SPC

Statistical Process Control and the Forest Products Industry

By Timothy M. Young and Paul M. Winistorfer

Many experts consider the American quality revolution of the 1980s a response to an American quality crisis that had reached major proportions. This quality revolution led to the overall integration of statistical process control (SPC) and total quality management (TQM) in many U.S. manufacturing sectors. The financial benefits of using SPC and TQM have been well documented (9,10,13,17,18,27).

A notable exception to the broad adoption of SPC and TQM by American industries has been the forest products industry. Some forest products companies have adopted SPC and TQM at several manufacturing facilities, but there is a lack of industry-wide adoption of SPC and TQM. One possible reason for this lack of widespread adoption by forest products companies may be the absence of similar international market forces of the 1970s and 1980s that forced change in the American automotive and electronics industries, i.e., loss of market share to Japanese competition. However, as timber scarcity worsens in the 21st century, higher raw material costs may be the impetus for change.

The 21st century promises to bring social pressures on the availability and use of natural resources. The forest products industry is already experiencing dramatic changes in the availability of timber from national forestlands, and environmental pressures are mounting on private forestlands. The resulting economic scarcity of raw materials will require the competitive forest products companies of the 21st century to improve quality, increase productivity, and lower manufacturing costs. SPC and broader philosophies such as TQM offer proven continuous improvement strategies to meet the challenges facing the forest products industry.

History of SPC and TQM in the Forest Products Industry

Many consider W. Edwards Deming (1900-1993) to be the founder of the “third wave of the industrial revolution.” Deming, originally a Western Electric engineer, began this industrial transformation using statistical principles established in the 1920s by his colleague Walter A. Shewhart (1891-1967) (26). Deming was ignored by many U.S. manufacturers, but in 1950 he was invited to Japan to give a series of lectures on the application of statistical methods to manufacturing processes (Fig. 1). Joseph M. Juran followed Deming to Japan in 1954 and gave a series of lectures on applying quality principles to the entire organization, which later became known as Total Quality Management (15,17,18). Others in the quality profession such as Armand Feigenbaum, Kaoru Ishikawa, George Box, and Genichi Taguchi also made significant global contributions in the 20th century in applying SPC to industrial processes (1,13,16,27).

Many experts agree that the American quality revolution began in earnest in 1980 after W. Edward Deming’s appearance on the television broadcast *If Japan Can ... Why Can’t We?* The automotive industry

What is SPC?

Statistical Process Control (SPC) uses statistics (the science of collecting, analyzing, and interpreting data) to achieve and maintain control of process and production variation within a repetitive manufacturing process.

An example of SPC would be when measurements of lumber thickness are taken continously during the production process and these data are charted to determine if the thicknesses fall within control limits. If the data indicate a problem, the process would then be adjusted to eliminate the unacceptable variation.

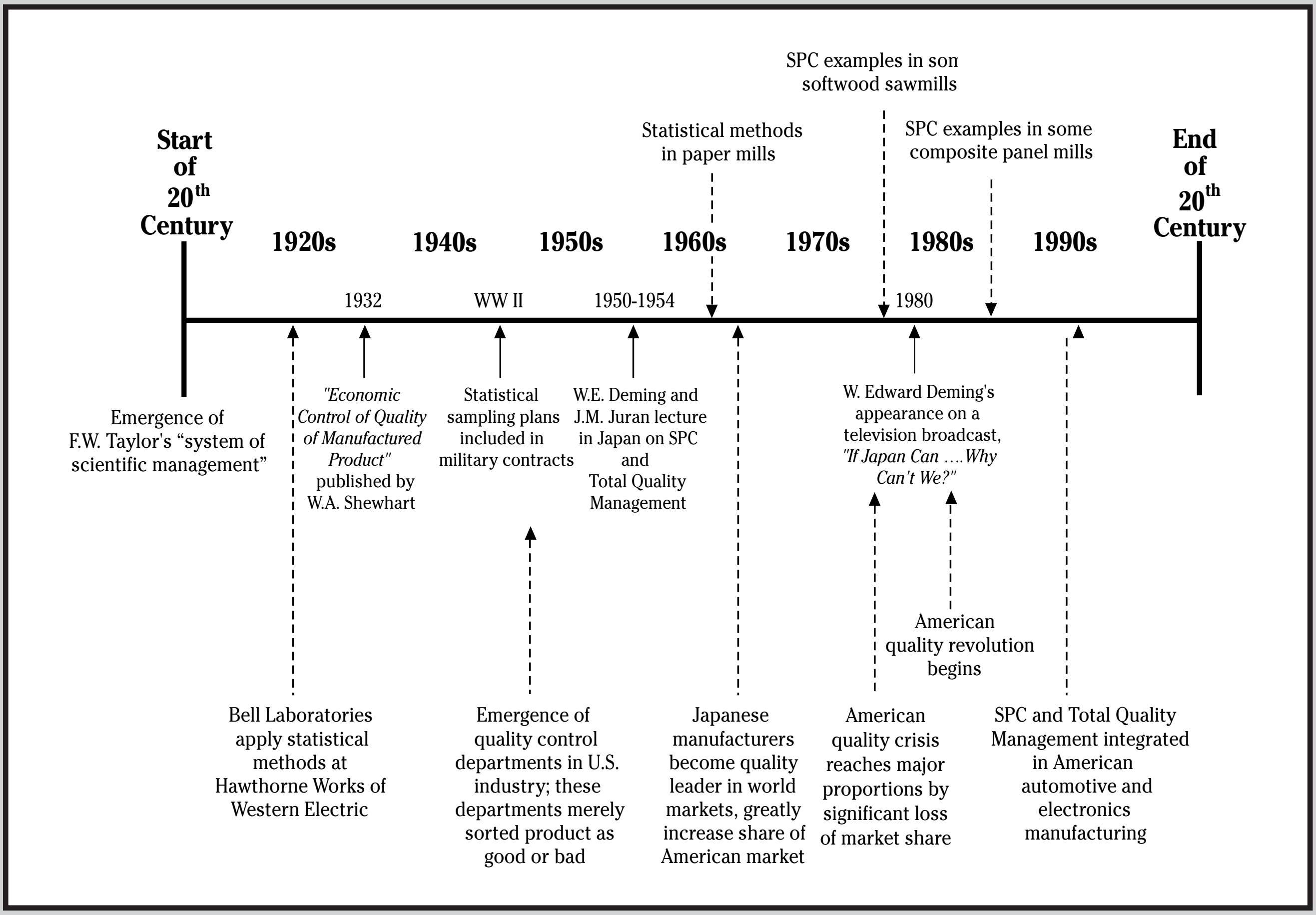


Figure 1. Evolution of SPC and quality in U.S. manufacturing.

was the first to adopt the principles of the quality revolution, but it quickly spread to the electronics, chemical, and food-processing industries.

The pulp and paper sector was the first in the forest products industry to apply statistical sampling methods to the inspection process, in the early 1960s (12). SPC applications in the pulp and paper industry did not become prevalent until the early 1980s (12). However, given the continuous process flow and high-speed production of paper manufacture, the paper industry has relied more on Engineering Process Control, which is an advanced computer-based process control method (11,14,19,21,28,29,31).

Brown (2,3) documented SPC applications in the softwood lumber industry in the late 1970s. Such applications were used to control and improve softwood lumber thickness. Some plywood and wood composite panel manufacturers began using SPC in the mid- to late-1980s (6,20,22). Such applications were scarce and sometimes driven by company-specific quality initiatives.

SPC applications have been virtually nonexistent in the hardwood lumber sector (6). Even though Cassens et al. (6) and Brown (3-5) have documented the potential financial benefits from using SPC to reduce hardwood lumber target sizes, adoption of such techniques by the hardwood lumber industry has not occurred. Reasons for the lack of industry-wide adoption of SPC by the forest products industry are perplexing. Is it a lack of awareness of SPC and its benefits? Or doesn't SPC fit well with the traditional management structures of some forest products companies (7,8,15,24,32,33)?

Measuring the Financial Loss Due to Variation
"The Taguchi Loss Function"

It is widely accepted that the financial loss to an organization due to product variation is best quantified by Taguchi's quality loss function (27). When an objective characteristic y (e.g., thickness) deviates from its target value m, some financial loss will occur. The financial loss or quality loss can be assumed to be a function of y, which we will designate $L(y)$. When y meets the target m, the loss of $L(y)$ will be zero, i.e., $L'(m) \cong 0$. The larger the deviation of y from the target m, the greater the loss to the producer and consumer (refer to illustration).

Through Taylor series expansion around the target value m, one can express the quality loss function as a squared term multiplied by a constant k:

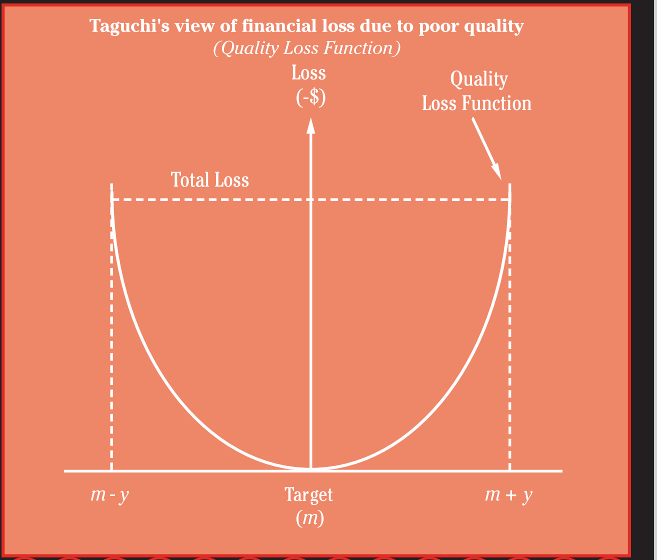
$$L(y) = k(y - m)^2$$

When the magnitude of the deviation is outside of the consumer's tolerance specification, the product is not usable. Let the cost due to a defective product be A (i.e., $A = L(y)$) and the corresponding magnitude of the deviation from the target be Δ (i.e., $\Delta = (y - m)^2$). The value of the constant k is determined from the following equation:

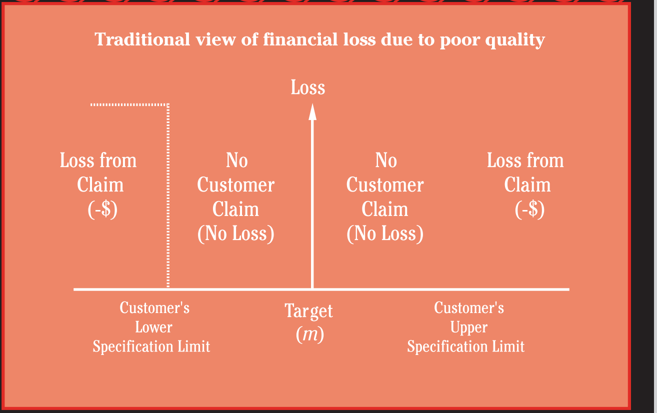
$$k = \frac{\text{Cost of defective product}}{(\text{Tolerance})^2} = \frac{A}{\Delta^2}$$

The Taguchi loss function shows that even small deviations from target induces financial loss even though the product remains usable to the producer or consumer.

The traditional view of manufacturing to a specification limit assumes that economic loss due to a customer claim does not occur until the product is outside of a specification limit (refer to illustration). This traditional view is no longer accepted as a method for measuring economic loss during manufacture. Leading quality experts have pointed out the importance of the Taguchi loss function (9,10,13,17,18,23,25,30).


Taguchi's view of financial loss due to poor quality

(Quality Loss Function)


Traditional view of financial loss due to poor quality

A General Description of SPC

SPC applies probability and sampling theory to production processes. SPC prevents the manufacture of defective product that would have otherwise occurred under a system where final inspection is the only quality control system. Traditional quality control systems rely on final inspection of manufactured product relative to a set of customer specification limits. This system may sometimes prevent delivery of poor quality to the customer, but it does not ensure continuous improvement of manufactured product and it is very costly to business organizations, i.e., recurring costs due to rework and scrap product.

SPC is a method of systematically analyzing variations and defects that will ultimately lead to the redesign of the production process to reduce variability (10,30). As Grant et al. (15) note, SPC implies that the individual operator rather than the quality control engineer is the best person both to identify unacceptable variation and to take remedial action. SPC requires operator training and gives the operator more responsibility for performance, innovation, capital equipment, and the work environment.

SPC requires detailed analysis of the production process, typically using process flow analysis charts. As a result, the manufacturing process is perceived as a single integrated system, and operators and managers have to communicate and share knowledge in order to diagnose problems. Many quality experts feel that one of the most critical errors that most production practitioners make is to focus on understanding how each component works in the production process as a means of understanding how the entire process works. Unfortunately this type of linear analysis may lead to optimization of individual components and sub-optimization of the overall system. SPC promotes the understanding of the interactions of the components as a means to improving the overall production system.

SPC is dynamic, focusing on long-term innovation and continuous improvement of the system where everyone in the company is involved in the decision-making process. Traditional management systems based on accounting and finance principles do not have the same goals as systems based on SPC and continuous improvement (9,10,23,25,33). The goal of continuous improvement is to reduce variation at all stages of the manufacturing process, which will in turn reduce costs and improve quality (refer to the sidebar that illustrates the Taguchi Loss Function).

Variation Reduction

Walter A. Shewhart's control chart philosophy focused on adjustment and improvement of the process and product by reducing variation. Shewhart looked at variability as being either within limits set by chance, or outside those limits. If variability was outside those limits, he believed that the source of variability could be identified, i.e., "special-cause" variation. The limits used in control charts are called "control limits" and are calculated from the process data; the limits are **not** engineering tolerance or specification limits. Control limits for Shewhart control charts are approximations of ± three standard deviations from the process average ($\bar{X}$). The upper control limit (UCL) is an approximation of the average plus three standard deviations; the lower control limit (LCL) is an approximation of the average minus three standard deviations (Fig. 2). Process variability within the control limits is called "common-cause" variation and represents variability that is relatively consistent over time, which is the result of many contributing process factors. Any process or product data outside the control limits is special-cause variation, which has an assignable cause due to the occurrence of an event in the manufacturing process. Thus, the control chart is a simple but effective tool for the presentation of data and an operational definition for

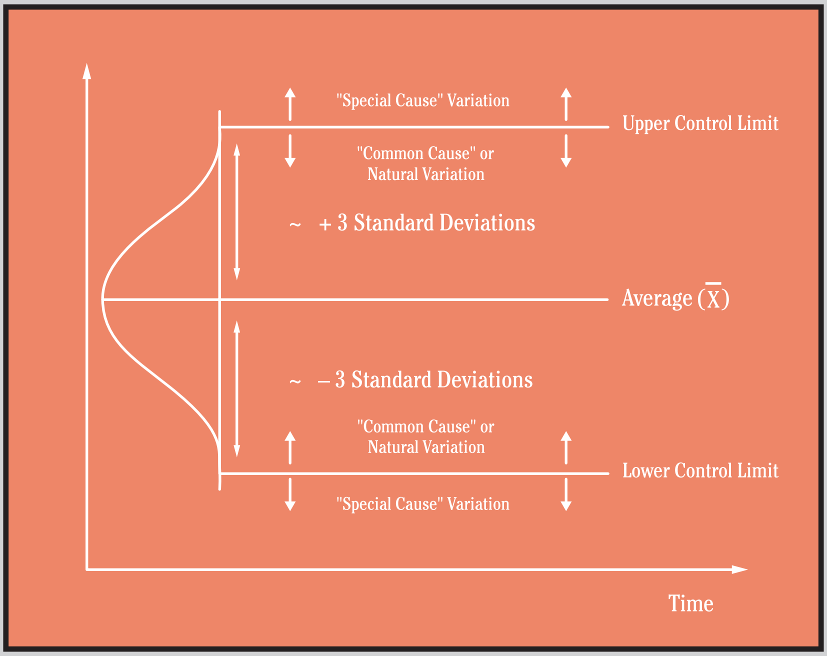


Figure 2. Theory of the Shewhart control chart.

knowing when a process is in trouble (26,30).

Continuous improvement using the control chart comes from a systematic elimination of special-cause variation. Special-cause variation is variation that is not common to the process and is assignable to an event. Such variation is considered beyond ± three standard deviations from the average. The Pareto principle suggests that 80 percent of process variation comes from 20 percent of the problems (17,18). Therefore, organizing special-cause variation by type of event and developing corrective action(s) that permanently eliminate those events from recurring results in reduced variation and continuous improvement of the system.

Shewhart control charts can be used for both measurement and attribute data. The basic theory of the control chart (i.e., average ± three standard deviations) is used for computing the control limits of control charts for both measurement and attribute data, but the specific formulation of the limits depends on the specific application and sample size. Measurement data are continuous and are taken using some type of measurement device (e.g., ruler, micrometer, infrared scanning laser detector, etc.). Attribute data are discrete and are counts of the number of defects, blemishes, etc.

Some important control charts for measurement data are: the X-bar and R charts, and X-Individuals and Moving Range charts. The X-bar and R charts are used for data that are subgrouped (i.e., $n > 1$) and the X-Individuals and Moving Range charts are used for individual observations (i.e., $n = 1$). The X-bar chart is used to assess the stability of the location of the process relative to its target and the R chart is used simultaneously to assess the stability of the process variation within and between subgroups. The X-Individuals chart is used for assessing the stability of both long- and short-term process location and the Moving Range chart is used to assess the stability of short-term process variation. The p chart, np chart, and c chart are control charts for attribute data, i.e., data based on counts of nonconforming items or blemishes. When using control charts based on attribute data, every count must have the same opportunity to occur, i.e., the counts may not occur in clusters or groups in the production process. The p chart is based on a running record where the counts are divided by the area of occurrence and the result is a proportion: p_i. If the area of occurrence for a count is the same, the np chart can be used. If it is only possible to count blemishes and not possible to count non-blemishes (e.g., holes in rolls of paper), the c chart is used. A detailed discussion of Shewhart control charts is given by Wheeler and Chambers (30).

Figure 3. Wonderware©'s SPC HMI system as applied to hardwood sawmilling as part of the Tennessee Quality Lumber Initiative

Human Machine Interface Technology

Human machine interface (HMI) technology has become a key element for many successful SPC systems. Given the "lean production model" that many forest product companies use in the 1990s, wood products are produced with fewer and fewer plant personnel. Such reductions in labor have led to the use of advanced HMI systems in the plant control room. It is no longer feasible to require one or two operators to develop and maintain multiple control charts of key process variables. The development of statistical software platforms that can be easily integrated with advanced HMI systems has allowed many companies to continue SPC systems that may have otherwise been discontinued due to lack of plant personnel to maintain the SPC system.

One leading SPC system using HMI technology was developed by Wonderware© corporation in the early 1990s (www.Wonderware.com). The SPC system is easily integrated with existing Wonderware process control HMI systems and can be easily customized by plant personnel that have some personal computing (PC) skills. The SPC/HMI system uses "point-and-click" PC software technology and allows operators the ability to easily monitor and input key information about the process. For example, operators can enter "special-cause" reasons for out-of-control points by simply clicking on the point (Fig. 3). Corrective action statements can also be added to any out-of-control point. The information is displayed instantly on Shewhart charts and can be seen by anyone that has access to the local area PC network. An archive is maintained of the SPC data and such data can be downloaded to other software packages for further analysis. The technology also exists to monitor the SPC/HMI system "off site" using telephone modems and PC Anywhere© software.

Elements for a Successful Continuous Improvement Program using SPC

SPC cannot be installed. SPC is a statistical method for continuous improvement that involves structured problem solving based on identifying sources of variation using Shewhart control charts. The commitment to continuous improvement using SPC must come from the senior management in the organization. "Grass-roots" SPC efforts on the plant floor have not been successful in the past (9,10,25,30). Plant floor personnel may not be empowered to make critical management decisions that involve changes to the process or redefining operator responsibilities. The following elements are necessary when implementing a continuous improvement system using SPC in a wood products company:

> **The primary goal of the Tennessee Quality Lumber Initiative is to improve the quality of hardwood lumber from Tennessee producers.**

- Strong support from senior management.
- Training in the philosophy of continuous improvement and SPC for all levels of management, supervisors (team leaders), operators, operator helpers, and graders.
- Linkage of key product attributes with key process variables and control charting of such variables.
- Active "plant floor" facilitation by personnel knowledgeable regarding SPC and continuous improvement.
- Establishment of handwritten control charts before automating to a control charting software system.
- Use of an SPC software system that is user-friendly.
- Elimination of special-cause variation.
- Use of Deming's "Plan-Do-Check-Act" cycle of making changes or improvements to the system (9,10).
- Involvement of operators, operator helpers, supervisors, and key management in structured problem solving sessions.
- Inclusion of accomplishments from continuous improvement in traditional reward system.

The following actions would be barriers to continuous improvement:

- Use SPC to record out-of-control points and discipline the accountable personnel, rather than using SPC as a learning tool.
- View SPC as a "package" that can be installed.
- Control chart a large number of variables and not learn about the variation from the critical few variables.
- Allow supervisors (team leaders) and operators to ignore SPC.
- Rely on the Quality Department to improve quality.
- Ignore successes from continuous improvement.

A Statewide Continuous Improvement Initiative

The Tennessee Quality Lumber Initiative (TQLI) is a major research, extension, and marketing initiative being developed by the Tennessee Forest Products Center at the University of Tennessee. The core of the TQLI is implementing SPC/HMI technologies in the hardwood sawmill industry in Tennessee. Tennessee is one of the leading hardwood lumber producers in the nation, with annual production of approximately 900 million board feet. The primary goal of the TQLI is to improve the quality of hardwood lumber from Tennessee producers.

The initiative is a multi-phase research program where SPC is used to reduce hardwood lumber thickness variation, which will allow producers to saw closer to target, reduce target thickness, and improve yield. Other benefits would accrue to producers from reducing lumber thickness variation in drying and surfacing production processes, and in shipping. Phase I of the TQLI uses SPC with "real-time" control charting to reduce thickness variation and lumber target sizes using advanced HMI technology. The HMI system uses Wonderware software on a personal computer platform and allows operators to monitor SPC and other animated process systems in a real-time setting. Thickness measurements are taken using electronic, digital micrometers with wireless transmitters.

Other phases of the TQLI will focus on integrating advanced engineering process control with SPC. The HMI systems are linked with programmable logic controller (PLC) systems. The latter phases of the TQLI will use advanced laser technology to measure lumber thickness.

Once fully developed, the TQLI will include a statewide marketing program to promote Tennessee Quality Lumber© (web.utk.edu/~tfpc/). Producers will be provided with marketing materials that may be used to promote their lumber products on the basis of less variation and better quality.

Driving Forces for Adoption of SPC by the Forest Products Industry

Economic scarcity of wood fiber and the resulting higher raw material costs for manufacturers will be a driving force for change in the forest products industry in the 21st century. The upward pressure on raw material costs will affect the competitive position of many forest products companies, which will promote change for improved productivity and lower costs. SPC and more general philosophies such as TQM will help many forest products companies improve product quality, productivity, and competitive position.

Many industries have realized business advantages and improved competitive position from adopting SPC. A summary of the advantages and disadvantages of using SPC are shown in Figure 4.

SPC, TQM, and continuous improvement are more than fads or buzzwords. These business philosophies cannot be installed or grafted onto existing systems that are inefficient. If forest products companies are going to fully utilize the benefits of these philosophies, organizational change is necessary. Such change requires a commitment from senior management, middle management, supervisors, and operators on the plant floor. The benefits to an organization from adopting SPC, TQM, or continuous improvement philosophies have been well documented. Forest products companies can benefit from adoption of these principles. Society also benefits when efficient manufacturing methods are developed that prevent defective product manufacture, and thereby waste less of our forest resources.

Adopt SPC	Don't Adopt SPC
Low-risk & Inexpensive Technology	Status Quo Manufacturing
"Data-based" Decision-Making	"Opinion-based" Decision-Making
Reduced Variation	"Fire-Fighting" Instead of Continuous Improvement
Reduced Manufacturing Costs	Managing Customer Claims Instead of Continuous Improvement
Improved Product Value	Maintain Current Product Value
Continuous Improvement from Permanent Corrective Action	Less Capital for Investment; Capital Spent Fighting "Equipment" Fires
More Capital for Investment	

Figure 4. A statistical process control comparison.

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