Tennessee Quality Lumber Initiative (TQLI)

Reducing Lumber Thickness Variation using Real-Time Statistical Process Control

A Cooperative Research study with Anderson-Tully Corporation, The University of Tennessee and U.S. Forest Service

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Executive Summary

Competitive market pressures and constrained hardwood log supply are external factors that are changing the hardwood sawmill industry in the 21st century. Successful hardwood sawmills continue to strive for improved production efficiency and low manufacturing costs while maintaining competitive product value. Hardwood lumber thickness is intentionally over-sized during manufacture to allow for sawing variation, lumber drying shrinkage, and surfacing for secondary product manufacture. The oversizing of hardwood lumber thickness due to excessive sawing variation requires higher target sizes that result in an opportunity cost to hardwood sawmills in sub-optimal log recovery. Competitive hardwood sawmills of the future will use statistical methods in lumber manufacture that focus on reducing lumber thickness variation that result in lower target sizes and higher log recovery.

A technology feasibility study was conducted from April 2001 until March 2002 at Anderson-Tully Corporation in Vicksburg, Mississippi. Anderson-Tully Corporation is the largest manufacturer of hardwood lumber in North America with an annual capacity of 98 MMBF. Anderson-Tully Corporation has two hardwood sawmills in Vicksburg (Mills K and D). There were four study objectives for each mill: (1) develop a low cost, real-time statistical process control (SPC) system to monitor lumber thickness variation and; (2) distribute the real-time SPC system to all sawing centers and supervisor offices at Mills K and D; (3) train Anderson-Tully Corporation in the principles of statistical process control; and (4) determine if the real-time SPC system had an effect on lumber thickness variation, target sizes, log recovery and manufacturing costs.
The first study objective was satisfied. A real-time SPC system was developed for both mills for approximately $27,000, which satisfied the first study objective. Features of the system included two PC servers using Wonderware® human machine interface technology (HMI) with distributed real-time control charts in all sawing centers and management offices. Thickness data were collected immediately after sawing using wireless caliper technology. The system included a Microsoft® Access 2000 reporting system. The most expensive components of the real-time SPC system were the two PC servers with 21” monitors (~$7,000), Wonderware® HMI software ($5,000), two Mitutoyo® wireless caliper receiver boxes (~$4,600), and the wireless transmitters and calipers (~$3,200). Remaining costs of the real-time system were for PC monitors, monitor cables, monitor booster boxes, “Interduct” conduit and clamps.

The second study objective was satisfied. The thickness data in a statistical process control (SPC) format were distributed to all sawing centers and management offices at the instant of measurement using wireless transmitters as attached to calipers. The data were also available to any PC on Anderson-Tully’s LAN using “Carbon-Copy” software.

The third study objective was satisfied when 15 management and sawing personnel were trained in October 2001 in the principles of statistical process control (SPC). A follow up training session was conducted in December 2001 with three personnel responsible for quality control at both mills. The December 2001 training session was focused on analyzing sources of variation using Ishikawa diagrams and components of variance techniques to determine “within-board” and “between-board” sources of variation for the gangsaw at Mill K.
The fourth study objective was partially satisfied. There was statistical evidence ($\alpha = 0.05$) at Mill D that suggested that the average thickness of 4-quarter Ash (*Fraxinus caroliniana*) declined by 0.060” over the course of the study period. The average thickness of Cottonwood (*Populus deltoides*) 4-quarter lumber at Mill D declined by approximately 0.035” during the study period.

Lumber produced at the resaw machine center generally had the largest standard deviation for all species at both Mills K and D. “Within-board” variation was the largest component of variance for every species for all of Mill K machine centers. Within-board” variation was the largest component of variance for every species for the headrig machines centers at Mill D. “Between-board” variance was the largest component of total variance at the resaw at Mill D.

The average overrun for Mill K for all species increased by approximately 2.6% after the installation of the real-time SPC thickness improvement system. The average overrun for Mill D for all species declined by approximately 1.1% after installation of the real-time SPC thickness improvement system. The decline in overrun at Mill D was due to a consistent 1% increase in average log volume for all species, which was due a log grading procedure change at Mill D. We believe the log grading procedure change negated the ability to detect any improvement in overrun from the installation of the SPC system.

The average “Common and Better” grade had a statistically significant shift of 3% at Mill K after installation of the real-time SPC thickness improvement system due to a reduction in “thin-edges” on lumber (e.g., *wedge-shaped lumber with an edge less than*...
The “Common and Better” average grade for Mill D had a statistical shift of 4% after installation of the real-time SPC thickness improvement system.

The estimated annual potential financial cost savings of the installation of the real-time SPC thickness improvement system for Mills K and D was approximately $752,100. Interpretation of the potential cost-savings was based on financial data provided by Anderson-Tully Corporation and was based on a savings of $709,120 due to overrun improvement. An additional potential gain of $42,980 was estimated from the improvements in the percentage of “Common and Better” grade lumber.

The technology feasibility study of developing a low cost real-time SPC system should be repeated in several more hardwood sawmills. Future real-time SPC systems should expand upon the existing measurement system of wireless caliper technology and include other low cost types of measurement platforms for estimating lumber thickness. The technology feasibility study as outlined in this report may continue at the existing hardwood sawmill and include more detailed lumber recovery and financial analyses. A possible next phase would test the use of laser-measured thickness and automated scanning to measure every sawn board for all products by machine center. The next phase of the study is contingent on obtaining sources of funding.

**Keywords:** Technology feasibility study, real-time statistical process control, human machine interface platforms, hardwood lumber, target sizes, thickness variation.
Introduction

Hardwood lumber thickness is intentionally over-sized to allow for sawing variation, surfacing of rough lumber and shrinkage during the drying process. The amount of material that must be removed from rough-cut hardwood lumber depends on the variation due to surface roughness (within-board variation), size variation between sawn boards (between-board variation), and size variability caused by irregular drying (Young and Winistorfer 1998; Young et al. 2000). Brown (1982) attempted to model this relationship using the following deterministic equation:

\[ T = F + P + (Z \cdot S_t) \]

\[ T = \frac{F + P + (Z \cdot S_t)}{1 - S_h/100} \]  

where,  
- \( T \) = target thickness for lumber (inches),  
- \( F \) = final dried lumber thickness (inches),  
- \( P \) = planer allowance (inches),  
- \( S_h \) = percent thickness shrinkage due to drying (decimal),  
- \( S_t \) = thickness standard deviation of lumber (inches),  
- \( Z \) = \( Z \)-score, the lower \( \alpha/2 \) percentage point of the unit normal distribution (some use this as the percent undersize allowed).

Even though Brown (1982) admits that there are limitations to his deterministic equation [1], the general principle of the equation holds, i.e., greater thickness variation during sawing \( S_t \) requires greater sawing target sizes.\(^1\)

The hardwood lumber industry has noted the importance of thickness variation and target sizes as indicated by their response to a National Hardwood Lumber

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\(^1\) Brown (1982) has indicated in personal conversations with the authors (2001) that the \( S_h \) percent thickness shrinkage statistic is not a constant and is a statistical density function, which may make equation [1] over-estimate sawing targets.
Association (NHLA) survey in 1996. Two of the industries top three research priorities were: (#2) develop techniques or technologies to improve sawing accuracy and reduce thickness variation; and (#3) develop decision support tools, which maximize quality recovery from logs (NHLA 1996).

The over-sizing of hardwood lumber during the sawing process leads to financial losses and impairs an organization’s competitiveness. Some have suggested that the over-sizing of rough sawn lumber can lead to opportunity costs of $50,000 to $250,000 per year depending on the capacity of the sawmill (Brown 1997; Cassens et al. 1994; Wengert 1993).

Traditional quality control programs in the hardwood lumber industry vary greatly and are tailored to the individual needs of a sawmill. One quality control function that almost all sawmills have in common is the grading of lumber, which is based on a criteria designed by the NHLA to ensure an accurate and consistent grade of lumber. Even though the grading of hardwood lumber is a quality control technique, it does not ensure continuous improvement of the process, and it is not focused on reducing lumber target sizes and thickness variation (Figure 1, page 25). Excessive lumber thickness variation can also reduce the grade of lumber, e.g., wedge-shaped lumber (personal communication: Anderson-Tully Corporation 2002).

The contemporary philosophy of continuous improvement is based on using statistical methods, primarily the Shewhart control chart, to define variation as either special-cause or common-cause variation. Defining and quantifying variation is considered to be the starting point of continuous improvement (Shewhart 1931; Deming 1986, 1993). After variation is quantified, short-term variation reduction occurs from the
prevention of assignable causes that lead to special-cause variation, e.g., elimination of cants that are not square, elimination of variation at shift change, elimination of product setup variation, etc. Long-term variation reduction comes from improvements to the manufacturing system, which reduces the amount of common-cause variation, e.g., change from circular saw to band saw, more consistent speed of headrig carriage, long-term mechanical improvements to headrig carriage, etc.

Figure 1. An illustration of the contrast between the decision-making processes in (a) Traditional Quality Control, and (b) Continuous Improvement.
Tennessee Quality Lumber Initiative (TQLI)

The purpose of the Tennessee Quality Lumber Initiative (TQLI) is to improve the quality of lumber and improve utilization of the timber resource. The Tennessee Quality Lumber Initiative (TQLI) is an applied research initiative at The University of Tennessee, Tennessee Forest Products Center. The TQLI’s main funding is from The University of Tennessee Agricultural Experiment Station (McIntire Stennis #75) and the special USDA Wood Utilization Research grant. In this study the U.S. Forest Service and Anderson-Tully Corporation provided additional funds.

Research Objectives

This report summarizes the findings of a research study that was conducted at two hardwood sawmills in Vicksburg, Mississippi owned by Anderson-Tully Corporation. There were four study objectives for each mill: (1) develop a low cost, real-time statistical process control (SPC) system to monitor lumber thickness variation and; (2) distribute the real-time SPC system to all sawing centers and supervisor offices at Mills K and D; (3) train Anderson-Tully Corporation in the principles of statistical process control; and (4) determine if the real-time SPC system had an effect on lumber thickness variation, target sizes, log recovery and manufacturing costs.

Real-Time Statistical Process Control

This study builds upon the statistical principles developed initially by Walter Shewhart from his work in 1931 titled "Economic Control of Quality of Manufactured Product," which were popularized in U.S. manufacturing in the 1980s by W. Edward Deming (Shewart 1931; Deming 1986, 1993). The purpose of statistical process control
(SPC) is to prevent the manufacture of defective product. Traditional quality control relies on inspection of the final manufactured product and sorts bad product from good product. Continuous improvement is generally not considered to be a component of traditional quality control. Traditional quality control does not have any formal feedback-loop mechanism to ensure that the same defective product will not be manufactured in the future. Continuous improvement is data driven and works upstream in the process in an attempt to identify and eliminate problems that lead to the manufacture of defective product (Young 1997; Young and Guess 1994). In this study SPC was used to quantify lumber thickness variation.

![Control Chart Diagram]

**Figure 2. Basic form of a control chart.**
The primary tool of SPC is the control chart, which quantifies variation as either special-cause or common-cause variation (Figure 2, page 29). The control limits on control charts are used to determine if the variation is inherent to the process (common-cause variation inside the control limits) or if the variation is from an assignable-cause (special-cause variation).

Figure 3. An illustration of improvement due to reduced lumber thickness variation from (a) initial installation of a real-time SPC system and (b) after long-term exposure to real-time SPC when special-cause variation is reduced.
cause variation outside the control limits). Samples outside the control limits are often referred to as “out of control” samples. Even though previous research addressed the use of SPC to improve hardwood sawmill processes, the research did not address the significance and immediate improvement that can be obtained from the use of real-time SPC (Copithorne et al. 1994; and Leicester 1994).

Real-time SPC is a powerful continuous improvement tool where machine operators and managers see real-time process data on control charts (Figure 3, page 30). Real-time SPC enhances Shewhart’s concept of preventing the manufacture of defective product by reducing the time interval between the viewing of process data and taking action on special-cause variation (Young and Winistorfer 1999; Young and Winistorfer 1998). We believe that viewing control charts from historic production run is less effective for continuous improvement than is the use of real-time SPC.

**Human Machine Interface Platforms**

Human Machine Interface (HMI) technology is the operations viewing platform for information technology in manufacturing systems. HMI technology promotes visualization of the manufacturing process by presenting real-time data to machine operators. HMI technology depends on programmable logic control (PLC) systems that provide an electronic interface between machines and operators (Figure 4, page 32).

Even though HMI technology is not new, it has historically been expensive technology that was of a proprietary nature. The advent of companies such as Wonderware® and Intellusions® have greatly reduced the cost of HMI technology. Affordable HMI technology has created opportunities for the use of real-time SPC in the hardwood lumber industry that did not exist five years ago.
The Wonderware® HMI system was used in this study. Real-time SPC control charts on PC monitors were developed and distributed at sawing centers at both Mills K and D. The sawing centers at Mill K were the gangsaw, resaw, left headrig and right headrig (Figures 5, 6, 7 and 8, pages 33 and 34). HMI platforms were also installed at Mill K at the supervisors’ office and near the grading stations where lumber sampling stations were located (Figures 9 and 10, page 35). The sawing centers at Mill D were the left headrig, right headrig and resaw (Figures 11, 12, and 13, pages 36 and 37). HMI platforms were also installed at Mill D at the supervisors’ office and near the grading stations where lumber sampling stations were located (Figures 14 and 15, pages 37 and
Remote access to the HMI system and viewing of the real-time SPC system using “Carbon Copy” software were part of the system.

Figure 5. Real-time SPC display at the gangsaw control room for Mill K.

Figure 6. Real-time SPC display at the resaw control room for Mill K.
Figure 7. Real-time SPC display at the left headrig control room for Mill K.

Figure 8. Real-time SPC display at the right headrig control room for Mill K.
Figure 9. Sampling station and real-time SPC display at Mill K.

Figure 10. Real-time SPC display in supervisor’s office at Mill K.
Figure 11. Real-time SPC display at the right headrig control room for Mill D.

Figure 12. Real-time SPC display at the left headrig control room for Mill D.
Figure 13. Real-time SPC display at the resaw sawing center at Mill D.

Figure 14. Sampling station and real-time SPC display at Mill D.
Figure 15. Real-time SPC display in supervisor’s office at Mill D.
Methods

Real-Time Statistical Process Control HMI Platform

Wonderware’s InTouch 7.1 SPCPro software package was used to develop the display screens and encode the scripting required for communication with the wireless caliper system. InTouch SPCPro was also encoded to communicate with Microsoft Access 2000. All data were stored in Microsoft Access 2000 from which a reporting system was developed. The main display screen for each mill included control charts of lumber thickness (Figures 16 and 17). All screens developed in the real-time SPC system are illustrated in Appendix A (Mill D) and Appendix B (Mill K). All encoding using Wonderware scripting is in Appendix C.

Figure 16. Main Wonderware InTouch SPCPro display window for Mill D.
Figure 17. Main Wonderware® InTouch SPCPro display window for Mill K.
Features of the system included visual alarms for “out of control” points and real-time data collection of assignable causes that lead to special-cause variation. The real-time recording of “corrective actions” for “out of control” samples was also an important part of the system (Figure 18).

Figure 18. Wonderware special-cause variation alarm with corrective action display for Mill D.
Real-time viewing of histograms and Pareto charts were part of the real-time SPC system. Histograms were created from the raw measurement data used for the control charts and were used to display the distribution and frequency of the collected data (Figure 19). Pareto charts were used to graphically present the number of occurrences of special-cause variation. While there were many possible causes for “out of control” samples, there were usually only one or two types of special-cause variation that produced the bulk of assignable causes, e.g., saw snaking, incorrect timber-bind, etc. (Figure 20, page 43).

![Histograms for the left and right headrigs thickness for Batesville Pecan 4-quarter.](image-url)
System Architecture

The system architecture was based on a Windows NT 4.0® operating system. PC monitors were displayed in both mills at all sawing centers, management offices and lumber sampling stations using a “splitter-box with booster” and 450 feet of monitor cable. The system was available to users on Anderson-Tully’s LAN using Carbon Copy® software. The research objective of developing a low cost real-time SPC system was satisfied using this system architecture (Figure 21, page 44).
**Wireless Caliper and HMI Interface**

Lumber thickness measurements were taken immediately after sawing using a digital caliper with wireless data communication to the PC server. A wireless Mitutoyo® caliper with transmitter and a 99-channel receiver-box were used in conjunction with...
Wonderware© InTouch SPCPro HMI software to measure lumber thickness in a real-time setting (Figure 22). The wireless caliper transmitted data up to 150 feet from the antenna of the receiver (Figure 23, page 46). The antenna of the receiver box was located approximately 100 feet from the receiver box by use of coaxial cable.

Omniserver© software was used with a copyright protected code to interface Wonderware© InTouch SPCPro with the Mitutoyo caliper measurement signal. The copyright protected code was developed by Young (2000) from The University of Tennessee Agricultural Experiment Station Idea Grant R11-2218-35.

Figure 22. Mitutoyo© caliper with transmitter.
Individual Board Measurements

Ten measurements were taken for each piece of lumber.\textsuperscript{2} The measurements were dispersed uniformly along the board where two sets of five measurements each were taken along each edge (Figure 24, page 47). All measurements were taken in the same sequence along the board in order to recognize patterns in the thickness of the lumber. The measurement system was based on research by Brown (1982).

The ability to detect patterns in the thickness of lumber was an important outcome of the study. The pattern recognition led to early detection of sawing problems and was an essential component of understanding sources of thickness lumber variation (Figure 25, page 47).

\textsuperscript{2} Note, six measurements were originally taken at Mill K starting in April 2001. The research team and quality control personnel at Anderson-Tully Corporation decided in August 2001 to take 10 measurements per board for each mill to improve the ability to recognize patterns in lumber thickness.
Individual Board Measurements

The location of individual thickness measurements will be taken with the digital caliper at the six locations identified below. The ten measurements will be dispersed along the board with three measurements along each edge.

Figure 24. Location of thickness measurements on an individual board.

A sampling platform was developed at the lumber grading area that will allow boards to be easily pulled from the board conveyor. The sampling platform has a painted inch ruler to allow for easy location of the sampling points.

Two measurements will be taken at the midpoint of the board on each edge (#3 & #8). Eight more measurements will be taken on the board at points #1, #2, #4, #5, #6, #7, #9 & #10 (see above), 12” each end. All measurements should always be taken in the same sequence, i.e., #1, #2, #3, #4, #5 &

Note: if unmeasurable wane is present at a data point, zero the caliper and data record. The software program will account for zeros.

Figure 25. Possible thickness variation patterns from repetitive sampling.
A sampling platform was developed near the lumber grading station at each mill. The sampling stations were developed to be ergonomically friendly, *i.e.*, *boards could be maneuvered off the green-chain without lifting*. Ten measurements were taken for each board in the same sequence. Measurements were taken approximately 1’ from the end of the board and were spaced equidistantly along the edges of the board. It was important for pattern recognition that all thickness measurements were taken in the same sequence, *e.g.*, 1,2,3,4,5,6,7,8,9 and 10.

**Board Sampling**

Board sampling was based on a stratified random sampling scheme. The scheme was derived from the historic lumber production by species and thickness. The stratified random sampling scheme was based on estimating the average thickness for a piece of lumber with a certainty level of 95% and an error level of 10% (Levy and Lemeshow 1991). A pre-study was conducted before installation of the real-time SPC system to derive estimates of the thickness average and thickness variance (*within-board and between-board variances*) for each species and thickness. These data were used to develop the stratified random sampling scheme.
Microsoft Access 2000® Reporting System

A reporting system was developed in Microsoft Access 2000®, which interfaced directly with the Wonderware® InTouch SPCPro HMI software. The reporting system featured daily, weekly and monthly reports of lumber thickness by species and thickness for any machine center. A graphical user interface was developed in the main menu of the reporting system that allowed the user to query the system with “point and click” ease of use (Figure 26). Any user of the Microsoft Access 2000® reporting system was capable of querying the database for any dates by species, thickness and machine system. All reports and display screens are presented in Appendix D.

![Microsoft Access 2000® main menu display.](image)
Results

**Low Cost Real-Time SPC System**

The real-time statistical process control (SPC) system was developed for approximately $27,000 for both mills K and D (equipment costs only). We believe that the first objective of the study was satisfied, *i.e.*, develop a low cost, real-time statistical process control system to monitor lumber thickness. The real-time SPC system used current PC technology and non-proprietary human machine interface (HMI) software. The most expensive components of the real-time SPC system were the two PC servers with 21” monitors (~$7,000), Wonderware® HMI software ($5,000), two Mitutoyo® wireless caliper receiver boxes (~$4,600), and wireless transmitters and calipers (~$3,200). Remaining costs of the real-time system were for PC monitors, monitor cables, monitor booster boxes, “Interduct” conduit and clamps.

The software interface between Wonderware® and the Mitutoyo® wireless caliper system was not included in the real-time SPC system costs. The software interface was developed by Young (2000) from The University of Tennessee Agricultural Experiment Station Idea Grant R11-2218-35. The total development cost of the software interface was approximately $5,075.

Labor costs for installation of the real-time SPC system at the sawmill site and travel costs to the sawmill site were not included in the $27,000 total equipment costs for the real-time SPC system for both sawmills. These costs were estimated to be approximately $94,422 and were cost shared by the U.S. Forest Service and The University of Tennessee. The U.S. Forest Service contract was administered by The University of Tennessee under the terms of research contract R112218-89. The
University of Tennessee cost share was part of the special grant awarded by the USDA for wood utilization research, contract R11-2218-54 (Winistorfer 1998).

**Distributed Real-Time SPC System**

The real-time SPC system was distributed to all sawing centers and management offices. The impact of the distributed real-time SPC system on sawyer perceptions cannot be underestimated. Even though it is difficult to estimate the quantitative benefits of changes in perceptions, the questions posed to researchers by some sawyers about thickness variation led us to believe that sawyers were more aware of thickness variation and actual target sizes with the PC monitors in sawing control centers.

**SPC Training**

The training of key personnel at Anderson-Tully Corporation in the principles of statistical process control was successful. Three upper management personnel were trained in the principles of statistical process control at The University of Tennessee, Tennessee Forest Products Center.\(^3\) Fifteen other Anderson-Tully Corporation personnel were trained in October 2001 in the principles of statistical process control on-site at Anderson-Tully Corp. in Vicksburg, Mississippi. Three quality control personnel were training in December 2001 in Ishikawa diagrams and components of variance techniques. The detailed training in December 2001 helped identify additional sources of thickness variation.

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\(^3\) The University of Tennessee, Tennessee Forest Products Center has a highly regarded workshop on statistical process control in the wood industry that is offered on a biannual basis. The 5-day class draws participants from across North America that are involved in almost every segment of the forest products industry. Over 90% of past participants have rated the outreach program as “Excellent.”
Lumber Thickness Averages and Variation

There was no statistical evidence for all species at Mill K to suggest that the average thickness, standard deviation or coefficient of variation declined for either mill by sawing center for 4-quarter lumber over the study period (Figures 27, 28 and 29). The left headrig sawing center for Mill K had a declining trend in standard deviation since July-2001. The resaw sawing center at Mill K had the highest standard deviation. All sawing centers for Mill K had lower standard deviations in February-2002.

![Figure 27](image1.png)

**Figure 27.** Standard deviation by sawing center for Mill K.

![Figure 28](image2.png)

**Figure 28.** Average thickness by sawing center for Mill K.
The average thickness for Mill K had no apparent trends. The coefficient of variation for all sawing centers for Mill K was stable throughout the study period (Figure 29). The resaw center at Mill K had the highest coefficient of variation. The left headrig at Mill K had a declining coefficient of variation during the study period.

![Coefficient of variation by sawing center for Mill K.](image)

The standard deviations for the sawing centers of Mill D were consistent throughout the study period. The right headrig had the smallest standard deviation and the resaw had the highest standard deviation (Figure 30).

![Standard deviation by sawing center for Mill D.](image)
The average thickness for 4-quarter lumber at Mill D by machine center was stable over the study period (Figure 31). The resaw had a consistently higher coefficient of variation than the left or right headrig. The left headrig had the smallest coefficient of variation (Figure 32).

Figure 31. Average thickness by sawing center for Mill D.

Figure 32. Coefficient of variation by sawing center for Mill D.
There was statistical evidence ($\alpha = 0.05$) that the variation in Batesville 4-quarter lumber at Mill K declined in the last three months of the study period (Figure 33 and Table 1).

Thickness data for all species and products are presented in Appendix E.

Table 1. Average, median and standard deviations for Batesville 4-quarter lumber for all sawing centers.

<table>
<thead>
<tr>
<th>Month-Year</th>
<th>Number of Samples</th>
<th>Average Thickness</th>
<th>Means Test**</th>
<th>Sample Standard Deviation</th>
<th>Sample Variance Test***</th>
<th>Median</th>
<th>Median Test ****</th>
</tr>
</thead>
<tbody>
<tr>
<td>January – 2001</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
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<tr>
<td>February – 2001</td>
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<td>--</td>
</tr>
<tr>
<td>March – 2001</td>
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<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>April – 2001</td>
<td>404</td>
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<td>.037719”</td>
<td>a</td>
<td>1.135”</td>
<td>a</td>
</tr>
<tr>
<td>May – 2001</td>
<td>428</td>
<td>1.143”</td>
<td>b</td>
<td>.042393”</td>
<td>b</td>
<td>1.142”</td>
<td>b</td>
</tr>
<tr>
<td>June – 2001</td>
<td>1135</td>
<td>1.142”</td>
<td>bc</td>
<td>.040268”</td>
<td>abc</td>
<td>1.143”</td>
<td>bc</td>
</tr>
<tr>
<td>July – 2001</td>
<td>298</td>
<td>1.146”</td>
<td>bcd</td>
<td>.037807”</td>
<td>abcd</td>
<td>1.146”</td>
<td>b d</td>
</tr>
<tr>
<td>August – 2001</td>
<td>635</td>
<td>1.156”</td>
<td>e</td>
<td>.041152”</td>
<td>bcde</td>
<td>1.556”</td>
<td>e</td>
</tr>
<tr>
<td>September– 2001</td>
<td>204</td>
<td>1.151”</td>
<td>bcdf</td>
<td>.021082”</td>
<td>f</td>
<td>1.150”</td>
<td>d f</td>
</tr>
<tr>
<td>October – 2001</td>
<td>215</td>
<td>1.152”</td>
<td>b def</td>
<td>.028907”</td>
<td>a f</td>
<td>1.150”</td>
<td>d f</td>
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<tr>
<td>November – 2001</td>
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</tr>
</tbody>
</table>

*Blank cell indicates that no data were available.

**Each subscript letter corresponds to a specific row. For example, “a” corresponds to the first row with data and the significance test compares to the first row with subsequent rows. The letter “b” corresponds to row two, etc. Rows with different letters have significantly different averages at an $\alpha = 0.05$ using the Tukey Kramer HSD test for mean comparisons with unequal variance.

***Rows with different letters have significantly different variances at an $\alpha = 0.05$ using the modified Levene test.
There was statistical evidence ($\alpha = 0.05$) for Hackberry (*Celtis occidentalis*), Red Oak (*Quercus rubra*) and White Oak (*Quercus alba*) 4-quarter lumber at Mill K for all machine centers that the standard deviations in the last two months of the study period were lower than in the beginning of the study period (Figures 34, 35 and 36).

**Figure 34.** Box-Whisker plots of thickness for Hackberry 4-quarter lumber for all sawing centers for Mill K.

**Figure 35.** Box-Whisker plots of thickness for Red Oak 4-quarter lumber for all sawing centers for Mill K.
Both the left and right headrigs for Mill K had lower standard deviations for Red Oak (*Quercus rubra*) 4-quarter Red Oak lumber than did the resaw sawing center for the same species and product. This higher standard deviation for the resaw center for this species is a constraint to lower target sizes. The 4-quarter lumber for the Mill K headrigs had higher target sizes than may be necessary. However, unless Anderson-Tully Corporation is interested in developing sawing center specific target sizes, the resaw is the limiting factor for reduced target sizes and cost savings. Resources should be dedicated to determining the sources of variation in 4-quarter lumber at the resaw for Mill K.

Figure 36. Box-Whisker plots of thickness for White Oak 4-quarter lumber for all sawing centers for Mill K.
Mill D experienced a statistically significant reduction ($\alpha = 0.05$) in average thickness for Ash (*Fraxinus caroliniana*) 4-quarter lumber one month after the real-time SPC system was installed (Figure 37). The average thickness for this species declined by 0.056” in the second month and another 0.031” in the third month. The average thickness stabilized for the remaining months of the study at approximately 1.110”. The long-term decline of 0.060” represented a significant cost savings to Anderson-Tully Corporation (Figure 37 and Table 2). All thickness data for Mill D are in Appendix F.

Table 2. Average, median and standard deviations for Ash 4-quarter lumber at Mill D.

<table>
<thead>
<tr>
<th>Month-Year</th>
<th>Number of Samples</th>
<th>Average Thickness</th>
<th>Means Test**</th>
<th>Sample Standard Deviation</th>
<th>Sample Variance Test***</th>
<th>Median</th>
<th>Median Test ****</th>
</tr>
</thead>
<tbody>
<tr>
<td>March– 2001</td>
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<td>--</td>
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<tr>
<td>April – 2001</td>
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<tr>
<td>May – 2001</td>
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<tr>
<td>June – 2001</td>
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<tr>
<td>July – 2001</td>
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<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>August – 2001</td>
<td>33</td>
<td>1.170”</td>
<td>a</td>
<td>.019496”</td>
<td>a</td>
<td>1.169”</td>
<td>a</td>
</tr>
<tr>
<td>September– 2001</td>
<td>1015</td>
<td>1.114”</td>
<td>b</td>
<td>.055765”</td>
<td>b</td>
<td>1.116”</td>
<td>b</td>
</tr>
<tr>
<td>October – 2001</td>
<td>232</td>
<td>1.083”</td>
<td>c</td>
<td>.037046”</td>
<td>bc</td>
<td>1.088”</td>
<td>c</td>
</tr>
<tr>
<td>November – 2001</td>
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<td>1.094”</td>
<td>d</td>
<td>.031639”</td>
<td>bcd</td>
<td>1.090”</td>
<td>cd</td>
</tr>
<tr>
<td>December– 2001</td>
<td>409</td>
<td>1.101”</td>
<td>de</td>
<td>.046329”</td>
<td>e</td>
<td>1.098”</td>
<td>e</td>
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<tr>
<td>January -2002</td>
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<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>February-2002</td>
<td>627</td>
<td>1.112”</td>
<td>b</td>
<td>.043201”</td>
<td>e</td>
<td>1.110”</td>
<td></td>
</tr>
</tbody>
</table>
Mill D also experienced a statistically significant reduction ($\alpha = 0.05$) in average thickness for Cottonwood (*Populus deltoides*) 4-quarter lumber one month after the real-time SPC system was installed. The average thickness for this species declined in successive months by approximately 0.035” (Figure 38 and Table 3). The long-term decline of 0.035” may represent a significant cost savings at Mill D.

![Box-Whisker plots of thickness for Cottonwood 4-quarter lumber for all sawing centers at Mill D.](image)

**Figure 38.** Box-Whisker plots of thickness for Cottonwood 4-quarter lumber for all sawing centers at Mill D.

**Table 3.** Average, median and standard deviations for Cottonwood 4-quarter lumber at Mill D.

<table>
<thead>
<tr>
<th>Month-Year</th>
<th>Number of Samples</th>
<th>Average Thickness</th>
<th>Mean Test**</th>
<th>Sample Standard Deviation</th>
<th>Sample Variance Test***</th>
<th>Median</th>
<th>Median Test ****</th>
</tr>
</thead>
<tbody>
<tr>
<td>March– 2001</td>
<td>--</td>
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<td>May – 2001</td>
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<td>July – 2001</td>
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<tr>
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<td>422</td>
<td>1.173”</td>
<td>a</td>
<td>.022411”</td>
<td>a</td>
<td>1.176”</td>
<td>a</td>
</tr>
<tr>
<td>September– 2001</td>
<td>602</td>
<td>1.165”</td>
<td>b</td>
<td>.031267”</td>
<td>b</td>
<td>1.167”</td>
<td>b</td>
</tr>
<tr>
<td>October – 2001</td>
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<td>1.147”</td>
<td>c</td>
<td>.034648”</td>
<td>bc</td>
<td>1.151”</td>
<td>c</td>
</tr>
<tr>
<td>November – 2001</td>
<td>707</td>
<td>1.152”</td>
<td>d</td>
<td>.022387”</td>
<td>ad</td>
<td>1.152”</td>
<td>d</td>
</tr>
<tr>
<td>December– 2001</td>
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<td>1.147”</td>
<td>cde</td>
<td>.030644”</td>
<td>bc e</td>
<td>1.151”</td>
<td>cde</td>
</tr>
<tr>
<td>January -2002</td>
<td>--</td>
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<td>--</td>
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<td>--</td>
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<tr>
<td>February-2002</td>
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<td>cde</td>
<td>.025374”</td>
<td>d</td>
<td>1.151”</td>
<td>cde</td>
</tr>
</tbody>
</table>
Components of Variance

Sanders et al.’s (1994) statistical technique for estimating “within-board” and “between-board” variance as two components of total variance was used in the study. Since the resaw machine center has the largest total variance relative to other machine centers, the components of variance analysis may be helpful to Anderson-Tully Corp. in focusing resources on improving the most limiting machine center which limits future lumber target size reductions.

Mill K. -- “Within-board” variation was generally the largest component of variance for every species for all of Mill K’s machine centers (Tables 9g to 32g, Appendix G). A discussion with Anderson-Tully Corp. quality control personnel revealed that “timber-bind” might be an important source of “within-board” variation at both headrigs. “Timber-bind” is the delay in the movement of the middle-knee of the log carriage, which has a direct impact on the amount of movement of the middle portion of the log during sawing (Figure 39). The log is allowed to move less relative to the position of the middle knee if the “timber-bind” is set to a greater thickness (e.g., from 1/5” to ½”).

An analysis of “within-board” and “between-board” variance for 4-quarter Red Oak (Quercus rubra) for Mill K suggested that the “within-board” variance was the largest proportion of variation for all machine centers (Figures 40, 41, 42 and 43). The “within-board” variance as a proportion of total variance was more pronounced for both headrigs.
Figure 39. An illustration of “timber bind.”

Figure 40. Mill K "within" and "between" percent variation for the left headrig 4-quarter Red Oak.
Figure 41. Mill K "within" and "between" percent variation for the right headrig 4-quarter Red Oak.

Figure 42. Mill K "within" and "between" percent variation for resaw 4-quarter Red Oak.
Mill D. – “Within-board” variation was the largest component of variance for every 4-quarter species for Mill D’s left and right headrig machine centers (Tables 1g to 8g, Appendix G). The resaw machine center for Mill D had the larger proportion of “between-board” variance relative to “within-board” variance. An analysis of “within-board” and “between-board” variance for Batesville 4-quarter cottonwood (*Populus deltoides*) for Mill D (an important product type for Mill D) suggested that the “within-board” variance was the largest proportion of variation for all machine centers (Figures 44, 45 and 46). The “between-board” variance as a proportion of total variance was more pronounced at the resaw machine center for Mill D (Figure 46). A discussion with Anderson-Tully Corp. quality control personnel indicated that “un-square” cants might be the source of “between-board” variation.
Figure 44. Mill D "within" and "between" percent variation for the left headrig Batesville 4-quarter Cottonwood.

Figure 45. Mill D "within" and "between" percent variation for the right headrig Batesville 4-quarter Cottonwood.
Figure 46. Mill D "within" and "between" percent variation for resaw Batesville 4-quarter Cottonwood.
**Impact on Lumber Recovery and Grade**

A component of the fourth study objective was to determine if the application of the real-time SPC thickness improvement system had an impact on lumber recovery. Lumber recovery studies were conducted at Mills D and K “before” installation of the real-time SPC system and “after” installation of the real-time SPC system. The data used for lumber recovery analysis at both mills was actual daily recovery and average log volume (Doyle scale) collected by ATCO personnel. The species mix produced by each mill is presented in Figures 47 and 48.

It was not possible to complete the lumber recovery studies as outlined in the study proposal. While TFPC personnel were able to complete the pre-SPC installation lumber recovery studies at both mills for two species, it was not possible to match up species, average log size, and lumber product thickness for post-SPC installation recovery studies. The recovery data collected by ATCO personnel and used for this analysis actually increases the reliability of the results since it includes a larger log sample size and was collected over a longer period of time.

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Figure 47. Species distribution for Mill K during study period.
The “before” and “after” lumber recovery studies were enhanced by statistical analysis of the daily overrun lumber recovery statistic over the entire study period. The daily overrun statistic was because ATCO monitored lumber recovery using overrun and a long-term trend of overrun was available.

The statistical analysis consisted of analyzing the daily overrun using univariate and multivariate control charts (Hotelling 1947, Young et al. 1999). \(^4\) Overrun is defined as the ratio of lumber recovered from a set of logs to the scale of the logs:

![Species distribution for Mill D during study period.](image)

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\(^4\) Multivariate control charts are useful for understanding the multivariate mean of a process when variables are not independent. Multivariate control charts may be useful in analyzing sawmill productivity in detecting unusually high or low overrun. Since the overrun statistic is highly correlated with average log volume, a point above the control limit on the Hotelling’s T2 multivariate control chart would indicate special-cause variation. This event of special-cause variation may be the result of instances of lack of correlation between overrun and average log volume, opposite correlations between overrun and average log volume, unusually large or small overruns, or unusually large or small average log volume, etc. In this study a trend or increase in the variability in Hotelling’s T2 statistic for data within the control limit would indicate a change in the significance of the correlation between overrun and average log volume, e.g., overrun increasing at a faster rate than the rate of decline in average log volume. The Hotelling’s T2 multivariate control chart may be a better method for detecting true changes in overrun.
Many authors have noted the limitations of the use of the overrun lumber recovery statistic, *i.e.*, *overrun will increase as log diameter declines* (Brown 1982, 1997; Wengert 1993). ATCO uses the Doyle log rule to estimate the board footage of lumber in a log. The Doyle log rule estimates the volume based on log length, diameter, slabs, edgings, shrinkage and production of sawdust. In the Doyle log rule the allowance for slabs and edgings is too large for small logs and is too small for large logs. Therefore, the rule under-scales small logs and over-scales large logs. Inaccuracies of the rule also include only a 4.5% reduction of log volume for sawdust and shrinkage (most rules allow between 10-30%) and no allowance for taper.

Analytical limitations of the overrun lumber recovery statistic may be reduced with the use of multivariate control charts (Young *et al.* 1999). Multivariate control charts were used in the analysis given the moderate correlation between daily overrun and average log volume (Doyle scale).

An additional analysis that was not included in the original proposal consisted of an assessment of the daily change in “Common and Better” grade as a percentage of total lumber volume. The additional analysis of the potential impact of the real-time SPC thickness improvement system on lumber quality was an outcome of discussions with ATCO operations and management personnel. The discussions followed quality control staffs’ observations of periodic improvements in lumber quality from a reduction in

5 Overrun does not take into account inherent scale inaccuracy, poor scaling, simple error, small logs, improper deduct, or good sawmill practice (Williston 1988).
“thin-edges” which are caused from excessive within-board thickness variation. “Thin-edge” lumber is defined as lumber with thickness on the long-edge of the lumber that is below the minimum thickness specification. The occurrence of “thin-edges” on FAS grade lumber lowers the grade to 3C. The economic loss form a FAS to 3C grade reduction was significant.

**Mill K - Lumber Recovery.** -- The average overrun for Mill K for all species increased by approximately 2.6% after installation of the real-time SPC thickness improvement system (Figure 49). The variation in overrun was also greater after installation of the real-time SPC thickness improvement system. There was no statistical shift in average log volume after installation of the real-time SPC thickness improvement system (Figure 50). Average log volume variation was greater after installation of the real-time SPC thickness improvement system, which may correspond to the increase in variation in overrun. As expected, the correlation in overrun and average log volume for Mill K was significant (r = - 0.807, Figure 51). A multivariate control chart (Hotelling’s T2) of the overrun and average log volume indicated that an increase in variation had occurred after installation of the real-time SPC thickness improvement system (Figure 52). The out-of-control points of the multivariate control chart were due to atypically higher overrun. It is not clear as to the cause of the increased variation in both overrun and average log volume. The installation of SPC to monitor sawing variation should not have had any effect on the log supply or the method of estimating the board footage in the logs. It is likely that some variation in log supply (log diameters) also occurred at this time, which is indicated by the variance in the average log volume.
A review of overrun by species for Mill K indicated that Hackberry (*Celtis occidentalis*) had an improvement of 4% overrun after installation of the real-time SPC thickness improvement system (Figures 7h, 8h and 9h, Appendix H). The overrun increased despite an increase of 1% in the average log volume. There was an improvement in Red Oak (*Quercus rubra*) overrun of 5% and an increase 1.1% in average log volume after installation of the real-time SPC thickness improvement system (Figures 14h, 15h and 16h, Appendix H). Since the Doyle log rule typically overestimates the amount of lumber volume in a large diameter log and underestimates lumber volume on small diameter logs, it would be expected that as the average log volume increases, that overrun would decrease. The increases in both overrun and average log volume for Hackberry and Red Oak may indicate that increases in lumber recovery occurred after installation of the real-time SPC thickness improvement system.

![X-Individual Chart of Overrun % for Mill K](image)

**Figure 49.** X-Individual control chart of overrun for all species for Mill K.
Figure 50. X-Individual control chart of average log volume (Doyle scale) for all species for Mill K.

Figure 51. Mill K Correlation of overrun and average log volume – Doyle scale (1/01 to 3/02).
Mill K - Grade. — Typically the financial success of sawmills is dependent on the amount of No.1 “Common and Better” lumber that can be produced from the log supply. If more “Common and Better” lumber can be produced out of the same log supply, than an increase in profitability and log utilization has been achieved.

The “Common and Better” average grade had a statistical shift of 3% after installation of the real-time SPC thickness improvement system (Figure 53). The slope of a trend line through the daily “Common and Better” grade percentages was 0.06% and was statistically significant at an $\alpha = 0.05$ (Figure 54). The increase in “Common and Better” lumber was a result of quality improvements from use of the real-time SPC thickness improvement system realized from reductions in “thin-edges” on lumber (e.g., less wedge-shaped lumber). Operations and quality control personnel at Anderson-Tully Corporation noted reductions in “thin-edges” from use of the real-time SPC thickness improvement system.
improvement system. The reduction in “thin edges” is an example of using SPC as a continuous improvement methodology to prevent the manufacture of defective product.

![Image of X-Individual chart of “Common and Better” percentage for Mill K.]

**Figure 53.** X-Individual chart of “Common and Better” percentage for Mill K.

![Image of Trend line of “Common and Better” percentage for Mill K.]

**Figure 54.** Trend line of “Common and Better” percentage for Mill K.

\[ y = 55.3 + 0.06x \]

\[ R^2 = 0.065 \]
**Mill D – Lumber Recovery.** -- The average overrun for Mill D for all species declined by approximately 1% after installation of the real-time SPC thickness improvement system (Figure 55). The variation in overrun also declined after installation of the real-time SPC thickness improvement system. There was a statistically significant increase of 1.1% in average log volume for all species after installation of the real-time SPC thickness improvement system (Figure 56). Average log volume variation declined after installation of the real-time SPC thickness improvement system. It is unlikely that the installation of the real-time SPC thickness improvement system had any effect on log supply and log measurement that would lead to the changes observed. As expected, the correlation in overrun percent and average log volume for Mill D was significant ($r = -0.681$, Figure 57). Given the moderate negative correlation between overrun percent and average log volume, a multivariate control chart of these statistics (Hotelling’s T2) indicated more long-term stability in overrun after installation of the real-time SPC thickness improvement system (Figure 58). The out-of-control points on the multivariate control chart corresponded to incidents of atypically low average log volume and corresponding low overrun percentages.

A review of overrun percentages by species for Mill D indicated that every species had an increase in average log volume by approximately 1% in October or November 2001, which resulted in a corresponding decline of approximately 1% in overrun for every species. The reason for the consistent 1% increase in average log volume for every species was the result of a change in the log scaling procedure. It seems unlikely that the average log volume for every species would increase by approximately the same percentage at the same time period.
Ash (*Fraxinus americana*) had a decline in overrun percent of 1% (note, corresponding increase in average log volume of 1.3%), Figures 16h, 17h and 18h, Appendix H. Cottonwood (*Populus deltoides*) had a decline in overrun percent of 1% (note, corresponding increase in average log volume of 0.9%), Figures 19h, 20h and 21h, Appendix H. Gum (*Nyssa sylvatica*) had a decline in overrun percent of 1% (note, corresponding increase in average log volume of 1.2%), Figures 22h, 23h and 24h, Appendix H. Pecan (*Carya illinoensis*) had a decline in overrun percent of 1% (note, corresponding increase in average log volume of 1.1%), Figures 25h, 26h and 27h, Appendix H. Sycamore (*Platanus occidentalis*) had a decline in overrun percent of 1.1% (note, corresponding increase in average log volume of 1.1%), Figures 28h, 29h and 30h, Appendix H. Willow (*Salix nigra*) had a decline in overrun percent of 1.1% (note, corresponding increase in average log volume of 1.1%), Figures 31h, 32h and 33h, Appendix H.

Figure 55. X-Individual control chart of overrun for all species for Mill D.
Figure 56. X-Individual control chart of average log volume (Doyle scale) for all species for Mill D.

Figure 57. Mill D correlation of overrun and average log volume (8/01 to 3/02)
Mill D - Grade. -- The “Common and Better” average grade for Mill D had a statistical shift of 4% after installation of the real-time SPC thickness improvement system (Figure 59). The slope of a trend line through the daily “Common and Better” grade percentages was 0.08% and was statistically significant at an $\alpha = 0.05$ (Figure 60). Quality improvements from use of the real-time SPC thickness improvement system at Mill D were realized from reductions in “thin-edges” on lumber.

Operations and quality control personnel at Anderson-Tully Corporation noted the reduction in “thin-edges” at Mill D from use of the real-time SPC thickness improvement system. The reduction in “thin edges” at Mill D may be another example of using SPC as a continuous improvement methodology to prevent the manufacture of defective product.
Figure 59. X-Individual chart of “Common and Better” percentage for Mill D.

Figure 60. Trend line of “Common and Better” percentage for Mill D.
Financial Return

The economic significance of reductions in lumber target sizes (i.e., *average lumber thickness*) has been well documented (Brown 1982, 1994, 1997; Wengert 1993; Young et al. 2000, 2002). Brown (1982) and Wengert (1993) have suggested that reductions in lumber target sizes of 0.030” can result in annual cost savings of $250,000 for a hardwood sawmill with the capacity of Anderson-Tully Corporation. The cost savings or market value benefits are realized through improved lumber recovery.

There was statistical evidence that overrun increased at Mill K by 2.6% for all species after installation of the real-time SPC thickness improvement system with no statistically significant change in average log size. Most of the overrun percent increases at Mill K were due to increases in overrun in Hackberry and Red Oak. There was statistical evidence that overrun declined at Mill D by 1.1% for all species after installation of the real-time SPC thickness improvement system. The decline in overrun for Mill D occurred for every species by approximately 1%, which was associated with an approximate 1% increase in average log volume for every species.

The estimated annual potential financial cost savings of the installation of the real-time SPC thickness improvement system for Mills K and D was approximately $752,100 (Table 4). Interpretation of the potential cost-savings was based on financial data provided by Anderson-Tully Corporation and was based on a savings of $709,120 due to overrun gain. An additional potential gain of $42,980 was estimated from the improvements in the percentage of “Common and Better” grade lumber.

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6 The financial gain was estimated from Table 4 assuming a 1.5% net increase in overrun, which was the difference between the 2.6% increase at Mill K and the 1.1% decline at Mill D.
Even though the overrun percent is subject to error given its correlation with average log volume, great care was taken in the assessment of potential overrun gain using accepted statistical methods.

Table 4. Cost savings of one percent increase in overrun at Anderson-Tully Corporation.

<table>
<thead>
<tr>
<th>Species</th>
<th>Bd Ft</th>
<th>Log Ft</th>
<th>overrun</th>
<th>1% Increase*</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash</td>
<td>7,059,735</td>
<td>4,872,239</td>
<td>1.45</td>
<td>70,597</td>
<td>$51,183</td>
</tr>
<tr>
<td>Cottonwood</td>
<td>20,405,509</td>
<td>17,424,778</td>
<td>1.17</td>
<td>204,055</td>
<td>$111,822</td>
</tr>
<tr>
<td>Hackberry</td>
<td>8,131,668</td>
<td>5,506,458</td>
<td>1.48</td>
<td>81,317</td>
<td>$29,274</td>
</tr>
<tr>
<td>Red Oak</td>
<td>19,501,147</td>
<td>15,717,298</td>
<td>1.24</td>
<td>195,011</td>
<td>$121,102</td>
</tr>
<tr>
<td>White Oak</td>
<td>3,921,508</td>
<td>2,989,362</td>
<td>1.31</td>
<td>39,215</td>
<td>$11,960</td>
</tr>
<tr>
<td>Pecan</td>
<td>6,941,772</td>
<td>5,527,055</td>
<td>1.26</td>
<td>69,418</td>
<td>$34,084</td>
</tr>
<tr>
<td>Poplar</td>
<td>3,572,359</td>
<td>2,856,757</td>
<td>1.25</td>
<td>35,724</td>
<td>$28,328</td>
</tr>
<tr>
<td>Sycamore</td>
<td>3,916,313</td>
<td>2,894,923</td>
<td>1.35</td>
<td>39,163</td>
<td>$25,573</td>
</tr>
<tr>
<td>Willow</td>
<td>4,458,580</td>
<td>3,547,697</td>
<td>1.26</td>
<td>44,586</td>
<td>$29,872</td>
</tr>
<tr>
<td></td>
<td>77,908,591</td>
<td>61,336,567</td>
<td></td>
<td></td>
<td>$443,200</td>
</tr>
</tbody>
</table>

*Note the 1% increase was estimated by Anderson-Tully Corporation using sales average prices for 4-quarter lumber for each species, i.e., it assumes that the additional 4-quarter lumber footage realized for each species could be sold at existing prices.
Conclusions

Competitive pressures in the hardwood lumber industry are not likely to subside in the future. Improved sawmill efficiency and low manufacturing costs will be critical for the successful hardwood sawmill of the 21st century. The philosophy of continuous improvement and statistical process control (SPC) provide manufacturers with the ability to reduce lumber thickness variation, improve yield and lower manufacturing costs. Real-time SPC is a contemporary philosophy that enhances Shewhart’s traditional SPC philosophy of using the control chart to prevent the manufacture of defective product. Real-time SPC reduces the time interval between the viewing of process data and taking action on product variability. Real-time SPC is proactive and results in lower product defects relative to traditional SPC, which focuses on monitoring historic production data.

An applied statistical study was conducted to determine if a low cost, real-time SPC system could be developed for Anderson-Tully Corporation. The applied statistical study was part of a broader research initiative known as the Tennessee Quality Lumber Initiative (TQLI). The research goal of the TQLI is to conduct applied research in the area of manufacturing systems improvement for sawmills that will contribute to improving lumber quality and utilization of the forest resource.

The real-time SPC system was developed for approximately $27,000 (equipment costs only). Features of the system included a PC server using Wonderware® human machine interface technology with distributed real-time control charts in all sawing centers and management offices. Thickness data were gathered using wireless caliper technology. The system had real-time alarming of special-cause variation and a Microsoft Access 2000® reporting system.
There was statistical evidence ($\alpha = 0.05$) at Mill D that suggested that the average thickness of 4-quarter Ash ($Fraxinus caroliniana$) declined by 0.060” over the course of the study period. The average thickness of Cottonwood ($Populus deltoides$) 4-quarter lumber at Mill D declined by approximately 0.035” during the study period. Reductions in lumber thickness for other species at Mill D were inconclusive. There was statistical evidence ($\alpha = 0.05$) that indicated that lumber thickness variation declined at Mill K for Red Oak ($Quercus rubra$), White Oak ($Quercus alba$) and Batesville 4-quarter lumber (any species in existing product-species mix).

There was statistical evidence ($\alpha = 0.05$) at Mill K that lumber thickness variation declined over the study period for the left and right headrig sawing centers. The resawing center at Mill K had the most lumber thickness variation and is a constraint for reducing target sizes for all machine centers.

The average overrun for Mill K for all species increased by approximately 2.6% after installation of the real-time SPC thickness improvement system. The average overrun for Mill D for all species declined by approximately 1.1% after installation of the real-time SPC thickness improvement system. The decline in overrun at Mill D was due to a consistent 1% increase in average log volume for all species, which was due to a log grading procedure change at Mill D, e.g., an automated method of recording log grading changed the log grade estimate. We believe the log grading procedural change negated the ability to detect any improvement in overrun from the installation of the SPC system.

The “Common and Better” average grade had a statistical shift of 3% at Mill K after installation of the real-time SPC thickness improvement system due to a reduction in “thin-edges” on lumber. The “Common and Better” average grade for Mill D had a
statistical shift of 4% after installation of the real-time SPC thickness improvement system.

The estimated annual potential financial cost savings of the installation of the real-time SPC thickness improvement system for Mills K and D was approximately $752,100. Interpretation of the potential cost-savings was based on financial data provided by Anderson-Tully Corporation and was based on a savings of $709,120 due to a 1.5% overrun gain. An additional potential gain of $42,980 was estimated from the improvements in the percentage of “Common and Better” grade lumber.

The potential benefits from adopting a "low-risk" technology such as real-time SPC should not be ignored by the hardwood lumber industry. Even though this is an applied statistical study at two hardwood sawmills, there is evidence that other hardwood sawmills may benefit from the use of real-time SPC by reducing lumber thickness variation and target sizes. Additional research is needed to assess the quantitative improvements in lumber yield and manufacturing costs from the use of real-time SPC.
Recommendations for Anderson-Tully Corporation

- Reassess target sizes at mills D and K relative to the findings of this study.
- Determine sources of variation for the resaw machine centers at Mills K and D (these sawing centers are the limiting factors for reducing target sizes for both mills).
- Continue to sample lumber and use the real-time SPC system to put constant downward pressure on target sizes and understand sources of variation.
- Continue training plant personnel in the principles of SPC (sawyers should be included in this training).
- Aggressively investigate sources of lumber thickness variation at all sawing centers for both mills.
- Quantify the impact of target size reduction on lumber recovery.
- Assess the financial gain from target size reduction.
- Publicize the impacts of target size reduction and of real-time SPC impacts to all mill personnel (applaud their contributions).
- Invest in a real-time thickness laser measurement system and integrate the system with the existing Wonderware SPC system.
- Develop feedback rules for responding to out-of-control points (e.g., saw changes).
Literature Cited


