Tennessee Quality Lumber Initiative (TQLI)

Reducing Lumber Thickness Variation and Targets using Real-Time Statistical Process Control

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La Grande, Oregon Sawmill

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Executive Summary

Competitive market pressures and constrained softwood log supply are external factors that are changing the softwood sawmill industry in the 21st century. Successful softwood sawmills continue to strive for improved production efficiency and low manufacturing costs while maintaining competitive product value. Softwood lumber thickness is intentionally over-sized during manufacture to allow for sawing variation, drying shrinkage and surfacing. The over-sizing of softwood lumber thickness due to excessive sawing variation requires higher target sizes and are an opportunity cost to softwood sawmills. Competitive softwood 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 lumber recovery.

A technology feasibility study was conducted from June 2001 to March 2002 at the Boise Corporation sawmill in La Grande, Oregon. There were four study objectives for each mill: (1) develop a low cost, real-time statistical process control (SPC) system to monitor lumber thickness targets and variation and; (2) distribute the real-time SPC system to all sawing centers and supervisor offices; (3) train appropriate Boise Corporation personnel in the principles of SPC; and (4) determine if the real-time SPC system had an effect on lumber thickness variation, target sizes, lumber recovery and manufacturing costs.

The first study objective was satisfied. A real-time SPC system was developed for both mills for approximately $13,000. Features of the system included a PC server 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® SQL 7.0 database structure. The most expensive components of the real-time SPC system were the Wonderware® HMI software ($2,500), Mitutoyo® wireless caliper receiver boxes (~$2,500), 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 format was 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 Boise Corporation’s LAN using “PC Anywhere” software.

The third study objective was satisfied when four management personnel were trained in the principles of statistical process control. Division-level quality personnel from Boise Corporation trained operations personnel at La Grande in the principles of statistical process control.

The fourth study objective was partially satisfied. There was statistical evidence ($\alpha = 0.05$) that suggested that the average thickness of 4-quarter lumber declined at the headrig and resaw sawing centers over the course of the study period. There was also statistical evidence ($\alpha = 0.05$) that suggested that the standard deviation of 5-quarter lumber declined at the headrig and resaw sawing centers over the same time period.

The EDLF sawing center had the highest standard deviation for 4-quarter and 5-quarter lumber and was the limiting factor for further target size reductions. Sawline 4 of the EDLF had the highest standard deviation relative to other EDLF sawlines. The
The largest component of variance at the EDLF was “between-board” variance which was most pronounced on sawline 4.

The EDLF sawing center was the least capable sawing center of meeting specifications. The most capable sawing center of meeting specifications was the gangsaw. The resaw sawing center had a significant improvement in capability in the winter of 2002.

The technology feasibility study of developing a low cost real-time SPC system should be repeated in several more softwood 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 will continue at the existing softwood sawmill and include more detailed lumber recovery and financial analyses. It is recommended that the next phase of the feasibility study investigate the feasibility of using laser systems to measure lumber thickness.

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

Softwood lumber thickness is intentionally over-sized to allow for sawing variation, surfacing and shrinkage during the drying process. The amount of material that must be removed from rough-cut softwood 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:

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

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 over-sizing of softwood lumber during the sawing process, leads to financial losses and impairs an organization’s competitiveness. Some have suggested that the

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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.
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; Wengert 1993).

Traditional quality control programs in the softwood lumber industry vary greatly and are tailored to the individual needs of a sawmill. One quality control function that all sawmills have in common is the grading of lumber, which is based on rules established by a governing association which ensures consistent lumber grading standards. Even though the grading of softwood 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 20). Excessive lumber thickness variation can also reduce the grade of lumber, e.g., wedge-shaped lumber less than nominal thickness on any edge.

The contemporary philosophy of continuous improvement is based upon 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 head-rig carriage, long-term mechanical improvements to head-rig carriage, etc.
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 to improve the quality of lumber and improve utilization of the timber resource.
Lumber Initiative is an applied research initiative at The University of Tennessee, Tennessee Forest Products Center.

**Project Definition**

The purpose of this project was to develop and implement a valid green lumber measurement system at the La Grande, Oregon sawmill. Management at the mill selected a team to undertake the project.²

**Mission Statement**

The team agreed on the following mission statement: “Develop and implement a valid green lumber measurement system to optimize profit and fiber recovery.” The team agreed to accomplish the mission by: (1) examining current processes; (2) researching alternatives; and (3) recommending and implementing a measurement system.

**Research Objectives**

There were four research project objectives from the perspective of The University of Tennessee: (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; (3) train appropriate management and operational personnel in the principles of statistical process control; and (4) determine if

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² The team members consisted of: Mike Looslie – QC Supervisor (Team Leader), Albert Diggle – Mill Supervisor, Chris Greenough – Head Saw Filer, Glenn Ganon – Maintenance Superintendent, Brenda Dick – Administration (Team Recorder), Melissa Fullerton – Accountant, Pat Dodge – Mill Superintendent (Team Sponsor) and Rick Springer – Region Total Quality Manager.
the real-time SPC system had an effect on lumber thickness variation, target sizes, lumber 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 and Guess 1994). In this study SPC was used to quantify lumber thickness variation.

The primary tool of SPC is the control chart, which quantifies variation as either special-cause or common-cause variation (Figure 2, page 23). 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 outside the control limits). Samples outside the control limits are often referred to as “out of control” samples.
Real-time SPC is a powerful continuous improvement tool where machine operators and managers see real-time process data on control charts (Figure 3). 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.
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.
This study expands upon previous research, which examined methods for reducing softwood lumber target sizes and thickness variation (Brown and Page 1994; Cassens et al. 1994). Even though previous research addressed the use of SPC to improve softwood 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).

**Human Machine Interface Platforms**

Human Machine Interface (HMI) technology is the key interface of 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 26).

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® has greatly reduced the cost of HMI technology. Affordable HMI technology has created opportunities for the use of real-time SPC in the softwood lumber industry that did not exist ten 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 the La Grande sawmill. The sawing centers at the La Grande sawmill were gangsaw, headrig, EDLF and resaw (Figures 5, 6, 7, 8, 9, 10, and 11 pages 27 to 31). HMI platforms were also installed at the saw-filing room at the La Grande sawmill and at the supervisors’ office. Remote access and viewing of the real-time SPC system from Boise, Idaho using “PC Anywhere” software were also part of the system.
Figure 5. Real-time SPC resaw sampling station.
Figure 6. Headrig real-time SPC display.
Figure 7. EDLF real-time SPC display.

Figure 8. Resaw real-time SPC display.
Figure 9. “Saw file” room real-time SPC display.

Figure 10. Distance of real-time SPC display from “Saw-file” personnel.
Figure 11. Supervisors’ office real-time SPC display and PC server.
Methods

Real-Time Statistical Process Control HMI Platform

Wonderware’s InTouch 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 SQL 7.0®. All data were stored in Microsoft SQL 7.0® from which a “Crystal Reports” reporting system was developed. The main display screen for the headrig included control charts of “forward pass” and “backward pass” lumber thickness (Figures 12 and 13). All screens developed in the real-time SPC system are presented in Appendix A. All encoding using Wonderware® scripting is presented in Appendix B.

Figure 12. Main Wonderware® InTouch SPCPro display window for “Headrig.”
Real-time viewing of histograms 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 of the thickness data relative to specification limits (Figure 13).

Figure 13. Wonderware® InTouch SPCPro histograms window for headrig.
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 14).

Figure 14. Wonderware special-cause variation corrective action display for headrig.
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 Boise Corporation’s LAN using PC Anywhere® software. The research objective of developing a low cost real-time SPC system was satisfied using the pre-described system architecture (Figure 15).

Figure 15. General system architecture of real-time SPC system.
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 16). The wireless caliper transmitted data up to 150 feet from the antenna of the receiver (Figure 17, page 37). 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 16. Mitutoyo© caliper with transmitter.
Individual Board Measurements

Ten measurements were taken for each piece of lumber. The measurements were dispersed uniformly along the board where two sets of five measurements each were taken along each edge (Figure 18, page 38). 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 suggestions and prior research conducted by Brown (1982), Young et al. (2000) and Young et al. (2002).

Note, six measurements were originally taken starting in June 2001. The “Green Lumber Measurement Team” and research facilitators at the La Grande Sawmill decided in September 2001 to take 10 measurements per board to improve the ability to recognize patterns in thickness of lumber.
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 19).

**Figure 18.** Location of thickness measurements on an individual board.

**Figure 19.** Pattern recognition potential from consistent measurement locations.
A sampling platform was developed for the resaw in the winter of 2002. The sampling platform was developed to be ergonomically friendly, *i.e.*, *boards could be sampled 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.

**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.
Gage R&R Study using the Handheld Wireless Caliper

With the determination of how many pieces to sample and how to measure each piece, the team performed a measurement system analysis consisting of gage R&R studies (Wheeler and Lyday 1989). The first study results were less than satisfactory. Table 1 contains the results of the gage R&R study. Bolded items show the deficiencies with the caliper – too much variation attributed to the gage and not enough discrimination (indicated by the number of distinct categories). The general rule regarding the percent of variation attributed to the gage is ten percent or less. A result between 10 and 30% indicates the gage may be acceptable depending on the criticality of the attribute measured. The division standard is that less than 30% is generally acceptable. The rule regarding discrimination is that there should be five distinct categories. Plant management worked with the interns to attempt to reduce the variation attributed to the measurement system through training and standardization. The team improved test results by teaching personnel standard measuring procedures, coupled with practice and using the gage R&R testing as a training method (Table 2). The percent of variation fell to approximately 14% and the percent of tolerance was reduced to less than 30%. The number of distinct categories rose to 10, indicating a satisfactory measuring tool for the purposes of this project.
# Gage R&R Study - XBar/R Method

**Gage R&R for Results**

<table>
<thead>
<tr>
<th>Source</th>
<th>Variance</th>
<th>%Contribution (of Variance)</th>
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</thead>
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<td>Repeatability</td>
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<td>8.74</td>
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<tr>
<td>Reproducibility</td>
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<td>7.44</td>
</tr>
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<td>Part-to-Part</td>
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<tr>
<td>Total Variation</td>
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<td>100.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>StdDev (SD)</th>
<th>Study Var (5.15*SD)</th>
<th>%Study Var (%SV)</th>
<th>%Tolerance (SV/Toler)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Gage R&amp;R</td>
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<tr>
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<td>27.27</td>
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</tr>
<tr>
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<td>91.55</td>
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</tr>
<tr>
<td>Total Variation</td>
<td>2.35E-02</td>
<td>0.120876</td>
<td>100.00</td>
<td>201.46</td>
</tr>
</tbody>
</table>

Number of distinct categories = 3

**Table 1.** Gage R&R study before training.
The team followed the Boise Corporation “HOW” continuous improvement process in undertaking the project. The first step was to identify the opportunity. The team perceived the lack of a measurement system to be a cause of less than optimum performance in the area of fiber recovery which affects financial performance of the plant. In the second step of the HOW process, the team found that the current
measurement process consisted of set-up measures being taken and tracked using the L-size program. This process suffered from several shortcomings:

1. Personnel recorded only set-up measures and they only gathered the measures twice daily. This resulted in very few data points for analysis.
2. The L-size program limited the available statistical analysis to a select few charts.
3. The system did not present data real-time.
4. The data was available to a limited audience with no operators involved.
5. The data was not used to control or improve the sawing processes.

Along with the L-size, operators and filers monitored saw performance with the curve-catcher system. The system tracks saw deflection as logs are processed with real-time information fed back to the machine operator. The shortcoming here was that none of the data was captured for use in analyzing and improving the performance of the log sawing systems.

The next step for the team was to examine alternatives. The team reviewed four alternatives – 1) maintain the status quo, 2) enhance the L-size system, 3) install an optical scanning system, and 4) work with the University of Tennessee’s forest products lab to build a proprietary system. Given that the current system suffered the above-mentioned shortcomings, the team determined that maintaining the status quo was not a viable option. A vendor presented to the La Grande Team the latest in optical scanning methods for monitoring green lumber sizes. This system used cameras coupled with computer technology to determine size and feed the information back to the appropriate personnel. This system consisted of leading edged technology and possessed operating and environmental requirements incompatible with the La Grande operation. The team’s
main concern regarded poor sawmill lighting, flying sawdust and stained lumber affecting system performance. The team determined this system was not yet feasible for the La Grande operation. The team determined that two viable alternatives existed – enhancing the L-size system or developing a system with assistance from the University of Tennessee. The following table is the decision matrix used in evaluating the alternatives:

<table>
<thead>
<tr>
<th>Attribute</th>
<th>System</th>
<th>UT-Process</th>
<th>Discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost</strong></td>
<td></td>
<td>13,000</td>
<td>Cost to implement</td>
</tr>
<tr>
<td><strong>Computer Hardware</strong></td>
<td>Can run on existing</td>
<td>Requires additional</td>
<td></td>
</tr>
<tr>
<td><strong>Computer Software</strong></td>
<td>Exists</td>
<td>WonderWare, DDE?</td>
<td></td>
</tr>
<tr>
<td><strong>Availability of Personnel</strong></td>
<td>Oregon based</td>
<td>Tennessee</td>
<td>Timing issue?</td>
</tr>
<tr>
<td><strong>Service</strong></td>
<td>OK</td>
<td>OK</td>
<td>On-going service and support</td>
</tr>
<tr>
<td><strong>Networking</strong></td>
<td>Existing network capability</td>
<td>?</td>
<td>Compatibility with existing</td>
</tr>
<tr>
<td><strong>Info Feedback</strong></td>
<td>Not without adding monitors, etc</td>
<td>Yes</td>
<td>Feedback to operators, filers, mgrs., etc.</td>
</tr>
<tr>
<td><strong>SPC Flexibility</strong></td>
<td>Not without adding statistics software</td>
<td>Yes</td>
<td>Ability to select types of control charts, analysis, etc</td>
</tr>
<tr>
<td><strong>Expertise</strong></td>
<td>Typical lumber manufacturing</td>
<td>Strong SPC, PI</td>
<td></td>
</tr>
</tbody>
</table>

The team decided, given the above issues / concerns, to work with UT to develop the measuring system. Once the team decided, the next step was to build, test, and implement the system. Personnel from UT collaborated with plant personnel to determine the system components, measuring and sampling plans, statistical process control methods, and feedback loops.
Results

**Low Cost Real-Time SPC System**

The real-time statistical process control (SPC) system was developed for approximately $13,000 for the La Grande sawmill. 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 Wonderware® HMI software ($2,500), Mitutoyo® wireless caliper receiver box (~$2,500), and the wireless transmitter and caliper (~$1,600). 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 $13,000 total equipment costs for the real-time SPC system. These costs were estimated to be approximately $24,422 and were cost shared by the The University of Tennessee. The University of Tennessee cost share was part of the special grant awarded by the USDA for wood utilization research, contract R11-2218-054 (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 after the PC monitors were installed at the sawing control centers.

SPC Training

The training of key operations personnel at the La Grande sawmill in the principles of statistical process control was the responsibility of the Division-level Total Quality staff of Boise Corporation. Two division-level, one regional-level and one La Grande QC supervisor were trained in the principles of statistical process control by The University of Tennessee in 2000.\(^4\)

Lumber Thickness Averages and Variation

**Headrig.** -- There was statistical evidence to suggest that the averages and standard deviations for 4-Quarter lumber for both the forward and backward passes were lower in January and February 2002 when compared to the summer months of 2001 (Figures 20, 21 and 22). The reason for this decline may be due to an intentional reduction in target sizes given the lower standard deviations in January and February 2002.

---

\(^4\) 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.”
There was no statistical evidence to suggest that the standard deviations for either the forward or backward pass at the headrig were lower for 5-Quarter and 6-Quarter lumber thickness (Appendix C, Tables 24c, 25c, 27c and 28c). There was statistical
evidence ($\alpha = 0.05$) to suggest average thickness for 5-quarter lumber was lower for each consecutive month when samples were collected (Table 25c, Appendix C).

![Figure 22. Coefficient of variation for 4-quarter lumber at the headrig.](image-url)
Figure 23. Box-Whisker plots of 4-quarter lumber thickness for the headrig forward pass.

Table 3. Significance tests on average, variance, and median lumber 4-quarter thickness for headrig forward pass.

<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>
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<td>May–2001</td>
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<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
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</tr>
<tr>
<td>June–2001</td>
<td>--</td>
<td>--</td>
<td>--</td>
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<td>--</td>
<td>--</td>
<td>--</td>
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</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.

****Rows with different letters have significantly different medians at an $\alpha=0.05$ using one-sided Wilcoxon Rank Sum test.
Table 4. Significance tests on average, variance, and median lumber 4-quarter thickness for the headrig backward pass.

<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>
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<td>June–2001</td>
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</table>

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***Rows with different letters have significantly different variances at an $\alpha=0.05$ using the modified Levene test.

****Rows with different letters have significantly different medians at an $\alpha=.05$ using one-sided Wilcoxon Rank Sum test.
EDLF. -- There was statistical evidence ($\alpha = 0.05$) to suggest that the average thickness of 4-quarter lumber was thicker at the EDLF in the September and October of 2001 when compared to July and August 2001 (Figure 25). Sawline 3 produced thicker 4-quarter lumber when compared to the other sawlines. There was no statistical evidence to suggest that the standard deviation for any EDLF sawline changed during the study period (Figures 26 and 27). Refer to Figures 1c to 5c and Tables 1c to Tables 5c in Appendix C.

![Figure 25. Average Thickness of 4-Quarter Lumber at the EDLF.](image)

Figure 25. Average thickness of 4-quarter lumber at the EDLF.
Figure 26. Standard deviation of 4-quarter lumber at the EDLF.

Figure 27. Coefficient of variation for 4-quarter lumber at the EDLF.
**Resaw.** -- There was statistical evidence ($\alpha = 0.05$) to suggest that the average thickness of 4-quarter lumber declined for resaw sawline 2 over the study period (Figure 28, Figure 19c and Table 19c, Appendix C). Sawline 4, 4-quarter lumber had a significantly lower standard deviation relative to the other three sawlines of the resaw (Figure 29 and 30). There was no statistical evidence to suggest that the averages or standard deviations for 5-quarter lumber for the resaw, sawline 1 and 2 changed during the study period (Appendix C, Figures 26c and 27c, Tables 26c and 27c).

![Figure 28. Average thickness of 4-quarter lumber at the resaw.](image-url)
Figure 29. Standard deviation of 4-quarter lumber at the resaw.

Figure 30. Coefficient of variation of 4-quarter Lumber at the resaw.
Exponentially weighted moving average (EWMA) control charts of the Resaw sawlines were developed to determine if a shift in average thickness occurred for 4-quarter lumber during the interruption in measurements between October 2001 and January 2002. The EWMA charts suggest that average thickness has declined at all sawlines at the Resaw (Figures 18d to 21d, Appendix D).

![Figure 31. EWMA chart of resaw sawline 1.](image1)

![Figure 32. EWMA chart of resaw sawline 2.](image2)
Figure 33. EWMA chart of resaw sawline 3.

Figure 34. EWMA chart of Resaw Sawline 4.
Gangsaw. -- There was statistical evidence ($\alpha = 0.05$) to suggest that the average thickness of 4-quarter lumber for the gangsaw sawline 1 was greater than other sawlines at the beginning of the study period (Figure 35, Figure 6c and Table 6c, Appendix C). Sawline 4, 4-quarter lumber had a significantly lower standard deviation relative to the other three sawlines (Figures 36 and 37). The limiting factors for reducing target sizes at the Gangsaw appear to the higher standard deviations on sawlines 9 and 10.

![Figure 35. Average thickness for the gangsaw 4-quarter lumber](image-url)
Figure 36. Standard deviation for the gangsaw 4-quarter lumber

Figure 37. Coefficient of variation for the gangsaw 4-quarter lumber
**All Sawing Centers.** -- The limiting sawing center for reducing target sizes for 4-quarter lumber was the EDLF sawing center (Figure 38). When compared to other sawing center averages, the EDLF had the lowest average thickness (Figure 39). Opportunities may exist to further reduce target sizes at other sawing centers.

![Box-Whisker plot of standard deviations by sawing center.](image)

**Figure 38.** Box-Whisker plot of standard deviations by sawing center.

![Box-Whisker plot of averages by sawing center.](image)

**Figure 39.** Box-Whisker plot of averages by sawing center.
**Capability Analysis**

**Headrig.** – A capability analysis of 4-quarter lumber for the headrig, forward and backward passes, suggested that the backward pass was more capable in the winter 2002 relative to the fall of 2001. The improvement in capability is the result of a reduction in the backward pass standard deviation (Figures 1e-3e, Tables 1e-2e, Appendix E). The 5-quarter lumber for the forward and backward passes of the headrig was slightly more capable (Figure 13e-15e, Tables 12e-13e, Appendix E). Six-quarter lumber for the forward and backward passes of the headrig had the lowest capability of all products analyzed at the headrig (Figures 22e-24e, Tables 16e-17e, Appendix E).

**EDLF.** -- An analysis of the capability of 4-quarter lumber at the EDLF indicated that the EDLF was the least capable sawing center. There were two occurrences of negative $C_{pk}$ statistics, which indicated that the average thickness of 4-quarter lumber was greater than the upper specification limit (Figures 3e-6e, Tables 3e-4e, Appendix E).

**Resaw.** – The resaw capability for 4-quarter lumber for all sawlines significantly improved in the winter of 2002 (Figures 7e-9e, Tables 5e-6e, Appendix E). Sawline 4, 4-quarter lumber was the most capable of meeting specifications when compared to all other lumber produced at all of the other sawing centers.

**Gangsaw.** – The 4-quarter lumber produced on sawlines 1-5 at the gangsaw was more capable of meeting specifications relative to sawlines 6-10 at the gangsaw. With the exception of the resaw sawline 4, the gangsaw’s lower numbered sawlines had the highest capability (Figures 10e-12e, Tables 7e-8e, Appendix E).
Components of Variance

Headrig. -- An analysis of “within-board” and “between-board” variance for the forward pass 4-quarter lumber suggested that the “between-board” variance was the largest proportion of total variance (Figure 40). The “between-board” variance as a proportion of total variance was greater at the end of the study time period (Tables 1f and 2f, Appendix F).

An analysis of “within-board” and “between-board” variance for backward pass 4-quarter lumber at the headrig suggested that the “between-board” variance was the largest proportion of total variance (Figures 41). The trend in “between-board” variance was more pronounced near the end of the study time period (Tables 1f and 2f, Appendix F).

“Within-board” variation was the largest proportion of total variance for the 5-quarter lumber for both the forward and backward passes at the headrig (Tables 3f and 4f, Appendix F). The reason 5-quarter lumber had more “within-board” variation relative to
4-quarter lumber was unknown. There was no apparent pattern for “within-board” and “between-board” for 6-quarter lumber at the headrig (Tables 5f and 6f, Appendix F).

Figure 41. Headrig, backward pass "within" and "between" variation for 4-quarter lumber.

**EDLF.** -- An analysis of “within-board” and “between-board” variance for EDLF 4-quarter lumber suggested that sawlines 1, 2 and 3 had more “within-board” variation during the summer of 2001 (Tables 7f-10f, Appendix F). There was no dominant source of variation for sawlines 1, 2 and 3 during the fall of 2001. Sawline 4 for the EDLF had predominately more “between-board” variation during the study period (Figure 42).
**Resaw.** -- An analysis of “within-board” and “between-board” variance for the resaw 4-quarter lumber suggested that all sawlines had more “between-board” variation during the winter of 2002 (Tables 11f-14f, Appendix F). There was no dominant source of variation for any sawline during the summer and fall of 2001. Sawlines 3 and 4 for the resaw had a consistent pattern of more “between-board” variation during the study period (Figure 43).

---

**Figure 42.** EDLF "within" and "between" variation for 4-quarter lumber.
Gangsaw. -- An analysis of “within-board” and “between-board” variance for gangsaw 4-quarter lumber suggested that all sawlines had consistently more “within-board” variation during the study period (Tables 15f-24f, Appendix F). The pattern of predominate “within-board” variation was more pronounced the smaller the sawline number (Figures 43 and 44).
Figure 43. Gangsaw "within" and "between" variation for 4-quarter lumber, sawlines 1-5.

Figure 44. Gangsaw "within" and "between" variation for 4-quarter lumber, sawlines 6-10.
Lumber Recovery

The financial benefit of reducing variation in the sawing processes manifests itself in the improvement of the amount of fiber converted from the log to lumber. The Lumber Recovery Factor (LRF) improved during the periods of greatest use of the system and deteriorated when start-up issues and system faults prevented full employment of the system (Figure 45). Other factors that drive LRF were either constant or resulted in contrary trends, i.e., *diameter increased but LRF decreased*.

During June and July 2001, the project was in its early stages and a great deal of emphasis and communication surrounded the measuring of lumber thickness. During June and July 2001 LRF averaged 7.958 and 7.988 respectfully. This exceeded the

Figure 45. Control chart of Lumber Recovery Factor during study period.
baseline average of 7.849 with statistical significance of greater than 95% confidence. Late in August 2001, system failures caused a slowdown in data gathering and loss of immediate feedback. LRF in August 2001 was 7.869, which was greater than the baseline. September 2001 LRF was below the baseline average. The system was restored to full service in mid-September 2001. LRF improved in early October 2001.

**Financial Return**

True financial benefits of this project will result from proper application and utilization of the knowledge and data gathered. Reducing variation in green-lumber board thickness leads to reduced target sizes (Table 5). Reduced target sizes lead to more footage per log in the form of longer or wider or more boards being converted from the log. More footage of lumber from each log leads to lower wood costs on a product basis, thereby leading to improved profit or contribution margins. Table 5 illustrates the impact of sawing variation on target size.

<table>
<thead>
<tr>
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<th>Final Thickness</th>
<th>0.750</th>
<th>Final Thickness</th>
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<td>Planing Allowance</td>
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<td>Planing Allowance</td>
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<td>Shrinkage</td>
<td>3%</td>
<td>Shrinkage</td>
<td>3%</td>
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<td>Sawing Variation</td>
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<td>Undersize allowed</td>
<td>0.0034%</td>
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<td>Target</td>
<td>0.950</td>
<td>Target</td>
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</table>

Table 5. Impact of sawing variation on target sizes.

There is opportunity to improve recovery at La Grande by adjusting to target, i.e., many sawlines had averages greater than or equal to 0.980”. However, even greater potential exists by reducing variation. A reduction in standard deviation to 0.025” would enable a 0.020” reduction in target.

---

5 System failure at the La Grande sawmill was due to locating the PC hardware in an environment that did not have a controlled climate for ambient air temperature and humidity. The original location of the PC was contrary to the wishes of The University of Tennessee support team.
A “Saw-sim” simulation was made using Boise Corporation sawmill cutting patterns. The first iteration in “Saw-sim” had target sizes of 0.969” and the second iteration had target sizes of 0.949”. Both runs simulated sawing of the same set of logs (Table 6).

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</table>

Table 6. Saw-sim Logs
By reducing the target by 0.020”, the model produced 1% more lumber from the same set of logs. Along with generating more lumber, the products produced included more random width “shop”, less 1”x 4”, less 1”x 8”, and more 1”x 6”, 1”x 10” and 1”x 12” (Tables 7 and 8).

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<th>12'</th>
<th>14'</th>
<th>16'</th>
<th>Total</th>
<th>Percent</th>
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| Lumber Group: 5/4Shop |

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<th>12'</th>
<th>14'</th>
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<th>Total</th>
<th>Percent</th>
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</table>

Table 7. Sawsim Output at 0.969”
Based on actual data from the mill and simulation results, the La Grande sawmill has the potential to add $210,000 to revenue generated through September of 2001.

Considering factors of reduced shavings volume and reduced manufacturing cost per unit, the net impact to the bottom line was approximately $165,000 for nine months or $220,000 annually.

<table>
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<p>| Lumber Group: 5/4Shop |</p>
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<th><strong>8'</strong></th>
<th><strong>10'</strong></th>
<th><strong>12'</strong></th>
<th><strong>14'</strong></th>
<th><strong>16'</strong></th>
<th><strong>Total</strong></th>
<th><strong>Percent</strong></th>
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Table 8. Sawsim Output at 0.949”
Conclusions

Competitive pressures in the softwood lumber industry are not likely to subside in the future. Improved sawmill efficiency and low manufacturing costs will be critical for the successful softwood 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 is reactive and 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 the Boise Corporation sawmill in La Grande, Oregon. The applied statistical study was part of a broader research initiative by The University of Tennessee 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 $13,000. 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 using a Microsoft SQL 7.0\textsuperscript{©} database structure with a Crystal Reports\textsuperscript{©} reporting system.

There was statistical evidence ($\alpha = 0.05$) that suggested that the average thickness of 4-quarter lumber declined at the headrig and resaw sawing centers. There was also statistical evidence that the variation at the headrig and resaw sawing centers declined. The limiting factor for further reductions target sizes were the large variations associated with EDLF sawlines. The large variations of the EDLF sawlines make the EDLF the least capable sawing center of meeting specifications. Most of the variation at the EDLF sawline is due to “between-board” variation.

Based on actual data from the mill and the simulation results, the La Grande mill has the potential to add $210,000 to revenue generated from reduced target sizes. Considering factors of reduced shavings volume and reduced manufacturing cost per unit, the net impact to the profitability is approximately $165,000 for nine months or $220,000 annually.

The potential benefits from adopting a "low-risk" technology such as real-time SPC should not be ignored by any softwood lumber company. Even though this is an applied statistical study at one sawmill, the evidence is strong enough to suggest that real-time SPC may be beneficial to the entire softwood industry. Additional research is needed to assess the quantitative improvements in lumber yield and manufacturing costs from the use of real-time SPC.
Recommendations for Boise Corporation

The recommendation was to vigorously promote the system in 2002 at the La Grande sawmill to realize the potential financial gains documented in this study. The steps required to do this were:

- Evaluate staff needed to continue thickness measurement (level of measurement at the gangsaw should be reduced),
- Evaluate the logistics of the physical measurement process, (i.e., can measurements be safely taken at the machine center? If so, should the data collection employ radio frequency to transmit information?),
- Prioritize efforts on the EDLF and resaw,
- Standardize set up procedures,
- Mistake proof the measurement system (e.g., make the system more user friendly),
- Systematically identify sources of special-cause variation at all sawing centers,
- Systematically identify sources of common-cause variation at all sawing centers,
- Employ a real-time data collection system that will collect process data as related to lumber thickness,
- Investigate affordable laser measurement technology for real-time SPC.
Literature Cited


Appendix A

Wonderware® Screens for the La Grande Sawmill