on categories of nonconformities and developed precise definitions for each category. They created a check sheet, then inspected each item and tallied the number of occurrences (frequency) for each cause of nonconformity. Figure 1 presents the results.

Figure 1: Quality improvement project — a sample check sheet.

Project: Quality improvement project. Name: QIT. Location: Customer A. Dates: January 2002. Shift: All.		
Reason		**Frequency**
Size out of specification	IIII/ IIII	194
Loose knots	IIII/ IIII/ IIII/ III	18
Raised grain	IIII	4
Dents	III	3
Stain/rot	IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ I	31
Fuzzy grain	IIII/ IIII/	105
Splits	IIII/ IIII/ I	11
Machine tear-out	IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ I	61
Burn marks	IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII	44
Oil/grease marks	II	2
Total		**473**

Nonconformities were sorted from highest to lowest frequency, and the relative frequency for each was determined (Figure 2). For example, "size out-of-specification" was 194 out of 473 nonconformities, and so the relative frequency for size-out-of specification was:

194/473 = 0.41 = 41%

An optional final step is to calculate cumulative relative frequency. Cumulative relative frequency helps the user to readily see the combined effect of the "vital few" problems. For example, you could see that the top three quality problems were responsible for nearly 80% of the problems overall. To calculate cumulative relative frequency, add the relative frequency for each category of nonconformity to the sum of all preceding relative frequencies.

For example, there were 194 occurrences of size out-of-specification or 41% (relative frequency) of the total. There were 105 occurrences of fuzzy grain. Fuzzy grain was therefore responsible for 22% of the total. Size out-of-specification and fuzzy grain combined (cumulative relative frequency) were responsible for 63% of the total. Size out-of-specification, fuzzy grain, and machine tear-out combined were responsible for 76% of the total. The cumulative relative frequency for the least frequent category (oil/grease marks, in this example) should be 100%; however, it is slightly less due to rounding. Figure 2 shows the check sheet with the nonconformities arranged in descending order of frequency and with relative frequency and cumulative relative frequency calculated.

Figure 2: A sample check sheet showing nonconformities in descending order as well as relative frequency and cumulative relative frequency.

Project: Quality improvement project. Name: QIT. Location: Customer A. Dates: January 2002. Shift: All				
Reason		**Frequency**	**Rel. Freq. (%)**	**Cum. Rel. Freq. (%)**
Size out of specification	IIII/ IIII	194	41	41
Fuzzy grain	IIII/ IIII/	105	22	63
Machine tear-out	IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ I	61	13	76
Burn marks	IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ IIII	44	9	85
Stain/rot	IIII/ IIII/ IIII/ IIII/ IIII/ IIII/ I	31	7	92
Loose knots	IIII/ IIII/ IIII/ III	18	4	96
Splits	IIII/ IIII/ I	11	2	98
Raised grain	IIII	4	0.8	98.8
Dents	III	3	0.6	99.4
Oil/grease marks	II	2	0.4	99.8
Total		**473**	**99.8**	

Figure 3 is the Pareto chart for the data in Figure 2. The left vertical axis indicates the number (frequency) of each type of nonconformity. Always plot nonconformities in descending order of frequency, with the most frequent at the left vertical axis. The right axis indicates cumulative frequency.

The Pareto chart makes it easy to see that size out-of-specification, fuzzy grain, and machine tear-out are the major nonconformities. Quality improvement that focuses on these items will give the “biggest bang for the buck.”

Frequency, however, is not the only important consideration. Certain types of nonconformities, even if infrequent, may be very costly to scrap or rework. Therefore, the Pareto analysis should take into account both cost and frequency.

Though scrap and rework often involve very different costs, it’s possible to calculate an average scrap and rework cost based on the percentage of product in each category of nonconformity. For example, let’s say we estimate that 10% of material with size out-of-specification must be scrapped, but the remaining 90% can be reworked to produce a usable product. Further, let’s say that scrapping the product represents a loss of approximately $20 per item, and reworking costs approximately $11 per item. Therefore, our estimate of the average scrap and rework cost for size out-of-specification is:

(scrap cost) x (% scrap) + (rework cost) x (% rework) = scrap & rework cost
($20) x (10%) + ($11) x (90%) = $12

To account for frequency as well as scrap and rework costs, multiply relative frequency by cost to obtain relative cost. For example, we already determined that approximately 41% of nonconformities were size out-of-specification. Therefore, the relative cost due to size out-of-specification is:

0.41 x $12 = $4.92

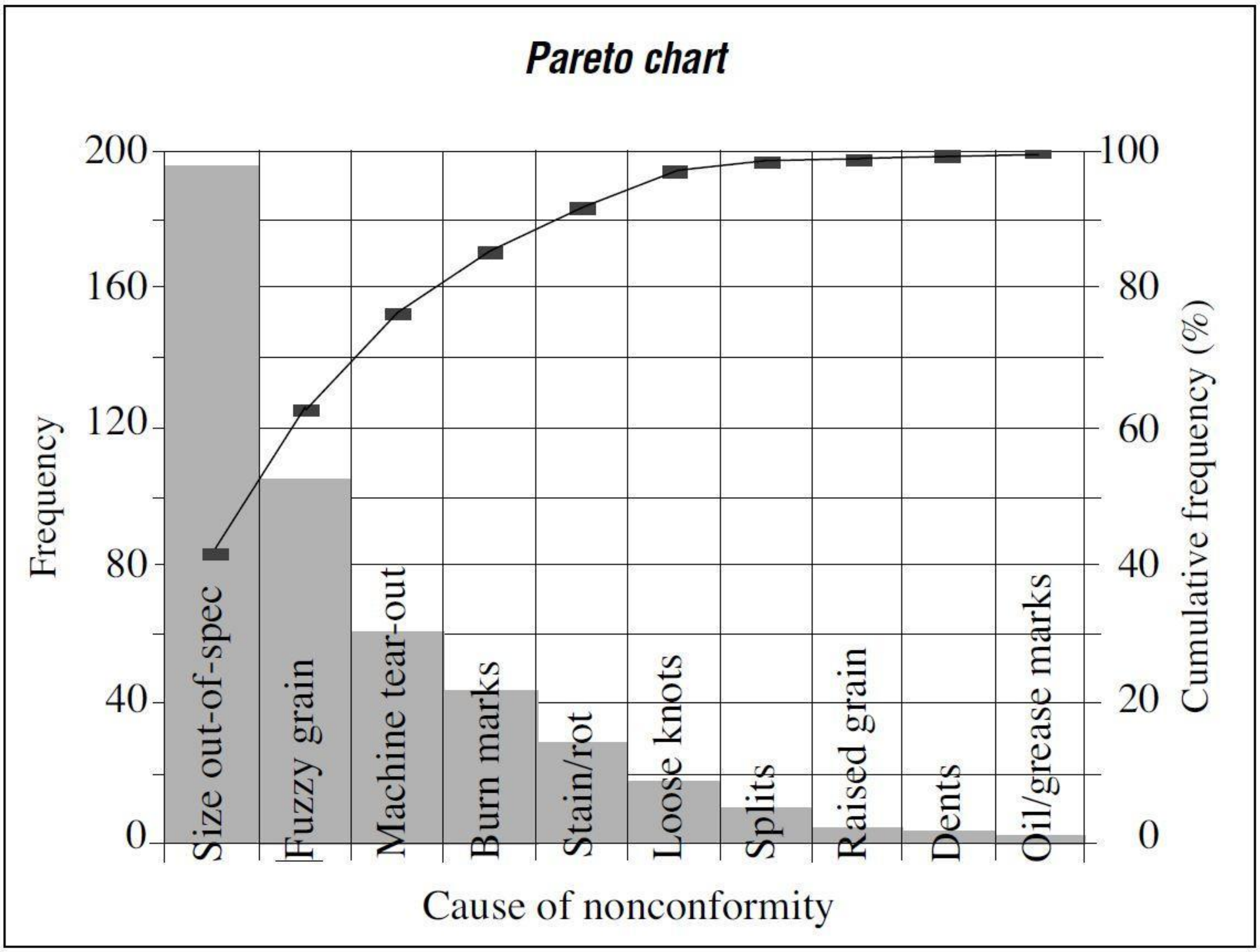

Figure 3: Pareto chart for the data in Figure 2.

Table 1 shows the relative costs, and Figure 4 shows the corresponding Pareto chart. We can see that size out-of-specification is the primary nonconformity from the standpoint of frequency (Figure 3) as well as relative cost to scrap or rework (Figure 4). Therefore, to get the “biggest bang for the buck,” it would be wise to begin the SPC program by focusing on problems that lead to size out-of-specification.

Table 1: Nonconformities and relative costs.

Nonconformity	Rel. Cost ($)	Rel. Freq. (%)	Cum. Rel. Freq. (%)
Size out-of-spec.	4.92	38	38
Machine tear-out	2.34	18	56
Fuzzy grain	1.76	13	69
Stain/rot	1.75	13	82
Loose knots	1.00	8	90
Burn marks	0.72	6	96
Splits	0.32	2	98
Dents	0.09	0.7	98.7
Raised grain	0.06	0.5	99.2
Oil/grease marks	0.03	0.2	99.4
Total	**12.99**	**99.4**	

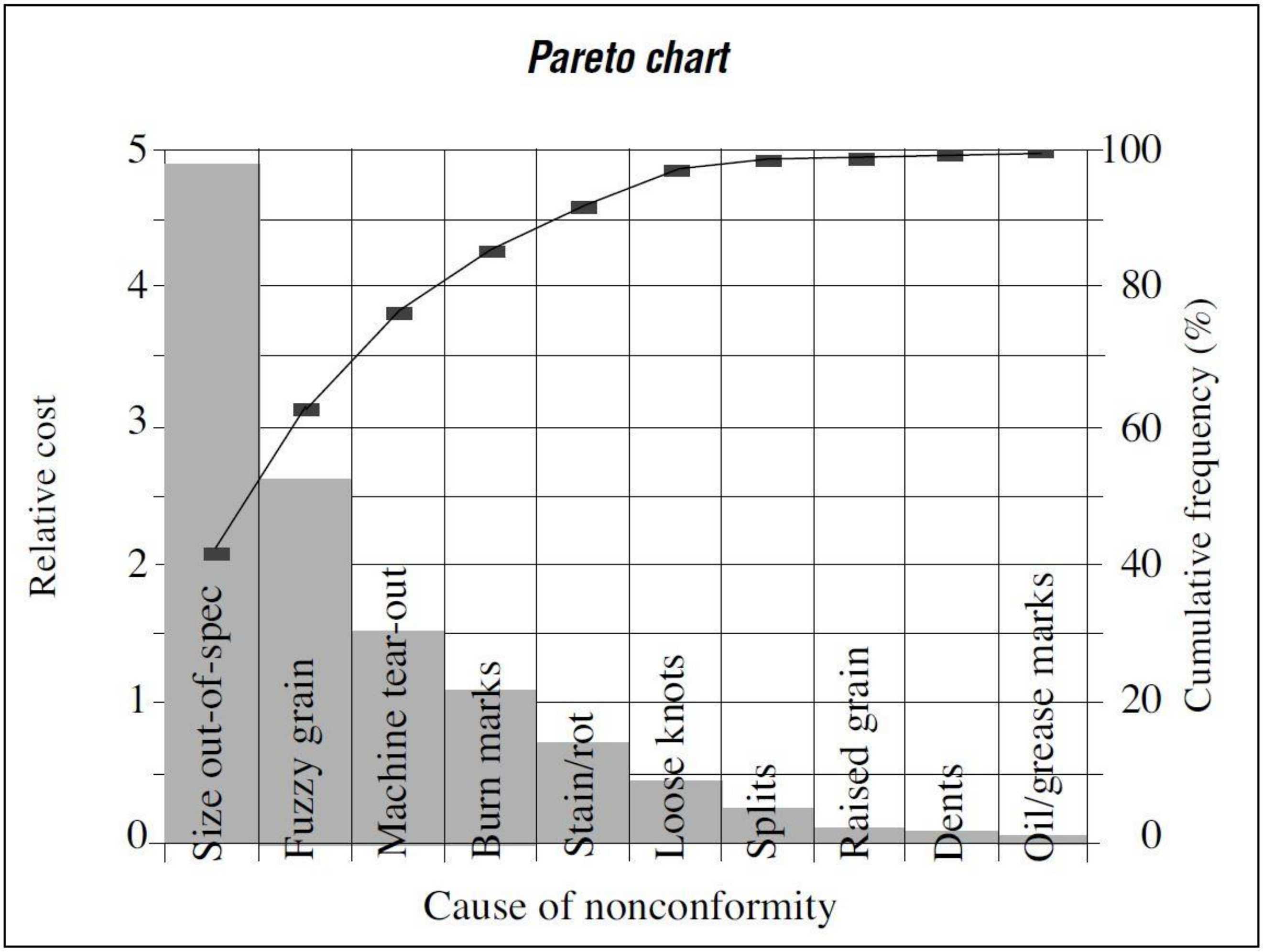

Figure 4: Pareto chart for the data in Table 1.

Summary

We now know the primary nonconformities and therefore where to focus initial efforts of an SPC program. We do not yet know, however, the specific processing steps that lead to a given nonconformity—that is, where and how the problem arises—and therefore we do not yet know where or what to monitor.

To help us discover the specific steps in the process that lead to a given nonconformity, it is helpful to develop a flowchart for the process. Flowcharts are the subject of the next report in this series.

For more information

Brassard, M., and D. Ritter. 1994. *The Memory Jogger II: A Pocket Guide of Tools for Continuous Improvement & Effective Planning.* Salem, NH: Goal/QPC. http://www.goalqpc.com/ (http://www.goalqpc.com/)

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

Ishikawa, K. 1982. *Guide to Quality Control*. Tokyo, Japan: Asian Productivity Organization.

Montgomery, D.C. 1997. *Introduction to Statistical Quality Control*, 3rd ed. New York, NY: John Wiley & Sons.

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

About this series

Publications in the Performance Excellence in the Wood Products Industry series address topics related to wood technology, marketing and business management, production management, quality and process control, and operations research.

For a complete list of titles, visit the Oregon State University Extension Catalog and search for "performance excellence": https://catalog.extension.oregonstate.edu/ (https://catalog.extension.oregonstate.edu/)

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Related publications

Part 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.

Statistical Process Control: Part 2, How and Why SPC Works

(https://extension.oregonstate.edu/catalog/pub/em-8733-statistical-process-control-part-2-how-why-spc-works)

This publication provides information to help managers understand and be confident in using Statistical Process Control as a profit-making tool. It includes descriptions of basic statistical concepts and SPC tools. ...

Scott Leavengood, James E. Reeb | Mar 2023 | EXTENSION CATALOG PUBLICATION Peer reviewed (Orange level) (https://extension.oregonstate.edu/peer-review-guidelines)

[Statistical Process Control: Part 5, Cause-and-Effect Diagrams](https://extension.oregonstate.edu/catalog/pub/em-8984-statistical-process-control-part-5-cause-effect-diagrams)

(https://extension.oregonstate.edu/catalog/pub/em-8984-statistical-process-control-part-5-cause-effect-diagrams)

Describes how cause-and-effect diagrams can help quality improvement teams identify the root causes of problems. Part of the Performance Excellence in the Wood Products Industry publication series.

Scott Leavengood, James E. Reeb | Aug 2009 | EXTENSION CATALOG PUBLICATION Peer reviewed (Orange level) (https://extension.oregonstate.edu/peer-review-guidelines)

[Statistical Process Control: Part 6, Design of Experiments](https://extension.oregonstate.edu/catalog/pub/em-9045-statistical-process-control-part-6-design-experiments)

(https://extension.oregonstate.edu/catalog/pub/em-9045-statistical-process-control-part-6-design-experiments)

Focuses on how design of experiments can help companies solve problems in manufacturing. Part of the Performance Excellence in the Wood Products Industry publication series.

Scott Leavengood, James E. Reeb | Oct 2011 | EXTENSION CATALOG PUBLICATION Peer reviewed (Orange level) (https://extension.oregonstate.edu/peer-review-guidelines)

Our focus for the prior publications in this series has been on introducing you to Statistical Process Control (SPC)—what it is, how and why it works, and how to use various tools to determine where to focus initial efforts to use SPC in your company.

SPC is most effective when focused on a few key areas as opposed to measuring anything and everything. With that in mind, we described how to:

- Use Pareto analysis and check sheets to select projects (Part 3)
- Construct flowcharts to build consensus on the steps involved and help define where quality problems might be occurring (Part 4)
- Create cause-and-effect diagrams to identify potential causes of a problem (Part 5)
- Design experiments to hone in on the true cause of the problem (Part 6)

Now, in Part 7, we describe the primary SPC tool: control charts. Assuming our experiment helped identify target values for key processes, we are ready to focus on day-to-day control and monitoring to ensure the process remains stable and predictable over time.

It is important, however, to not lose sight of the primary goal: Improve quality, and in so doing, improve customer satisfaction and the company's profitability.

How can we be sure our process stays stable through time?

In an example that continues throughout this series, a quality improvement team from XYZ Forest Products Inc. (a fictional company) determined that size out of specification for wooden handles (hereafter called out-of-spec handles) was the most frequent and costly quality problem. The team identified the process steps where problems may occur, brainstormed potential causes, and conducted an experiment to determine how specific process variables (wood moisture content, species, and tooling) influenced the problem.

Assuming the team makes a process change, they next need to (1) verify that the change actually produces the desired beneficial result and (2) ensure the process remains stable through time. In other words, they need to sustain the gains they've made.

Statistical Process Control: Part 7, Variables Control Charts

(https://extension.oregonstate.edu/catalog/pub/em-9109-statistical-process-control-part-7-variables-control-charts)

Describes control charts, the primary tools used in statistical process control. Part of the Performance Excellence in the Wood Products Industry publication series. The supplemental example spreadsheet below includes all data and charts from this publication.

Scott Leavengood, James E. Reeb | May 2015 | EXTENSION CATALOG PUBLICATION Peer reviewed (Orange level) (https://extension.oregonstate.edu/peer-review-guidelines)

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- Create cause-and-effect diagrams to identify potential causes of a problem (Part 5)
- Design experiments to hone in on the true cause of the problem (Part 6)
- Use the primary SPC tool—control charts—for day-to-day monitoring of key process variables to ensure the process remains stable and predictable over time (Part 7)

Variables control charts are useful for monitoring variables data—things you measure and express with numbers, such as length, thickness, moisture content, glue viscosity, and density. However, not all quality characteristics can be expressed this way. Sometimes, quality checks are simply acceptable/unacceptable or go/no-go. For these situations, we need to use **attributes control charts**.

It is important, however, to not lose sight of the primary goal: Improve quality, and in so doing, improve customer satisfaction and the company's profitability.

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The team's experiment revealed that moisture content as well as an interaction between

Statistical Process Control: Part 8, Attributes Control Charts

(https://extension.oregonstate.edu/catalog/pub/em-9110-statistical-process-control-part-8-attributes-control-charts)

Part of the Performance Excellence in the Wood Products Industry publication series, this publication and supplemental spreadsheet describes attributes control charts, a tool used in statistical process control.

Scott Leavengood, James E. Reeb | May 2015 | EXTENSION CATALOG PUBLICATION Peer reviewed (Orange level) (https://extension.oregonstate.edu/peer-review-guidelines)

Our focus for the prior publications in this series has been on introducing you to Statistical Process Control (SPC)—what it is, how and why it works, and how to use various tools to determine where to focus initial efforts to use SPC in your company.

Through this series, we described a variety of quality tools in terms of how they support implementation and use of SPC. The two primary SPC tools are control charts and process capability analysis.

A quick recap of this publication series: Parts 1 and 2 introduced SPC: what it is and how it works. In Parts 3 through 8, we walked through an example from XYZ Forest Products Inc. (a fictional company), following along as the company's quality improvement team began using SPC in response to customer complaints about size of wooden handles being out of specification (hereafter called out-of-spec handles). We described how the team:

- Used Pareto charts and check sheets to decide where to focus efforts (Part 3)
- Constructed flowcharts to build consensus on the steps involved and help define where quality problems might be occurring (Part 4).
- Created cause-and-effect diagrams to identify potential causes of a problem (Part 5)
- Designed an experiment to hone in on the true cause of the problem (Part 6)
- Used the primary SPC tools—variables and attributes control charts—to first assess stability of the process and then monitor key variables to ensure the process remains stable and predictable over time (Parts 7 and 8)

It is important to not lose sight of the primary goal of SPC: Improve quality, and in so doing, improve customer satisfaction and the company's profitability.

We've spent considerable effort identifying XYZ's most important quality problems, determining how to solve them, and then ensuring the process remains stable. Now we need to step back and ask how well the new-and-improved process is able to meet customer expectations. In short, we must shift our focus from stability to capability.

Our focus on customers in process capability analysis is not limited to external customers. Internal customers (that is, processes down the line) are important, too. In our XYZ example, external customer expectations are related to the size of wooden handles. However, the designed experiment (Part 6) revealed that controlling moisture content is

Statistical Process Control: Part 9, Process Capability Analysis

(https://extension.oregonstate.edu/catalog/pub/em-9111-statistical-process-control-part-9-process-capability-analysis)

Describes process capability analysis, a method for comparing the variability of a process relative to desired specifications. Part of the Performance Excellence in the Wood Products Industry publication series.

Scott Leavengood, James E. Reeb | May 2015 | EXTENSION CATALOG PUBLICATION Peer reviewed (Orange level) (https://extension.oregonstate.edu/peer-review-guidelines)