8-2001

A modified six sigma approach to improving the quality of hardwood flooring

Thomas N. Williams

To the Graduate Council:

I am submitting herewith a thesis written by Thomas N. Williams entitled "A modified six sigma approach to improving the quality of hardwood flooring." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

Timothy M. Young, Major Professor

We have read this thesis and recommend its acceptance:

Brian Bond, Frank Guess, Paul Winistorfer

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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A Modified Six Sigma Approach to Improving the Quality of Hardwood Flooring

Masters Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Thomas N. Williams
August, 2001

DEDICATION

This masters thesis is dedicated to my wife:

Nichole,

who provides a loving, caring,

encouraging and supportive atmosphere.

These are characteristics that contribute to the environment

that is always needed to achieve the goals ahead.

To David Bianconi for his support, friendship,

and helping me understand all about life and CHEESE!

To Orsa for helping to relieve the stress!

To the many friends who support me.

ACKNOWLEDGEMENTS

Many people have contributed to my learning experience at the University of Tennessee. I am thankful for my masters thesis advisor, Timothy M. Young, for his insight, thought provoking questions and guidance for my thesis. He has provided growth for my professional career, over the last two years, in more ways than I can express. In addition, I have also benefited from the other members of my thesis committee, Dr. Brian Bond, Dr. Frank Guess, and Dr. Paul Winistorfer, who provided an open door for questions and detailed suggestions that greatly improved my understanding of in-depth research. This work was supported by a special grant from the United States Department of Agriculture (USDA) for wood utilization research, under contract number R11-2218-95 and also funded by University of Tennessee, Agricultural Experiment Station McIntire-Stennis Funding #75.

I would also like to thank other members of the Tennessee Forest Products Center for their support and help through out this process. Many hours of data collecting was accomplished with the help of David Cox and my brother Nick Williams. Lab samples were prepared and tested with the help of Chris Helton.

Thanks to my best friend J.C. for always being there for me even when I could not make time for you. Thanks to David Bianconi for the weekly talks and guidance you shared from your heart and life experiences. Thanks to all the friends that supported me.

Finally, I am indebted to my wife, Nichole, for her continuous support, sacrifice and LOVE that allowed me to complete my masters thesis.

ABSTRACT

Total quality or continuous improvement is a consensus theme used by many industries for improving product quality and service. In the last decade a newer quality philosophy known as "Six Sigma" has become well established in many companies, *e.g., Motorola, General Electric, Ford, Honda, Sony, Hitachi, Texas Instruments, American Express, etc*. Some have suggested that the "Six Sigma" quality improvement philosophy is not only impacting the global business sector, but will also re-shape the discipline of statistics. The "Six Sigma" philosophy for improving product and service quality is based upon existing principles established by other well-recognized quality experts, *e.g., Deming, Juran, and Ishikawa*. The significant departure of the "Six Sigma" philosophy from existing quality philosophies is that it promotes a stronger emphasis on monitoring production yield and manufacturing costs associated with any quality improvement effort. The other significant contribution that "Six Sigma" makes to the quality movement is the detailed structure for continuous improvement and the step-by-step statistical methodology. The goal of any "Six Sigma" improvement effort is to obtain a long-term defect rate of only 3.4 defective parts-per-million manufactured.

The problem definition of the thesis was to determine if a modified "Six Sigma" philosophy for continuous improvement would improve the quality of hardwood flooring. The study was conducted over a six-month time period at a hardwood-flooring manufacturer located in Tennessee.

There were six research objectives: 1) Define the current-state of product variability for hardwood "flooring-veneer" and the specific attributes of "finished blank"

length, width, and "veneer-slat" thickness; 2) Determine the capability of the product attributes defined in objective one relative to specification limits; 3) Determine the current production yield and manufacturing costs associated with the manufacture of "veneer-slats;" 4) Define the sources of variability that influence the product attributes "finished blank" length, width, and thickness, and "veneer-slat" thickness (This involved a detailed understanding of the relationships that existed between key process variables that influenced "finished blank" length, width, and thickness and "veneer-slat" thickness); 5) Recommend to senior management the improvements necessary to enhance the overall quality of "veneer-slats;" 6) If any of the recommendations are adopted from objective five, the first four objectives would be repeated to determine if quality has improved.

There were four major findings resulting from this work. First, there was statistical evidence (at $\alpha = 0.05$) that top (p-value = 0.0007) and bottom (p-value = 0.0167) "veneer-slat" thickness increased as "finished blank" thickness increased. There was no significant statistical evidence (p-value = 0.3904) that indicated the thickness of the three middle "veneer slats" was affected by "finished blank" thickness. Second, 20% of rejected "veneer-slats" were good and 10% were down-gradable. Third, there was statistical evidence (p-value = 0.1126) that indicated "rip-saw" width was in control and the natural tolerance was 0.428 mm, which was within engineering tolerance. Target sizes of "rip-saw" width should be reduced to improve yield. Fourth, drying stresses and honeycomb were present in dried lumber. Drying schedules and proper conditioning of kiln loads were not appropriately executed. There was statistical evidence (p-value =

0.0001) that indicated top and bottom "veneer-slat" width was greater than the middle "veneer-slats" given the drying stresses.

Four recommendations made to senior management were: 1) If "finished blank" thickness variation could be reduced by improving blank molder setup there would be a cost savings of $520,000 dollars per year; 2) A conservative estimate of the cost savings associated with the recovery of the 20% misdiagnosed "veneer-slats" would be $500,000 dollars per year; 3) Analysis of the "rip-saw" indicated an 8% yield increase if "rip-saw" target sizes and saw kerf were reduced and; 4) Appropriate drying and conditioning schedules should be followed to reduce "veneer-slat" width stresses and moisture content variation (eliminating top and bottom "veneer-slat" width variation would result in cost savings of $10,000 dollars per year). None of the previously mentioned recommendations would require capital investment by the company.

Keywords. -- Modified "Six Sigma," hardwood flooring, continuous improvement, quality improvement, variation reduction, cost savings, yield improvement.

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CHAPTER 1

INTRODUCTION

In the early 20th century most U.S. forest products companies enjoyed the benefits of inexpensive raw material and low labor costs. For most forest products companies of this era, technology was a leading constraint to improved production (Maki 1993). Quality of final wood products during this era was of minimal importance to most wood producing companies (Young and Winistorfer 1999).

As the U.S. forest products industry entered the 21st century, they were faced with a panacea of issues. Environmental regulation and preservation interests have reduced the availability of wood fiber and resulted in higher raw material costs. Air quality restrictions have forced many forest products companies to invest in expensive air-quality control equipment. Labor costs are higher in the U.S. relative to labor costs in developing countries. The U.S. forest products industry is also faced with increasing domestic and international market competition from non-wood products such as plastic, aluminum, and concrete. The scenario faced by most U.S. forest products companies is lower profit margins due to higher raw material and manufacturing costs in the context of stable real-prices for final wood products. These economic constraints have forced many U.S. forest products companies to reassess manufacturing practices (Young and Winistorfer 1999). Some U.S. forest products companies have started assessing the potential benefits that may occur from adopting continuous improvement philosophies such as the "Six Sigma" quality philosophy (Young and Winistorfer 1999).

Total quality or continuous improvement is a consensus theme used by many industries for improving product quality and services (Young and Guess 1994; Young and Winistorfer 1999). In the last decade a newer quality philosophy known as "Six Sigma" has become well established in many companies, *e.g., Motorola, General Electric, Ford, Honda, Sony, Hitachi, Texas Instruments, American Express, etc.* (Harry 1997, 1998, 2000; Blakeslee, J.A., Jr. 1999). Some have suggested that the "Six Sigma" quality improvement philosophy is not only impacting the global business sector, but also will re-shape the discipline of statistics (Hahn *et al.* 1999).

The founder of the "Six Sigma" quality philosophy is Mikel Harry (Harry 1997, 2000). Harry's (2000) significant departure from existing quality philosophies is a stronger emphasis on monitoring production yield and manufacturing costs associated with the continuous improvement effort. Harry's (2000) other significant contribution to quality is the organization and step-by-step statistical methodology that he feels is necessary for successful continuous improvement.

The phrase "Six Sigma" is derived partially from statistics and capability analysis. A "Six Sigma" company is defined by Harry (2000) as one that produces a product and/or service that has variability, which is approximately six sample standard deviations (*i.e., six sigma* $\approx 6s$) inside the customer's specification limits. This results in the long-term manufacture of defective product at a rate of only 3.4 parts-per-million. Significant cost savings are associated with this higher level of quality.

Thesis Hypothesis

The hypothesis of this thesis was to determine if a modified "Six-Sigma" quality philosophy can improve the quality of hardwood flooring over a 6-month time frame. Improvements were defined by an improved production yield and decreased manufacturing costs.

Thesis Objectives

There were six research objectives: 1) Define the current-state of product variability for the specific attributes of "finished blank" length, width, and thickness and "veneer-slat" thickness; 2) determine the capability of the product attributes "finished blank" length, width, and thickness and "veneer-slat" thickness as related to engineering specifications; 3) determine the current production yield and manufacturing costs associated with the manufacture of "veneer-slats"; 4) define the sources of variability that influence the "finished blank" length, width, and thickness and "veneer-slat" (This involved a detailed understanding of the relationships that existed between key process variables that influenced the "finished blank" length, width, and thickness and "veneer-slats"); 5) recommend to senior management the improvements necessary to enhance the overall quality of "veneer-slats" and; 6) if any of the recommendations were adopted from objective five, the first four objectives would be repeated to determine if the quality of the product attributes have improved.

Contributions to Research

There were potential benefits of the thesis that may be useful to the forest product industry. The "Six Sigma" philosophy provides a step-by-step quality improvement methodology that uses statistical methods to quantify variation. The "Six Sigma" philosophy also estimates cost savings and yield improvements from variation reduction.

The results of this thesis work contributed to other quality philosophies by showing that significant sources of variability can be identified in a short period of time. However, modifications of the "Six Sigma" philosophy limit the degree to which quality can be improved in the short-term. The result of this work suggested an estimated large potential cost savings to the cooperating hardwood flooring manufacturer. The results of this thesis also showed that the "Six Sigma" philosophy may represent a long-term cultural shift for many forest products companies with traditional management styles.

CHAPTER 2

LITERATURE REVIEW

Competitive market pressures and economic scarcity of raw material will force many forest products companies to continually improve the quality of manufactured products. Such market pressures, combined with economic scarcity of wood fiber, will also force forest products companies to reassess inefficient and wasteful manufacturing practices.

The quality movement, which arose in Japan in the 1960s and forced the U.S. automotive industry to reassess its quality philosophies in the 1980s, is being adopted again by the U.S. forest products industry at the start of the 21^{st} century. For most wood produces companies the driving force in this quality effort is not offshore market competition, but domestic market competition combined with non-wood product substitution and economic scarcity of wood fiber.

U.S. companies in general have attempted to implement many quality and business improvement philosophies during the past quarter of a century, *e.g., Continuous Improvement, Total Quality Management, Reengineering and Six-Sigma Quality* (Deming 1986, 1993, Harry and Schroeder 2000, Juran 1992). Some companies have been successful in improving business profitability through improved quality while many have been unsuccessful (Grant *et al.* 1994, Harry and Schroeder 2000, Young *et al.* 2000). Even though there has been a panacea of quality improvement philosophies, many businesses have struggled to quantitatively define any business improvement after implementing a quality improvement initiative (Hayes *et al.* 1988). Many scholars feel the distinguishing factor between a successful and unsuccessful quality improvement strategy is that successful strategies have an underlying foundation in statistical methods (Breyfogle 1999, Ishikawa 1987, Juran and Gryna 1993). The contributions made by Deming, Juran, Ishikawa, Taguchi, Feigenbaum, and Harry to the overall quality movement through the use of statistical methods cannot be ignored (Aguavo 1990, Deming 1986 and 1993, Walton 1986).

Historical Perspective of Quality – Contributions by W.A. Shewhart

Quality initiatives began to develop in the early 1930s. Walter Shewhart made a significant contribution to the philosophy of quality improvement with his book "Economic Control of Quality of Manufactured Products" (Shewhart 1939). Shewhart (1939) with a stroke of a pen developed the control chart, which relied on probability and statistical theory to define common-cause and special-cause variation of manufactured products (Wheeler and Chambers 1992). Shewhart's work provided the statistical basis for many quality improvement initiatives of the 20th century (Shewhart 1931, 1939).

Shewhart's quality improvement philosophy represented a significant departure from the Scientific Management manufacturing philosophy of the 1930s and earlier (Taylor 1911). Even though Shewhart's views were being practiced within Bell Laboratories, most manufacturers of this era adopted the ideas and concepts of Scientific Management promoted by Frederick Taylor (Taylor 1911). Taylor is associated with the extreme division of labor and with using time and motion studies to turn people into mindless automatons (Hayes *et al.* 1988). Scientific Management had four basic principles: (1) Find the most efficient way to do a job; (2) Match people to tasks; (3) Supervise, reward and punish; and (4) Use staff to plan and control (Hayes *et al.* 1988).

Many feel that Taylorism led to the birth of managers and collective bargaining (Hayes *et al.* 1988). A statistician's view of Taylorism may find one serious shortcoming, *i.e., Taylorism does not attempt to define the natural variation of a process* (Deming 1986, 1993, Shewhart 1931, Shewhart and Deming 1939, Taylor 1947).

Shewhart continued to enhance his quality improvement philosophy in his second book titled, "Statistical Methods from the Viewpoint of Quality Control" (Shewhart and Deming 1939). Shewhart's second book introduced his colleague W. Edward Deming to many readers interested in quality control and improvement. The general theme conveyed by Shewhart and Deming in the book was that quality and productivity can be continually improved, *i.e., "as quality improves, costs decrease and productivity increases"* (Shewhart 1939). They introduced the notion of the "customer" and they felt the role of the manufacturer was to deliver a product to the customer that not only met their quality needs but also exceeded their expectations (Deming 1986, 1993, Shewhart and Deming 1939). Deming believed, "A satisfied customer is not enough. Business is built on the loyal customer, one who comes back and brings a friend" (Deming 1986, 1993).

Controlling and reducing variation in manufacturing reduces defective products and rework. Shewhart's philosophy as related to the control chart identifies and quantifies process and product variation. By collecting time ordered data the process can be constantly monitored. The Shewhart control chart defines variation as being either common-cause variation (natural system variation) or special-cause variation. Shewhart defined common-cause variation as variation that is inherent to the manufacturing system. Common-cause variation is caused by day-to-day machinery variation, operator-to-operator variation, supplier variation, etc. Shewhart defined special-cause variation as variation that occurs from an event in the manufacturing process. The event may be due to downtime, start-up, a new supplier, motor-stop, tool-wear, etc. Shewhart observed that variation due to common-causes exhibited a symmetric or normal distribution whereas variation due to special-causes goes beyond natural variation and does not follow typical statistical laws (Shewhart 1931, Shewhart and Deming 1939).

Shewhart control charts have upper control limits (UCL) and lower control limits (LCL). Control limits should not be confused with specification limits or engineering tolerance.[1] Control limits are approximations of plus (UCL) or minus (LCL) three standard deviations from the process average (X-bar or $\overline{X}$), Figure 1. Shewhart calculated control limits as plus or minus three standard deviations from the process average because 99.7% of the data would be contained within these limits, *i.e., the probability of misdiagnosing a data point outside these limits as special-cause variation is 0.003* (Shewhart 1931, Shewhart and Deming 1939, Wheeler 1993).

Shewhart stated "a process will be in control when through the use of past experience, we can predict, at least within limits, how the process will behave in the future" (Shewhart 1931). Special-cause variation is unpredictable and indicates the process is out of statistical control (Shewhart 1931, Shewhart and Deming 1939, Wheeler 1993). The benefit to manufacturers from using Shewhart control charts comes from the ability to predict the future, *i.e., if the process is in a state of statistical control, the limits can be extended out in to the future* (Deming 1943, 1986, 1993). The Shewhart control chart also quantifies the natural variation of a process or product.

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[1] Engineering Tolerance is defined as the difference of the upper specification limit (USL) and the lower specification limit (LSL).

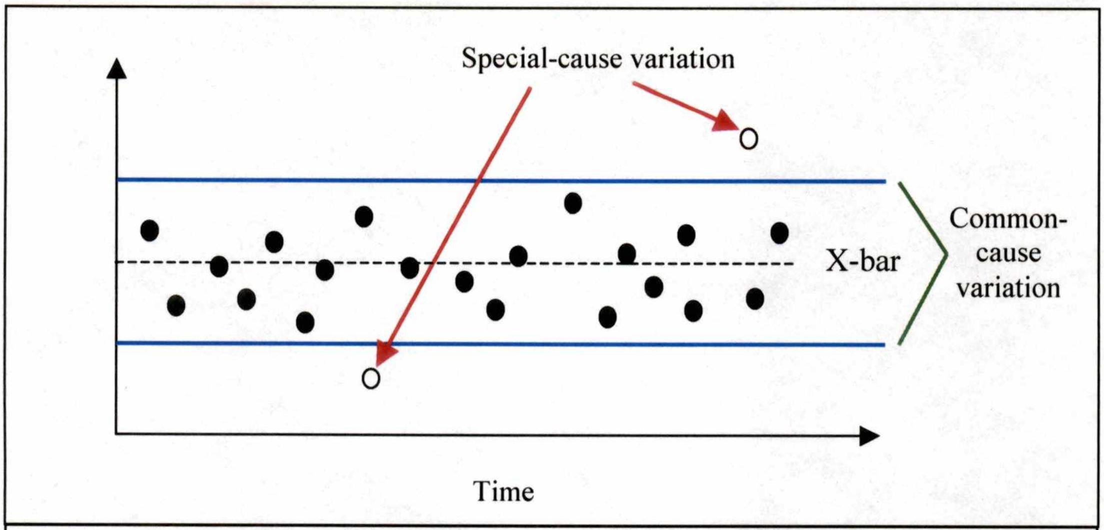

Figure 1. Illustration of Shewhart control chart.

Historical Perspective of Quality – Contributions by W.E. Deming

Even though W.E. Deming studied under W.A. Shewhart and was shunned by the U.S. automotive industry in the 1950s, he is considered by many to be the father of the "American Quality Revolution." In America, Deming became well known in 1984 after a prime-time NBC television broadcast titled, "If Japan can, Why can't we?" The television broadcast highlighted Japan's international business success in the 1970s and 1980s against the backdrop of a struggling U.S. economy and a U.S. automotive industry that was closing plants due to a loss of 25% market share due to Japanese competition (Walton 1986). The television broadcast highlighted Deming's work with the Japanese in the 1950s and 1960s and many feel the television broadcast was the start of the American Quality Revolution of the 1980s (Deming 1986, Scherkenbach 1991, Walton 1986).

Deming emphasized the importance of statistical thinking in the continuous improvement of processes. He felt that Statistical Process Control (SPC) and Shewhart's Plan-Do-Check-Act (PDCA) cycle were important tools to understanding sources of variability and improving processes. The continuous improvement philosophies of Deming were best communicated in his Fourteen Points for Management. His Fourteen Points served as a framework for quality and productivity improvement. Deming's 14 points were:

1. Create constancy of purpose toward improvement of product and service, with the aim to become competitive and to stay in business, and to provide jobs.

2. Adopt the new philosophy. We are in a new economic age. Western management must awaken to the challenge, must learn their responsibilities, and take on leadership for change.

3. Cease dependence on inspection to achieve quality. Eliminate the need for inspection on a mass basis by building quality into the product in the first place.

4. End the practice of awarding business on the basis of price tag. Instead, minimize total cost. Move toward a single supplier for any one item, on a long-term relationship of loyalty and trust.

5. Improve constantly and forever the system of production and service, to improve quality and productivity, and thus constantly decrease costs.

6. Institute training on the job.

7. Institute leadership. The aim of supervision should be to help people and machines and gadgets to do a better job. Supervision of management is in need of overhaul, as well as supervision of production workers.

8. Drive out fear, so that everyone may work effectively for the company.

9. Break down barriers between departments. People in research, design, sales, and production must work as a team, to foresee problems of production and in use that may be encountered with the product or service.

10. Eliminate slogans, exhortations, and targets for the work force asking for zero defects and new levels of productivity. Such exhortations only create adversarial relationships, as the bulk of the causes of low quality and low productivity belong to the system and thus lie beyond the power of the work force.

    - Eliminate work standards (quotas) on the factory floor. Substitute leadership.

    - Eliminate management by objective. Eliminate management by numbers, numerical goals.

11. Remove barriers that rob the hourly worker of his right to pride of workmanship. The responsibility of supervisors must be changed from sheer numbers to quality.

12. Remove barriers that rob people in management and in engineering of their right to pride of workmanship. This means abolishment of the annual or merit rating and of management by objective.

13. Institute a vigorous program of education and self-improvement.

14. Put everybody in the company to work to accomplish the transformation. The transformation is everybody's job (Deming 1986, 1993, Walton 1986).

Deming believed that one of the "great evils" of American management was to produce products or services to a "quality standard" or an "acceptable-level" of quality (Deming 1986). He felt that "quality standards" did not promote continuous improvement. He believed that "quality standards" produced numerical quotas, which were often times met "on paper" in the quarterly report but rarely could be verified on the plant floor.

Deming stressed the importance of constantly trying to improve product design and performance through research, development, testing, and innovation. He also emphasized that production and service systems should be continuously improved. He was emphatic about the idea that quality was not some minor function to be handled by inspectors, but a company's central purpose and a top priority of executive management. Deming felt that employees would not consider quality an important issue if there was not support and communication with executive management level within an organization (Deming 1986, 1993).

Deming understood the reason for Japan's success. He was quoted as saying "Hundreds of Japanese engineers learned the methods of Walter A. Shewhart. Quality became at once in 1950, and ever after, everybody's job, company wide and nation wide" (Aguavo 1990). Deming was also well known for his philosophy that reductions in variation lead to reductions in costs and improved productivity (Aguavo 1990, Deming 1986, 1993, Walton 1986).

Deming deemed that "quality is achieved through the never-ending improvement of the process, for which management is responsible" (Kilian 1992). Deming defined three quality categories: (1) "Quality of design/redesign;" (2) "Quality of conformance;" and (3) "Quality of performance." Quality of design is based on consumer research, sales analysis, and service call analysis and leads to the determination of a prototype that meets the consumer's needs (Gitlow 1987). In considering consumers' needs, the critical aspect is that firms look years ahead to determine what will help customers in the future. Next, specifications are constructed for the prototype and disseminated throughout the firm and back to the suppliers, *i.e., "Quality of Conformance."* "Quality of performance" is the determination through research and sales/service call analysis of how a firm's products or services are actually performing in the marketplace. "Quality of performance" leads to "quality of redesign," and so the cycle of the never-ending improvement continues (Aguavo 1990, Gabor 1998, Gitlow 1987).

Deming was a firm believer in Walter A. Shewhart's teachings of the "Control Chart." The understanding of common-cause and special-cause variation was a critical element of Deming's philosophies. Deming was quoted, "Management must realize that unless a change is made in the system (which only management can make), the system's process capability will remain the same. This capability will include the common-cause variation that is inherent in any system. Workers should not be penalized for common-cause variation; it is beyond their control" (Deming 1986, 1993, Gitlow 1987, Shewhart and Deming 1939).

Such things as poor-lighting, lack of training, or poor product design lead to common-cause variation. New materials, a broken die, or a new operator could cause special-cause variation. Workers can become involved in creating and utilizing statistical methods so that common and special-cause variation can be differentiated and process improvements can be implemented. Since variation produces more defective and less uniform products, the crucial understanding is that managers know how to reduce and control variation. Understanding and controlling variation can lead to the total achievement of quality (Deming 1986, 1993, Shewhart 1931, Shewhart and Deming 1939).

Managers must understand that there is no easy way to change the current situation. There can be no quick results because what is needed is a continuing cycle of improved methods of manufacturing, testing, consumer research, product redesign, etc.

This view extends to include the company's vendors, customers, and investors. All must play a role in the continuing improvement of quality.

Deming made great contributions to the quality movement through his work in statistical thinking and management philosophies. His work in statistics provided a way to analyze data for the purpose of improving and controlling processes. His idea was to reduce variation in the process by identifying possible sources of variation by using the statistical tools available. Once improvements were made to the process, the PDCA cycle was again reinitiated to promote continuous improvement (Aguavo 1990, Gabor 1998, Gitlow 1987, Walton 1986, Wheeler 1993).

Deming's Influence on Japan's Early Quality Initiatives

After World War II, Japan's economy was suffering from the post-war economic depression. In 1950 Dr. W. Edward Deming was invited by the Japanese Union of Scientists and Engineers (JUSE) to go to Japan. He gave a series of lectures on quality control to Japan's top engineers and managers. Unlike the United States, Japan embraced Deming's principles and began to experience positive results eighteen months after his first lecture.[2] Deming predicted Japan would begin to successfully compete in international markets within five years after his first visit. In the mid-1950s, Japan began to experience tremendous improvements in the quality of their products (Neave 1990). Deming's prediction was inaccurate. Japan began capturing international market share in the automotive and electronic industries within four years of his first visit (Aguavo 1990, Deming 1993, Walton 1986).

[2] The America of the fifties and sixties had scorned Deming and his teaching and in effect driven him abroad to find his students. America in those days was rich and unchallenged and there were few competing foreign products (Halberstam 1986).

Japan to this day (the world's 2nd largest economy) attributes their economic success to Dr. W. Edward Deming. Japan awards the coveted "Deming Prize" once a year to a Japanese company that has made the most significant improvements in quality. Japan televises the "Deming Prize" award presentation on prime-time TV in Japan which represents a significant departure from western culture TV programming (Aguavo 1990, Deming 1986, 1993, Gabor 1990, Walton 1986).

Other Important Contributors to the Quality Movement

There were many other scholars that made significant contributions to the quality movement. Joseph M. Juran, Genichi Taguchi, Armand Feigenbaum, and Kaoru Ishikawa are a few of the other recognized scholars that made significant contributions to the quality movement.

Joseph M. Juran

Joseph M. Juran was best recognized for his philosophies of "Total Quality Management" and "Cost of Quality." In the early 1960's, Juran initiated the concept of the cost of quality, which reemphasized management's responsibility for quality. He felt that quality related costs occurred in two categories: "unavoidable" and "avoidable." He felt that design-flaws contributed to "avoidable" costs incurred during manufacturing or from customer complaints. Juran felt that more planning and attention needed to occur at the design stage of products to reduce avoidable costs of poor quality (Juran and Gryna 1951, 1993).

Total Quality Management (TQM) refers to an integrated approach by management to focus all functions and levels of an organization on quality and continuous improvement. TQM emphasizes customer-focused quality not just for customers of the final product but also for the organization's internal customers (Kilian 1992). Implementation of TQM requires total participation and commitment company-wide.

TQM is not a program to achieve a specific, static goal, but instead is a process committed to continuous quality improvement. The reason why continuous quality improvement is an integral part of TQM is that Juran felt a company must continuously improve to survive in a fast-changing and highly competitive business environment (Grant *et al.* 1994).

Juran had significant contributions to the development of TQM. Juran believed, quality management's specific task was not only to identify and eliminate variation, but also to serve customer expectations. The entire company must embrace TQM as a customer focused quality improvement initiative (Grant *et al.* 1994, Juran 1992).

TQM comprises a group of techniques for enhancing competitive performance by improving the quality of products and processes (Grant *et al.* 1994). To successfully implement TQM systematic changes in management practice include: redesign of work, redefinition for managerial roles, redesign of organizational structures, learning of new skills by employees at all levels, and reorganization of organizational goals. Proper implementation of TQM has seen numerous financial gains for many companies (Grant *et al.* 1994).

Genichi Taguchi

In the 1960s Genichi Taguchi was best known for the development of the "Taguchi Loss Function." This function measures financial loss to an organization due to product variation. Taguchi emphasized in the "Taguchi Loss Function" the importance of manufacturing product that is "on-target." Taguchi felt that if variation were minimized around the target, the cost due to variation would also be minimized. Taguchi stressed that any deviation from the target will result in increased cost. In the Taguchi Loss Function the financial loss to an organization increases as a quadratic function the farther the product deviates from the target. Taguchi's Loss Function is in extreme contrast to traditional quality control where it is assumed that a financial loss does not occur until the product is outside of specification, *e.g., customer rebate or claim* (Figure 2). Taguchi and Deming felt that it was too late once a product was manufactured outside of customer specifications, *i.e., the customer may be lost forever* (Deming 1986, 1993). Taguchi's philosophy promoted the continuous reduction of variation (Fuller 1998, Ishikawa 1987, Taguchi 1993, Young and Winistorfer 1999).

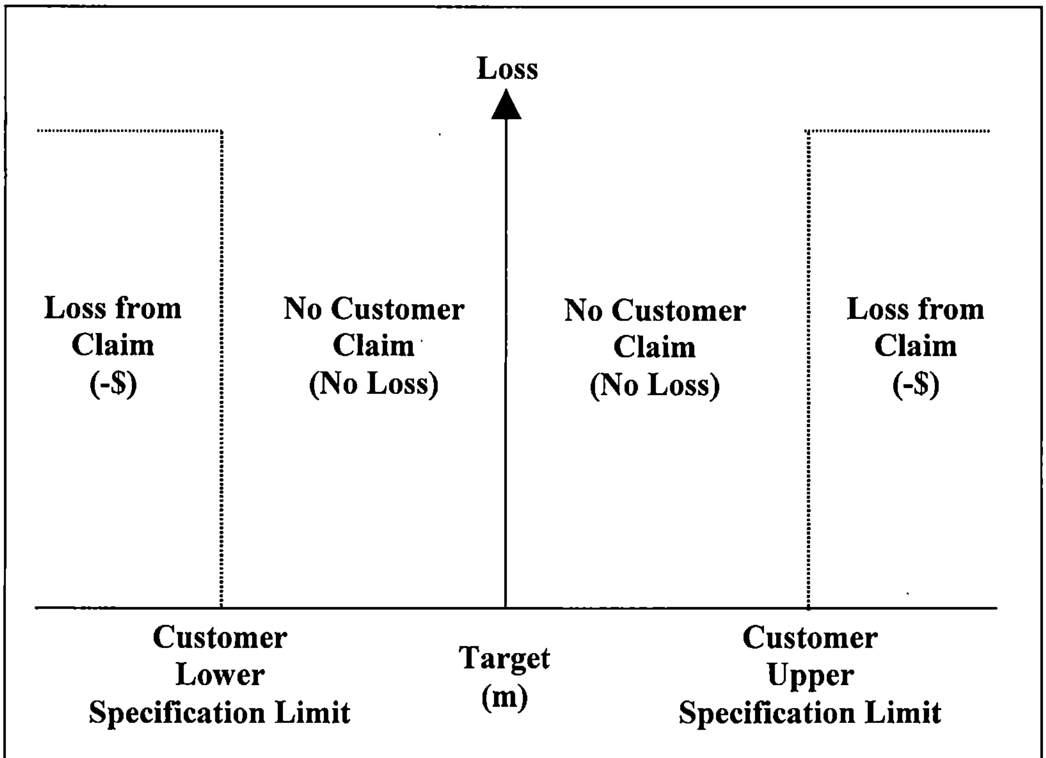

Figure 2. Traditional view of financial loss.

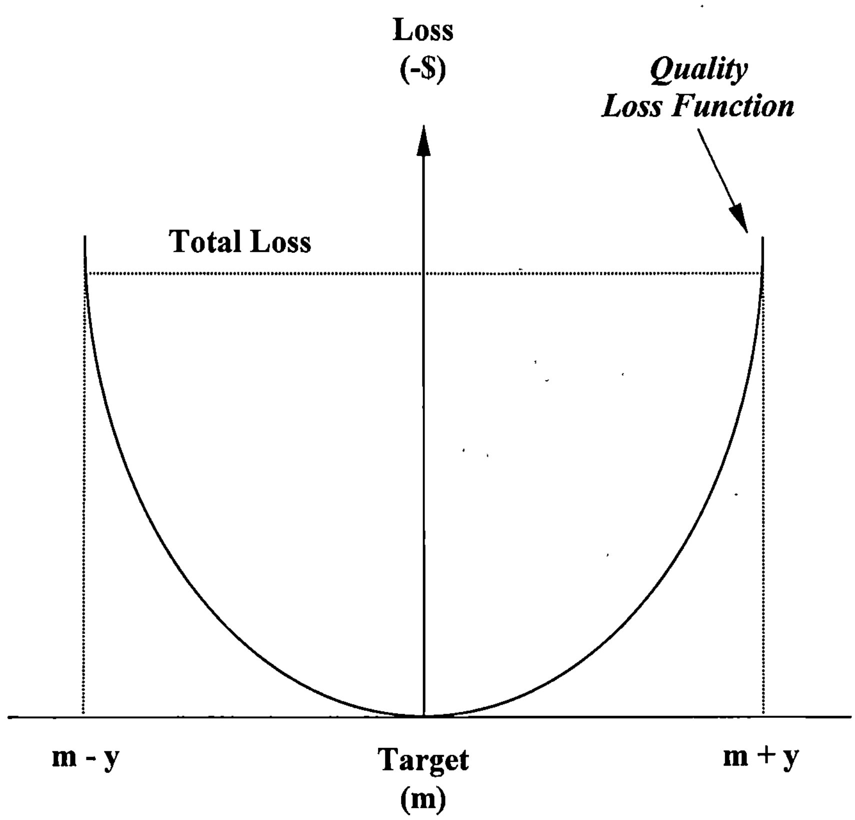

Figure 3. Illustration of the Taguchi Loss Function.

Taguchi's function is defined by an objective characteristic *y (e.g., thickness)* as it deviates from a target value ***m*** (Figure 3). The financial loss from deviations from target can be assumed to be a function of *y*, which is designated L(*y*). If $y = m$, L(y) ≅ 0. The Taguchi Loss Function shows that even small deviations form target induce financial loss even though the product remains usable to the producer or consumer (Young and Winistorfer 1999).

Deming stated, "The most important use of the Taguchi Loss Function is to help us change from a world of meeting specifications, to continue reduction of variation about the target through process improvements" (Deming1993). Deming's main argument was that conforming to some engineering tolerance limits was not good enough. Deming believed, manufacturing products that meet the target specification are closer to achieving continuous improvement than products that are not on target.

Taguchi also made contributions to the statistical discipline known as Design of Experiments (Taguchi 1993). Taguchi's "Robust Design" methodology consisted of three elements: "system design," "parameter design," and "tolerance design" (Nicholas 1998). "System design" is achieved through careful selection of parts, materials, and equipment. "Parameter design" is to produce a robust product or process that will remain close to target and will perform well under a range of variation elements in the production environment. "Tolerance design" is to reduce variation around the target value by tightening tolerances on factors that will affect the variation (Nicholas 1998).

Armand Feigenbaum

Armand Feigenbaum's major influence on the quality movement was his concept of "Total Quality Control." Feigenbaum defined "Total Quality Control," as "an effective system for integrating the quality-development, quality-maintenance, and quality-improvement efforts of the various groups in an organization to enable marketing, engineering, production and service at the most economical levels which allows for full customer satisfaction" (Feigenbaum 1991).

The word "Total" in "Total Quality Control" implied that quality control was everyone's job. Feigenbaum's definition of quality was to obtain complete customer satisfaction by providing a product and service that is designed, built, marketed, and maintained at the most economical cost. He felt that this philosophy would provide motivation for all company employees, from top management through assembly workers; including office personal, dealers, and service people (Feigenbaum 1991, 1996, 1997).

The scope of "Total Quality Control" relied on the underlying principles of quality to identify customer requirements. A complete measurement of customer requirements does not end until the product was placed in the hands of the consumer who continually remains satisfied. "Total Quality Control" was designed to guide synchronized actions of people, machines, and information to achieve the goal of customer satisfaction (Feigenbaum 1991, 1996, 1997).

The key features of Feigenbaum's concept of "Total Quality Control" were:

- Communication of quality in company-wide and plant-wide activities;
- Strategic planning for quality;
- Competitive market leadership through strong customer quality assurance;
- Measure of profitability improvement and return-on-investment from quality initiatives;
- Rapid product development and introduction;
- Maintaining and updating technology;
- Elimination of work building relationships with vendors and suppliers;
- Identifying key factors within an organization that lead to "Total Quality Control."

Kaoru Ishikawa

Kaoru Ishikawa is considered by many scholars to be the founder and first promoter of the "Fishbone" diagram (or Cause-and-Effect Diagram) for root cause analysis (Ishikawa 1987). He also is recognized for the concept of Quality Control (QC) circles. The philosophy of the "Fishbone" or Cause-and-Effect diagram represents a structured brainstorming approach to problem solving. The basic idea of the "Fishbone" diagram was to make a listing of all of the possible causes that may have an effect on a known problem. Ishikawa categorized the "Fishbone" diagram into five main categories (Materials, Methods, People, Machines, and Measurement), Figure 4. Ishikawa felt that the "Fishbone" diagram was a key tool to be used by workers for problem solving in Quality Control (QC) circles. Ishikawa felt strongly about the proper use of problem solving tools in the improvement of quality.

His concept of the Quality Control (QC) circle was to bring production workers, maintenance, design engineers, and managers together in organized meetings to solve problems. The QC circles were critical in the complete root-cause analysis of any problem. The QC circles were responsible for diagnosing problems and developing permanent solutions for problems (Hermens 1997, Ishikawa 1987, Nicholas 1998).

Traditional Quality Control versus Continuous Improvement

Traditional quality control was replaced in the 1980s in many U.S. companies with the philosophy of continuous improvement (Deming 1986, Juran 1992, Juran and

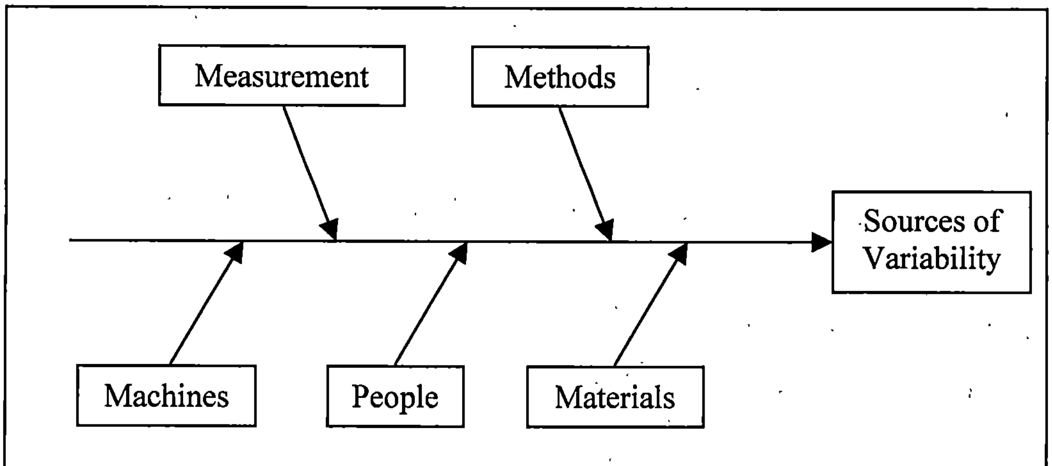

Figure 4. Example of the Fishbone Diagram.

Gryna 1993). Unfortunately, many U.S. forest products companies continue to practice the traditional philosophy of quality control (Young and Winistorfer 1999).

Key features of traditional quality control as defined by Cole (1998):

- Conformance checks to specification limits;
- Quality control is defined as a functional specialty within the company;
- Quality control is a specialized function carried out by technical experts;
- Focus is on inspection after the product is manufactured which promotes "reactive" behavior;
- No attempt to quantify variation;
- Product is manufactured to a standard within the framework of company quality goals, *e.g., quality goal in 2001 will be 96% A-grade*;
- Quality standards are agreed upon through consensus decision-making with executive management.

Traditional quality control does not focus on continuous improvement but is focused on conforming to specifications or engineering tolerance. There is no feedback-loop or cycle within the decision-making process of workers that promotes the improvement of quality through the reduction of process variation. Traditional quality control is reactive and focuses on the sorting of unacceptable product from acceptable product (Cole 1998, Deming 1986, Feigenbaum 1997, Fuller 1999). Traditional quality control concepts rely on technical experts to improve quality instead of involving all employees.

Continuous improvements initial focus is on defining customer needs and expectations. Continuous improvement contrasts with traditional quality control in that it involves all employees of the company and does not place the burden for quality conformance solely on the shoulders of technical experts. Key features of continuous improvement as defined by (Deming 1986, 1993, Juran 1992, 1995):

- Customer preferences are internalized in the design and manufacture of product;
- Continuous improvement is integrated in all aspects of a company's business culture;
- Quality of manufactured product or service is used to distinguish a company from other competitors;
- All employees are involved in the quality effort;
- Focus is on preventing the manufacture of defective product and not on reacting to product outside of specification;
- Cycle of continuous improvement that never ends (Plan-Do-Check-Act);
- All employees are trained in statistical methods and quality philosophies;
- Emphasis on communication across departments;
- Use of statistical methods to quantify variation and separate "fact" from "opinion;"
- Marketing function attempts to predict changes in customer needs and expectations.

Even though continuous improvement philosophies are present in many American industries (automotive, electronics and aerospace), many forest products companies tend to practice traditional quality control (Young and Winistorfer 1999). The "Technical Director" of a plant is responsible for quality and the testing-lab in which conformance checks are made (Young and Winistorfer 1999). Even though the aspect of "quality control" is important to the forest products industry, quality control by itself does not ensure the continuous improvement of processes and products.

The "Six Sigma" Quality Philosophy

The most recent quality philosophy to be adopted by businesses around the world is known as "Six Sigma." The founder of the "Six Sigma" philosophy is Mikel Harry (Harry and Schroeder 2000). Mikel Harry developed and implemented his "Six Sigma" philosophy with the Motorola Corporation and the philosophy has had great success at the GE Corporation (Harry and Schroeder 2000). Many companies such as Ford, Xerox, Intel, Honda, Sony, Hitachi, Texas Instruments, American Express, etc., have adopted the "Six Sigma" quality philosophy.

"Six Sigma" derived its name from the Greek letter sigma (σ). Sigma is used in statistics to define the parametric statistic "population standard deviation" (Pyzdek 1999). Six sigma is defined in statistics as six population standard deviations, which in a parametric sense would encompass 99.74% of the data population. The "Six Sigma" quality philosophy should not be confused with the statistical definition. Even though the "Six Sigma" quality philosophy derives its name from a statistic, it is a broad quality philosophy that focuses on using statistical methods to improve quality, decrease cost, reduce waste, rework, and streamline business operations (Breyfogle, 1999). The "Six Sigma" quality philosophy incorporates many of the traditional quality philosophies established by Shewhart, Deming, Juran, Taguchi, and Ishikawa. The "Six Sigma" philosophy enhances many of the established philosophies by developing an organized framework for continuous improvement (Harry and Schroeder 2000). The "Six Sigma" philosophy departs from traditional quality philosophies in its detailed focus on financial performance and its harsh treatment of employees that do not show a financial return from a "Six Sigma" quality initiative.

If "Six Sigma" quality is obtained, a company will only produce a long-term[3] rate of 3.4 defects per million parts produced (Figure 5, page 27). Financial benefits are substantial when an operating system performs at 6-sigma quality instead of 3-sigma quality where control limits equal the specification limits. At the operational level, the goal of implementing "Six Sigma" is to move product or service attributes within the zone of customer satisfaction and reduce process variation (Blakeslee 1999, Hahn *et al.* 1999, Harry and Schroeder 2000). "Six Sigma" closely examines companies' repetitive processes using statistical methods and translates customers' needs into separate tasks by defining the optimum specification for each task (Defeo 1999, Harry 1999).

The term "Six Sigma" is defined by Harry as producing products or services in the long-term that are on target and that are six sample standard deviations (*s*) within the specification limits, *i.e., only 3.4 parts will be outside the specification limits.* Each control limit in the short-term[4] in a "Six Sigma" process is three standard deviations inside the corresponding specification limit. The number of defects produced at a short-term "Six-Sigma" quality rate would manufacture one part defective per billion opportunities (Figure 6, page 28). Harry (2000) realized that most manufacturing processes have a changing process average. To account for this Harry (2000) defined long-term "Six Sigma" quality as producing products or services that are at least 4.5 sample standard deviations within the specification limits due to a wandering process average around the target.

[3] Long-term process capability shifted 1.5σ takes into consideration wandering process average (Figure 5, page 27).
[4] Short-term process capability centered being able to achieve six sigma standards, without taking into account a wandering process average (Figure 6, page 28).

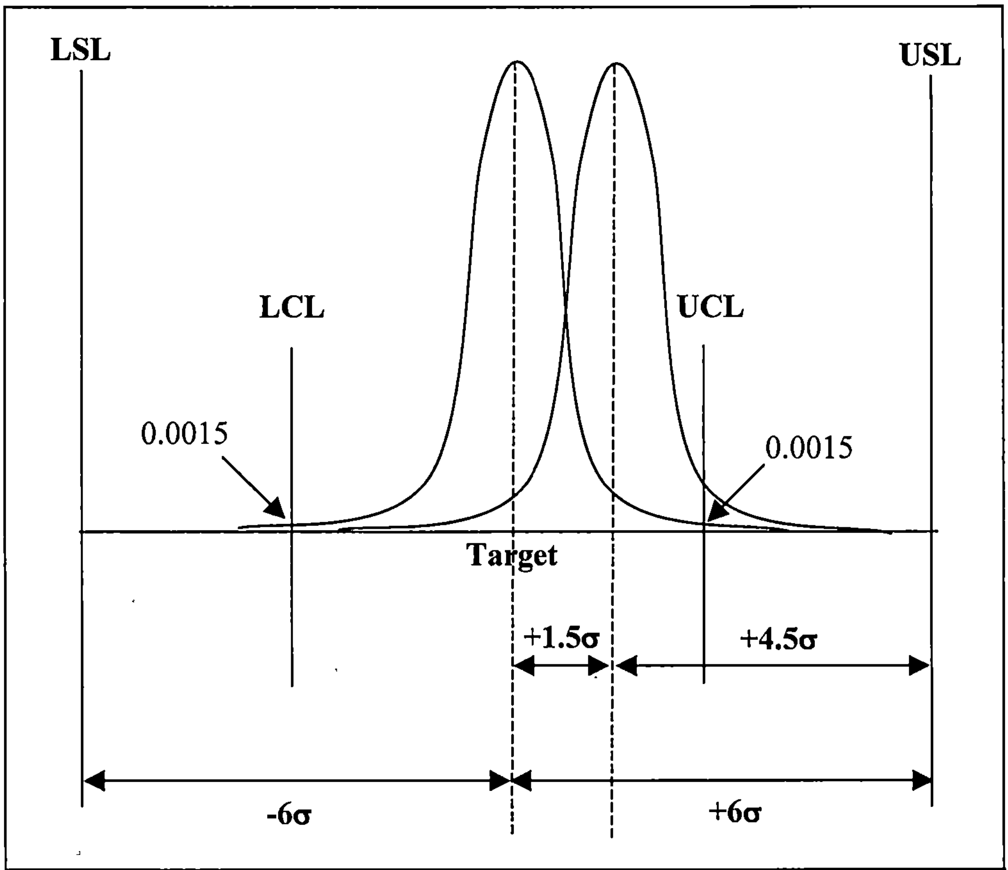

Figure 5. Illustration of long-term "Six Sigma" capability.

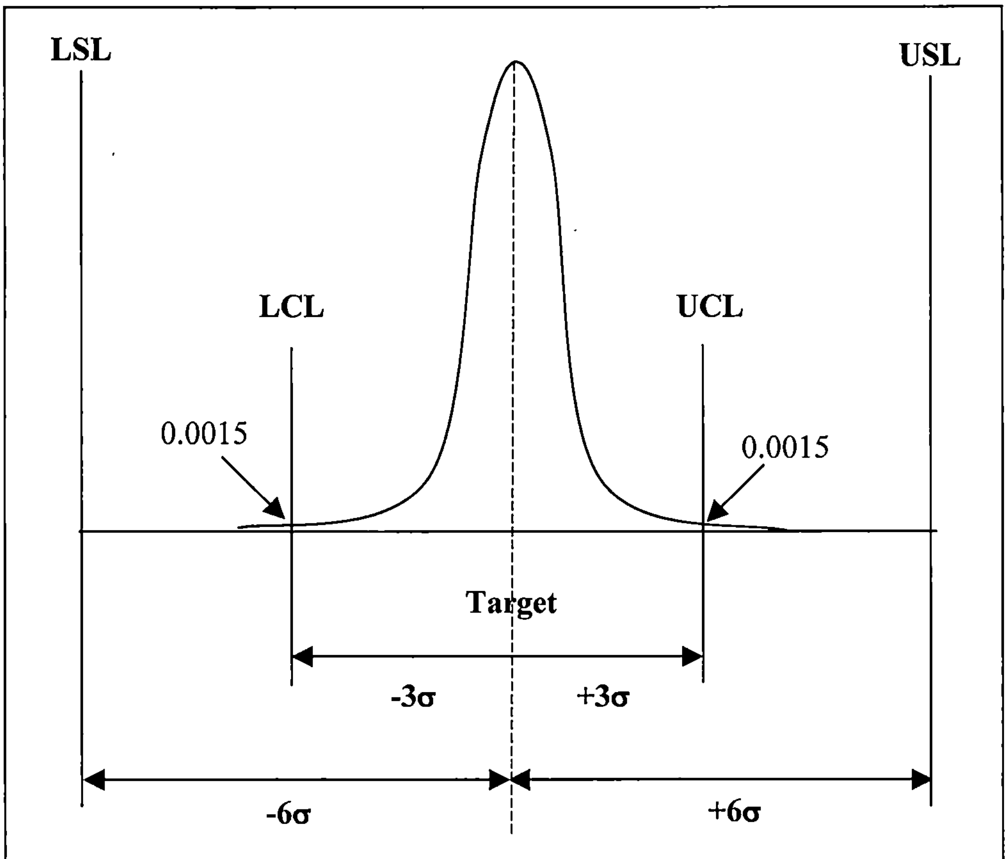

Figure 6. Illustration of short-term "Six Sigma" capability.

The Breakthrough Strategy

Mikel Harry's "Six Sigma" step-by-step methodology is further defined by Harry (2000) as the "Breakthrough Strategy" (Table 1, page 30). The "Breakthrough Strategy" consists of four stages: (1) Identification; (2) Characterization; (3) Optimization; and (4) Institutionalization. Each "Breakthrough Strategy" stage has several subcomponents (Harry and Schroeder 2000).

The "Recognize and Define" phase falls under the "Identification Stage." The "Recognize and Define" phase defines the inputs that influence customer expectations during this phase. The "Measure and Analyze" phase falls under the "Characterization

Table 1. The "Six Sigma" Breakthrough Strategy.

The "Six Sigma" Road Map			
	Stages	**Breakthrough Strategy Phases**	**Objectives**
BREAKTHROUGH STRATEGY	Identification	Recognize and Define	Define inputs to defining customer expectations
	Characterization	Measure and Analyze	Measure variability and current capability
	Optimization	Improve and Control	Optimize the process to attain "Six Sigma" defined capability and control process variation to maintain the desired capability level
	Institutionalization	Standardize and Integrate	Transform corporate culture

Stage." Aspects critical to quality are measured and described during this phase. The "Improve and Control" phase is part of the "Optimization Stage." This phase involves optimizing the process to attain "Six Sigma" defined capability and controlling process variation to maintain the desired capability level, *i.e., ± 6s within the specifications.* The "Standardize and Integrate" phase is part of "Institutionalization Stage." In this phase, the methods and results used in the previous three stages are woven into the corporation's culture (Harry and Schroeder 2000).

Identification Stage. -- Business success ultimately depends on how well companies meet customer expectations in terms of quality, price, and availability. In order to satisfy this customer value set, any process must be in statistical control and within the customer specification limits, *i.e., the process must be capable.* Variation within the process has a direct impact on business results in terms of cost, cycle time, and the number of defects, which affect customer satisfaction. This stage helps companies define customer expectations and defines what impact the variation has on profitability (Harry and Schroeder 2000).

Characterization Stage. -- The "Characterization Stage" assesses the current state of a process and establishes goals. This stage establishes a baseline, or benchmark for quality, which provides a starting point for measuring improvements. The "Measure and Analyze" phase is the key component of the "Characterization Stage." An action plan is developed in this stage to narrow the gap between the current state of the process (natural variation) and the company's goal to meet customer expectations (specifications). A process flow diagram is a key tool in this stage. The process flow diagram defines the process flow in step-by-step detail. The process flow diagram helps define components of the process that are wasteful or flawed. The process flow diagram is revised and is a template for process improvement (Harry and Schroeder 2000).

Optimization Stage. -- The "Optimization Stage" identifies the necessary steps for reducing variation. Adjustments and improvements to key process variables are defined in this stage using thorough statistical tools, *e.g., Design of Experiments, regression analysis, correlation analysis, etc.* The goal of the "Optimization Stage" looks at a large number of variables in order to determine the vital-few variables that have the greatest impact on reducing variation (Harry and Schroeder 2000). Once the vital-few variables are defined, the next step is to define improvement strategies to reduce variation in the context of the PDCA cycle. Statistical process control is used to control the process once the desired level of variability is attained.

Institutionalization Stage. -- The "Standardize and Integrate" phases make up the "Institutionalization Stage." This phase involves institutionalizing the improvement strategies developed in the previous stage by developing communication tools for analyzing and monitoring the process. The goal of this stage is to make continuous improvement part of the corporate culture. As stated by Harry (2000), "As companies improve the performance of various processes, they should standardize the way those processes are run and managed. Standardization allows companies to design their processes to work more effectively by using existing processes, components, methods, and materials that have already been optimized and that have proven their success."

The strength of the "Breakthrough Strategy" comes from the interaction within all levels of the company that are necessary to complete all four stages. The four stages overlap to ensure that the company completes each of the stages in a methodical and disciplined way. The "Breakthrough Strategy" can be very beneficial if it is carried out in the prescribed manner (Harry and Schroeder 2000).

Production Yield and Manufacturing Cost Variation

Harry's departure from some existing quality philosophies is that it has a very strong emphasis on monitoring production yield and manufacturing costs associated with the continuous improvement effort (Harry and Schroeder 2000). Harry has indicated that a dollar amount can be associated with variation (Recall the Taguchi Loss Function). By reducing variation within the process, a company can reduce manufacturing and warranty costs, and increase the amount of available capital. Harry's philosophy as related to monitoring production yield and costs parallels the philosophies of Shewhart, Deming, Juran, Taguchi and Ishikawa. Harry (2000) departed from previous quality philosophies in the sense that all production yield and costs should be defined and monitored in the context of any quality initiative. He further departed from previous quality philosophies by indicating that a financial return should be estimated from any quality initiative. Harry (2000) showed the financial significance of reducing the defective parts manufactured by reducing variation (Table 2). Many companies take false comfort in that if quality goals are met if the natural variation (natural tolerance ~ 6s) is equal to the specification limits (engineering tolerance). If control limits equal specification limits, 2,700 defective parts per million are produced. For example, one can only imagine the chaos that would occur in the U.S. if telephone communications had a defect rate of 2,700 errors per million communication attempts.

If natural variation is approximately three standard deviations within the specification limits (*i.e. "Six Sigma" quality*) and the process average is equal to the target, 0.002 defective parts per million are produced. The reduction in defects from 2,700 defective parts to 0.002 defective parts per million represents significant cost savings and profitability improvement to any organization (Blakeslee 1999, Breyfogle 1999, Defeo 1999, Harry and Schroeder 2000, Hild *et al.* 2000, Pande *et al.* 2000).

Harry (2000) gives an example of the financial significance of reducing process variation. Suppose a company has its natural tolerance equal to engineering tolerance (control limits = specification limits) and the manufacturing cost is ten dollars per manufactured part. If the company produces 100,000 parts per day, 270 parts would be defective (Breyfogle 1999, Harry and Schroeder 2000).

Table 2. Number of defective parts as related to process standard deviation.

Specification Limit	**Percentile**	**Defective Parts per Million (ppm)**
± 1 sigma	68.27	317,300
± 2 sigma	95.45	45,500
± 3 sigma	99.73	2,700
± 4 sigma	99.9937	63
± 4.5 sigma (long-term)	99.99966	3.4
± 5 sigma	99.999943	0.57
± 6 sigma (short-term)	99.9999998	0.002

The direct loss to the company, assuming the parts cannot be reworked, is $2,700 per day or $985,500 per year (Note that the loss in this example does not take into account additional profitability loss). In this example, a one standard deviation improvement (defined by Harry as a one sigma improvement), equates to 6.3 parts defective per 100,000 parts manufactured. The direct loss from a one standard deviation reduction in natural variation is $63 per day or $22,995 per year. The direct cost savings in this scenario would equate to $962,505 per year. Additional savings would also be realized from increased profitability due to improved yield.

Even though Mikel Harry's "Six Sigma" philosophy appears to rely on existing quality philosophies, acceptance in the 21st century of "Six Sigma" quality by the business sector cannot be ignored (Breyfogle 1999). Perhaps the organizational structure of "Six Sigma" is easier to interpret and implement by companies. The focus on monitoring yield and cost improvements associated with variation reductions due to "Six Sigma" is aligned well with many corporate cultures and business philosophies of the 21st century (Harry and Schroeder 2000).

The Forest Products Industry and Quality

In the early 20th century most U.S. forest products companies enjoyed the benefits from inexpensive raw material and low labor costs. For most forest products companies of this era, technology was a leading constraint to improved production (Maki 1993). Quality of final wood products during this era was of minimal importance to most wood producing companies (Young and Winistorfer 1999).

As the U.S. forest products industry entered the 21st century, they were faced with a panacea of issues. Environmental regulation and preservation interests have reduced the availability of wood fiber and resulted in higher raw material costs. Raw material costs of the furniture and wood flooring manufacturers are their highest costs of production. Air quality restrictions have forced many forest products companies to invest in expensive air-quality control equipment. Labor costs are higher in the U.S. relative to labor costs in developing countries. The U.S. forest products industry is also faced with increasing domestic and international market competition from non-wood products such as aluminum and concrete. The scenario faced by most U.S. forest products companies is lower profit margins due to higher raw material and manufacturing costs in the context of stable real-prices for final wood products. These economic constraints have forced many U.S. forest products companies to reassess manufacturing practices (Young and Winistorfer 1999). Some U.S. forest products companies have started assessing the potential benefits that may occur from adopting continuous improvement philosophies such as the "Six Sigma" quality philosophy (Young and Winistorfer 1999).

Quality initiatives are not new to the forest products industry. The pulp and paper industry in the 1960s used statistics to monitor variation in pulp yield and paper caliper

(Fadum 1987, Taguchi 1993). Statistical sampling methods were used in the pulp and paper industry in the final inspection process. There is also some documentation of the use of Statistical Process Control (SPC) by the pulp and paper industry in the early 1980s (Young and Winistorfer 1999). However, statistical methods for the continuous improvement of processes and final product were replaced in this industry by ISO9000 initiatives and a stronger interest in engineering process control (Murrill 1991, Nicholas 1998).[5, 6] A review of current published literature for the pulp and paper industry did not indicate any substantial continuous improvement initiatives.

In the 1980s some plywood and wood composite panel manufacturers had began using SPC. At this time the application of SPC was scarce and often times driven by company defined quality initiatives (Young and Winistorfer 1999). Today there are more wood composite companies using SPC. The use of SPC has been seen in the fiber drying operation, resin and wax addition, etc.

The softwood lumber industry implemented some SPC and quality control programs in sawmills in the Pacific Northwest in the late 1970s, which expanded through Canada and the United States in the early 1980s (Brown 1995). In a sawmill controlling and reducing sawing variation is a key element for quality improvement initiatives (Brown 1979, 1982, 1992, 1997). Sawing variation leads to excessive thickness variation and actual thicknesses tend to be greater than targets. Log to lumber recovery is reduced by thick lumber (Brown 1995). Reductions in target sizes of 0.100" have led to annual

[5] ISO9000 – an international set of quality assurance standards to achieve and assess the level of quality a company performs. ISO standards serve to articulate, clarify and systematize the different types of information within a company (Nicholas 1998).
[6] Engineering Process Control – is the use of mathematical algorithms in the context of programmable logic controllers (PLCs) to control the production process, *e.g., motor speed, belt-speed, valve opening, etc.* (Murrill 1991).

savings at some sawmills of $250,000 (Young *et al.* 2000). Maki (1993) states, "Statistical Process Control is an important step in minimizing sawing variation that can be attributed to problems such as dull saw blades, misplacement of the log, or feeding the log too fast through the saw." These problems can cause within and between board variations. Control charts for each machine center allow for such problems to be detected and minimized (Maki 1993).

Although SPC is commonplace in the softwood sawmill industry, SPC applications in the hardwood lumber industry are virtually non-existent (Cassens *et al.* 1994, Young and Winistorfer 1999). There have been some success stories among several companies that have adopted SPC (Young *et al.* 2000). Brown (1995), Cassens *et al.* (1994) and Young *et al.* (2000) have documented financial gains from using SPC to reduce hardwood lumber target sizes. Even though financial gains from using SPC have been reported in the literature, the hardwood lumber industry as a whole has not embraced continuous improvement (Young and Winistorfer 1999).

In the furniture and cabinet industries a survey was conducted in early 1990s to determine the current level of involvement in the use of statistical methods for quality control in manufacturing operations (Patterson and Anderson 1996). The survey indicated that only a small number of furniture and cabinet industries were using statistical methods to reduce process variation and improve final product quality.

The furniture and cabinet industry have been investing in automated processing centers. The processing centers use robotic technology such as Computer Numerically Control (CNC) machines to machine parts. The CNC centers have led to improved consistency and uniformity in manufactured parts. Some companies have started incorporating SPC principles in the monitoring of CNC system performance (Patterson and Anderson 1996).

Like the U.S. automotive industry of the 1980s, the forest products industry of the 21st century is reassessing their management and manufacturing philosophies. This reassessment involves assessing the benefits of continuous improvement using statistical methods. Even though the U.S. forest products industry will not face loss of market share due to Japanese competition, the industry is faced with higher raw material and manufacturing costs in the context of stable final product prices (Young and Winistorfer 1999). The adoption of continuous improvement philosophies such as "Six Sigma" may improve the competitiveness of many forest products companies by reducing costs and improving final product value (Young and Winistorfer 1999). The potential benefits to society are better product value, more jobs and a wiser use of the forest resource.

CHAPTER 3

METHODS

Problem Definition

The problem definition of the thesis was to determine if a modified "Six Sigma" philosophy for continuous improvement can improve the quality of hardwood flooring. This problem definition was studied over a six-month time period and included an analysis of production yield and manufacturing costs.

Research Objectives

1. Define the current-state of product variability for hardwood "veneer-slat" thickness and the specific attributes of "finished blank" length, width, and thickness (Table 3, page 43).
2. Determine the capability of "veneer-slat" thickness and the "finished blank" attributes length, width, and thickness as related to engineering specifications (Table 3, page 43).
3. Determine the current production yield and manufacturing costs associated with the manufacture of "veneer-slat" (Table 3, page 43).
4. Define the sources of variability that influence the "finished blank" length, width, and thickness, and "veneer-slat" thickness. This will involve a detailed understanding of the relationships that may exist between key process variables that influence the "finished blank" length, width, and thickness and "veneer-slat" thickness (Table 3, page 43 and Table 4, page 44).

5. Recommend to senior management the improvements necessary to enhance the overall quality of "veneer-slats" (Table 3, page 43).
6. If any of the recommendations are adopted from objective five, the first four objectives would be repeated to determine if the quality of "finished blank" length, width, and thickness and "veneer-slats" thickness improved (Table 3, page 43).

Selection of Hardwood Flooring Manufacturer for the Thesis Study

Three secondary wood products manufacturers were interviewed as potential candidates for participation in the thesis. A hardwood flooring manufacturer in Tennessee was selected as the best candidate for this thesis given the strong level of interest in continuous improvement that was exhibited by senior management. The company also had a well-defined quality control system and quality control support personnel.

The selected company had a strong interest in focusing the thesis effort on one component ("veneer-slat") of the "eight-foot strip" hardwood composite flooring product. This product had a high profit margin and was considered to have a higher level of customer value relative to other flooring products.

Modified Six Sigma Philosophy

<u>Part I: Identification Stage</u>

Harry's (2000) "Six Sigma" philosophy for continuous improvement emphasizes the importance of understanding customer expectations and value. Harry's philosophy is based on the belief that it is impossible to improve a company's quality or overall competitive position without aligning its products and/or services with customer expectations and value. An example of customer expectations and value as related to this thesis would be hardwood flooring that is aesthetic, durable, affordable, uniform, and quiet when walked upon.

A detailed assessment of customer expectations and value was beyond the scope of this thesis. An interview of the senior management revealed a strong knowledge of customer value as related to their "eight-foot strip" hardwood composite flooring product. The "veneer-slat" component of the "eight-foot strip" hardwood composite flooring product was considered to have a direct impact on thickness uniformity, aesthetics, and durability.

Part II: Characterization Stage

The characterization stage established a baseline or benchmark for product quality and was the starting point for measuring improvements (Harry 2000). To establish the financial benchmark a detailed analysis of production yield and manufacturing costs was attempted. A general description of the process flow for "veneer-slats" production is given in Figure 7, pages 45 to 47.

The first step in this stage was to establish a baseline or benchmark for product variation and quality (Pyzdek 1999). This was accomplished by conducting a detailed capability analysis of "veneer-slats" and the process variables that were inputs into the manufacture of "veneer-slats." The process capability study was conducted for "finished blank" length, width, and thickness and "veneer-slats" thickness. The capability analysis used traditional C_{pk}, C_p and contemporary Taguchi C_{pm} capability indices to establish a benchmark (Breyfogle 1999; Taguchi 1993).[7]

This step also included an assessment of the components of total product variance for "finished blank" thickness, width, and length of "veneer-slats" thickness. Total product variance (σ_T^2) was defined as the summation of process variance (σ_p^2) and measurement variance (σ_m^2), *i.e.*, $\sigma_T^2 = \sigma_p^2 + \sigma_m^2$.

Total process variance (σ_P^2) was estimated using the manufacturer's data and data collected as part of the thesis sampling plan. Total process variance within the manufacturing system for "veneer-slats" consisted of variability due to material, machines, operators, methods, and measurement.

Total measurement variance (σ_m^2) was estimated from a "Gauge R&R" study combined with a discrimination ratio statistic developed by Wheeler (1989). The gauge R&R study quantified the measurement variance (σ_m^2) as the summation of gauge variance (σ_g^2) and appraiser variance (σ_o^2), *i.e.*, $\sigma_m^2 = \sigma_g^2 + \sigma_o^2$.

Part III: Optimization Stage

The optimization stage focused on understanding and quantifying the relationships that existed between the "vital few" input process variables that influenced the length variance, width variance, and thickness variance of "finished blanks" and "veneer-slat" thickness. Harry (2000) believes this is the critical stage in improving and

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[7] C_{pk} is defined as the minimum of [(USL – Average)/3s, (Average – LSL)/3s]
C_p is defined as (USL – LSL)/6s
C_{pm} is defined as $(USL - LSL)/\{6[(Average - Target)^2 + s^2]^{1/2}\}$
where, USL is the upper specification limit
LSL is the lower specification limit
s is the sample standard deviation
s^2 is the sample variance

controlling a process. This stage provides the company with an array of improvements that ultimately improves profitability and customer satisfaction (Harry 2000). The key step in this stage is to understand the relationships that exist between process variables and key product attributes. Ishikawa diagrams were critical first steps in this stage.

The final step of this stage was conducted when recommendations were made to senior management. These recommendations included manufacturing system changes, management practice adjustments, and changes to existing quality control methods.

Part IV: Institutionalization Stage

The institutionalization stage is defined in the "Six Sigma" philosophy as the stage of standardizing procedures and processes. These standards are based on the outcomes of the characterization and optimization stages. This stage also includes a continuous monitoring of the control and capability of the process. Documentation of improvements to product quality, production yield, and manufacturing costs are an important aspect of this stage.

Due to the six-month time frame of this thesis it was not feasible to monitor long-term improvements in "veneer-slats." Also, there was a significant change in senior management that led to the elimination of the quality control department. The new senior management did not allow any implementation of "Institutionalization Stage."

Table 3. A modified structure to the organization of the Six Sigma philosophy.

Implementation Stage	Objective	Methods	Assumptions
Stage I. Identification	Define Customer Expectations and Value for Hardwood Flooring.	Marketing surveys and research	Company has defined the customer expectations and value
Stage II. Characterization	1. Define the current state of product variability "finished blank" thickness, length and width and "veneer-slat" thickness of hardwood composite flooring. 2. Define the current state of the capability for all product attributes. 3. Define current state for production yield and manufacturing costs.	• Shewhart control charts • Capability Analysis • Cost Accounting • Taguchi Loss Function	None
Stage III. Optimization	1. Define the sources of variability in the manufacture of product attributes. 2. Understand the relationships between key input process variables that effect product attributes variability. 3. Root-cause analysis of sources of variation for key input process variables. 4. Recommendations to senior management.	• Ishikawa or fishbone diagrams • Deming's Plan-Do-Check-Act Cycle • Gauge R&R	None
Stage IV. Institutionalization	1. Define the current state of product variability for the "veneer-slat" component of the "eight-foot strip" hardwood composite flooring product. 2. Define the current state of the capability for this product. 3. Define the current business state.	• Shewhart control charts • Capability Analysis • Cost Accounting	Senior management will be willing to implement recommendations

Table 4. Measurement specifications for process flow at all stages.

Stage	Type of Measurement	Specifications	Measurement Device
Incoming Lumber	Moisture Content Measure: 24 hour oven drying test	Upper: 7.2% Target: 5.85% Lower: 4.5%	Electronic scale
Incoming Lumber	Thickness	LCL: > 26mm	Calipers
Rip Saw	Width	UCL: 71 mm Target: 70 mm LCL: 69 mm	Calipers
Optimizer "Prefinished blank"	Length	230 ± 1 mm 285 ± 1 mm 340 ± 1 mm	Calipers
"Finished Blank" Molder	Width	UCL: 65.20 mm Target: 65.15 mm LCL: 65.10 mm	Calipers
"Finished Blank" Molder	Thickness	LCL: > 24 mm	Calipers
Trim Saw	Length	215.1 ± 0.1 mm 270.1 ± 0.1 mm 325.1 ± 0.1 mm	Calipers
"Veneer-Slat"	Thickness	Upper: 3.6 mm Target: 3.5 mm Lower: 3.4 mm	Calipers

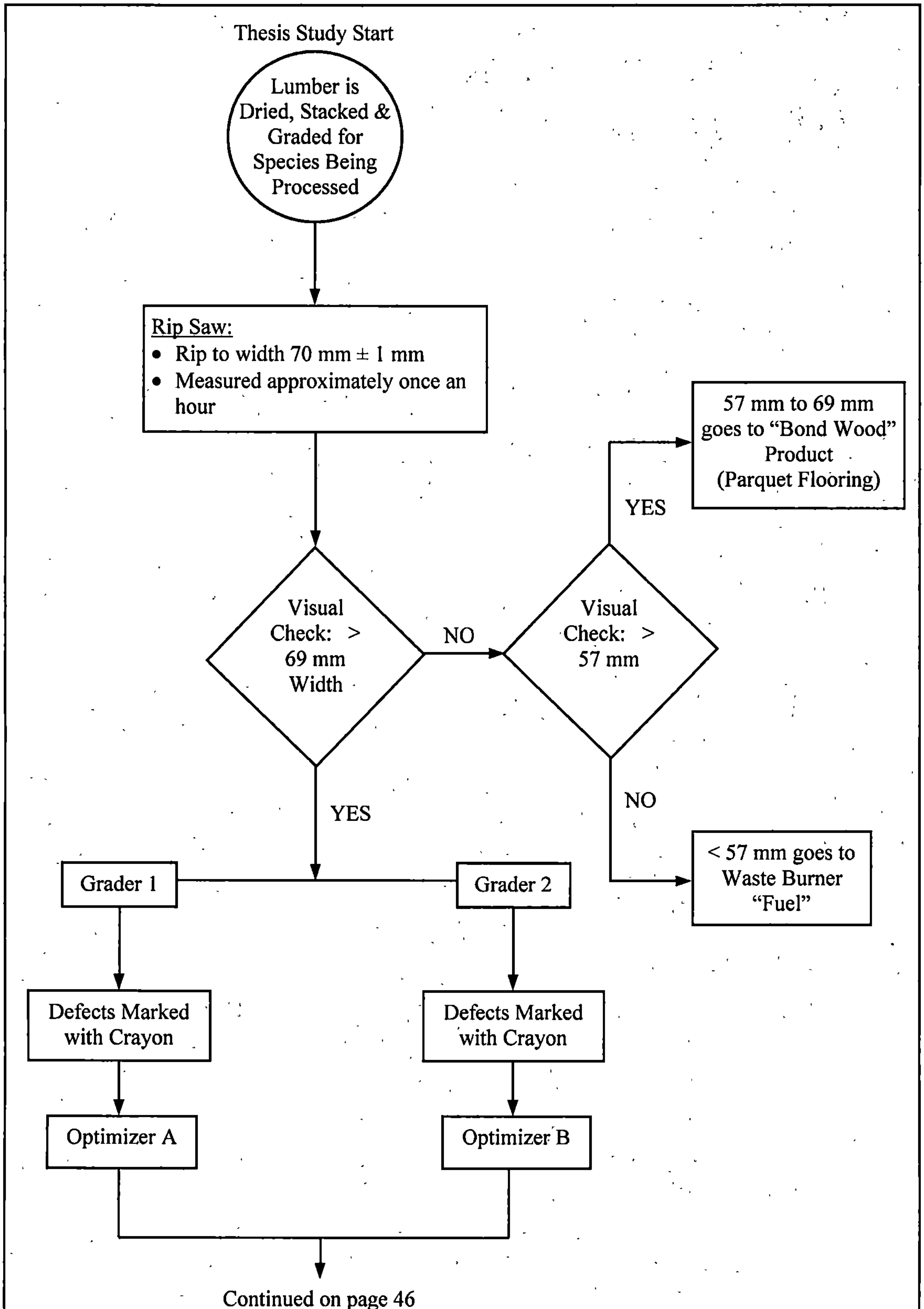

Figure 7. Process flow chart for hardwood composite flooring.

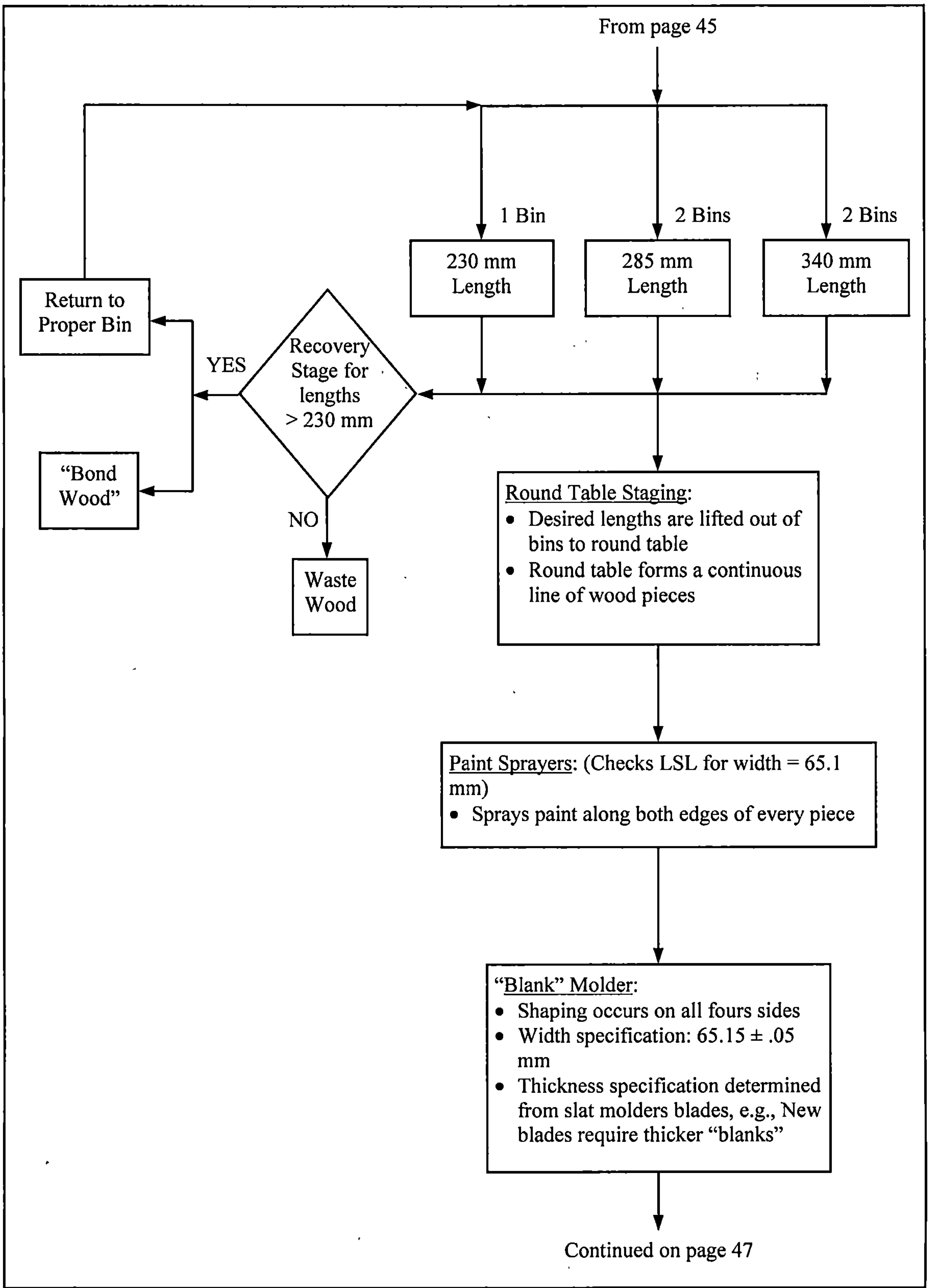

Figure 7. Continued.

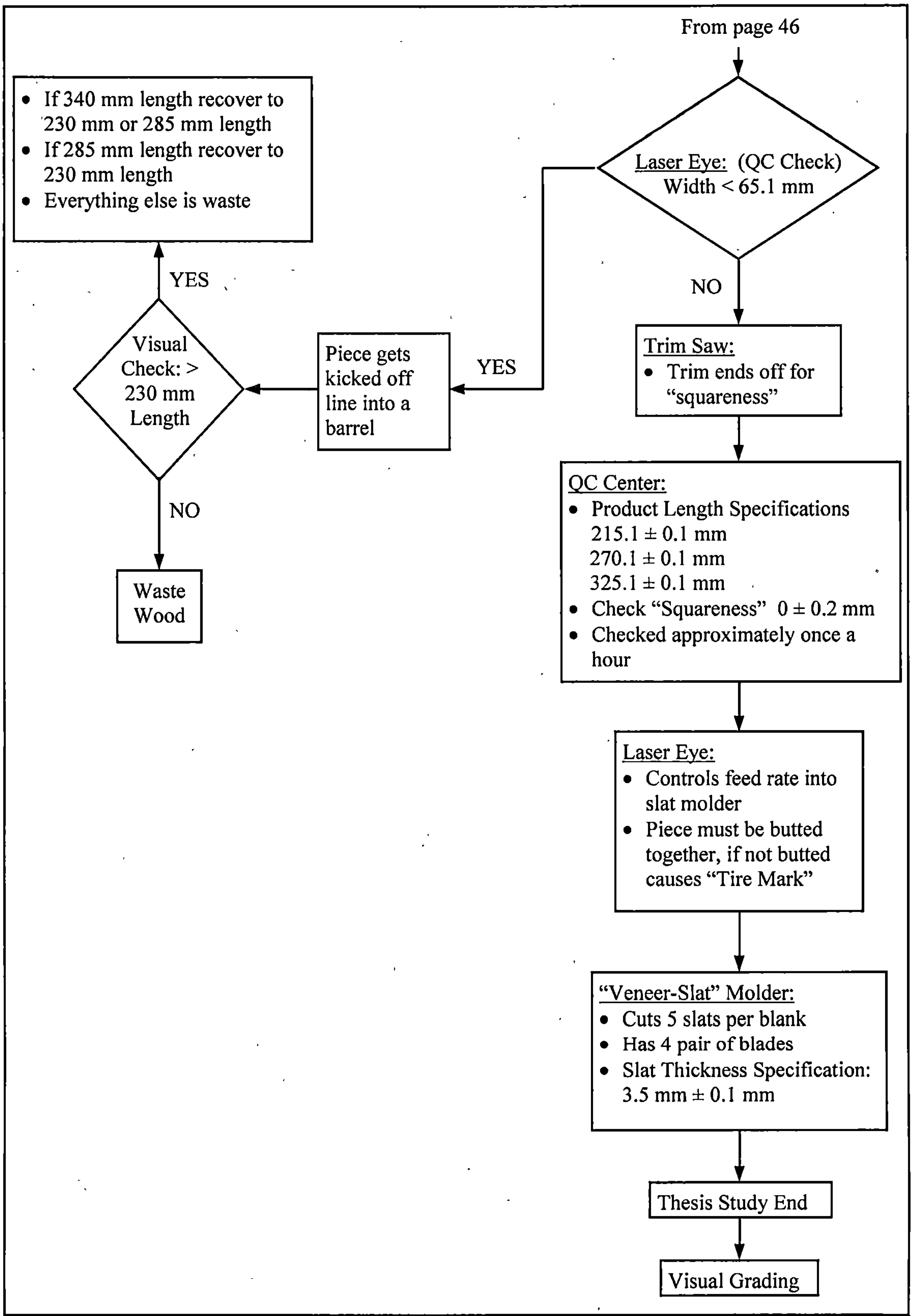

Figure 7. Continued.

CHAPTER 4

RESULTS AND DISCUSSION

The modified Six Sigma methodology as applied to a Southeastern United States hardwood-flooring manufacturer led to the identification of significant sources of variability. Even though it was not determined if a modified Six Sigma methodology could be used instead of a complete Six Sigma methodology (Harry 2000), five of the six thesis objectives were satisfied. The first objective of quantifying variation was satisfied, *i.e. define the current-state of product variability for the specific product attributes of "finished blank" thickness, length and width, and "veneer-slat" thickness*. The second objective was also satisfied when the capability of the product attributes were quantified for the last 15-months. Estimates of current production yield and some manufacturing costs were collected over a 15-month study period, which partially satisfied objective three. Objective three was only partially satisfied given that the management was reluctant to reveal all cost data. Significant sources of variability were defined and quantified in the thesis study, which satisfied objective four. The fifth objective was satisfied when recommendations for improving the process and reducing variability were presented to senior management of the hardwood-flooring manufacturer on April 11, 2001. The sixth objective was not satisfied. The hardwood-flooring manufacturer did not allow any further investigation of the hardwood-flooring plant process after improvement recommendations were made on April 11, 2001.[8] In attempt to partially

[8] All data has been coded and changed to millimeters to protect the confidentiality of the company. The hardwood-flooring manufacturer had a change in an executive management position during the course of the thesis study. The new Vice President of the company did not allow any further investigation.

fulfill objective six, a Gauge R&R[9] study was conducted under controlled conditions at The Tennessee Forest Products Center. An attempt was also made to estimate the potential cost savings from implementing the recommendations developed in objective five.

Manufacturer's Characteristics

There were seven species of hardwood flooring manufactured by the company. The seven species were: red oak (*Quercus rubra*), white oak (*Quercus alba*), hard maple (*Acer sacchrum*), Brazillian cherry (*Jatoba*), ash (*Fraxinus americana*), black cherry (*Prunus serotina*), and Merbau (*Instia spp*) (Figure 8). Red oak flooring comprised approximately 50% of the manufacturers annual production (Figure 8). The thesis study was conducted on red oak (*Quercus rubra*), white oak (*Quercus alba*), and hard maple (*Acer sacchrum*) flooring "veneer-slats." These species consumed about 75% of annual production (Figure 8).

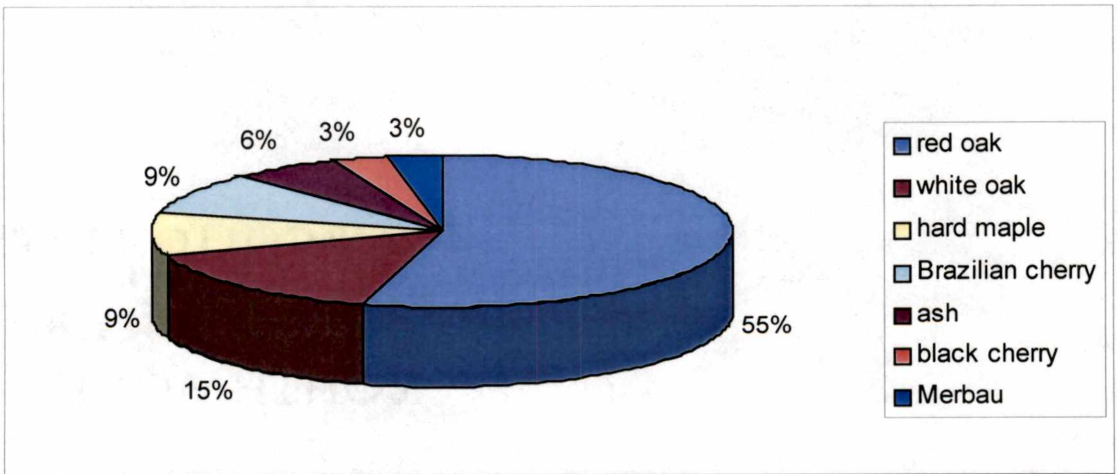

Figure 8. Annual usage of hardwood lumber by species.

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[9] Gauge R&R – The evaluation of measuring instruments to determine capability to yield a precise response. Gauge repeatability is the variation in measurements considering one part and one operator. Gauge reproducibility is the variation between operators measuring one part (Breyfogle, 1999).

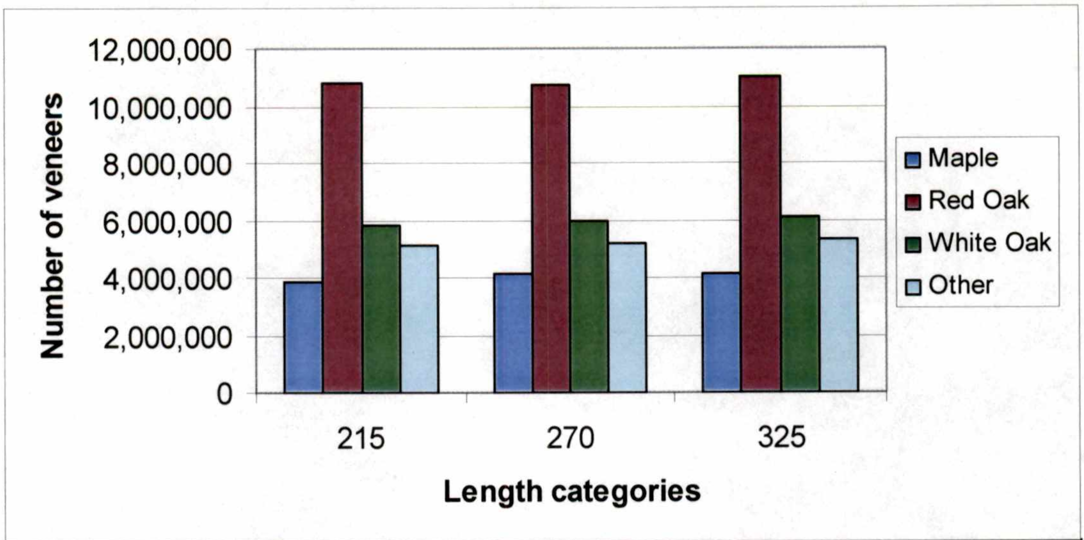

Figure 9. Bar chart on production of "veneer-slats" for species and length categories.

Three different lengths of blanks were manufactured for each species studied (215 mm, 270 mm, and 325 mm). Each species and length category had the product attributes of "finished blank" thickness, length, width, and "veneer-slat" thickness. The annual production of "veneer-slat" was predominately red oak (Figure 9). Measurements were taken for each product attribute using a Mitutoyo caliper (Figure 10, page 51)

Quantifying Process Variability - Objective 1

"Finished Blank" Thickness for Target Length 270 mm

The sample standard deviation, *s*, was used as an estimate of process variability. The sample average and medians were used as estimates of the process location (X-bar). The variability as represented by the standard deviation in "finished blank" thickness varied from 0.05 mm to 0.25 mm from January 2000 to March 2001 (Figure 11, page 52). The runs chart in Figure 11, page 52, were samples of "finished blank" thickness taken by the manufacturer. Measurements as part of the thesis plan were taken in September 2000, and January and February 2001, in an attempt to gather additional data to estimate

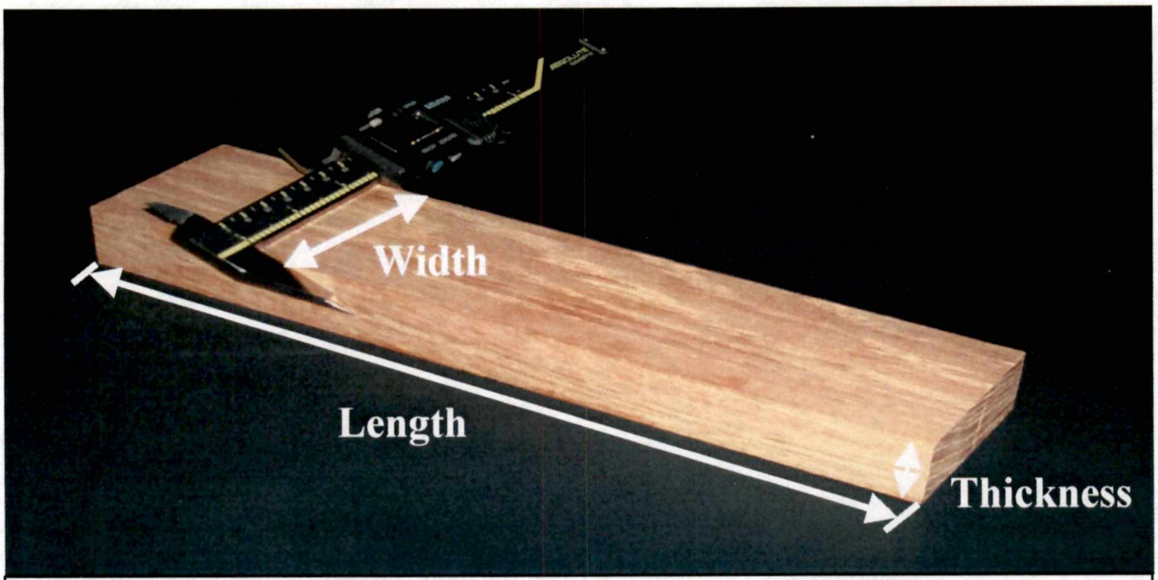

Figure 10. Product attributes measurements.

variance from which a sampling scheme was later determined. Thesis sampling plan estimates of standard deviation and the manufacturers estimates of standard deviation did not coincide (Appendix A, page 132-144). The thesis sampling plan sample size was larger than the manufacturer's sample size. Even though the standard deviation in Figure 11, page 52, may indicate a slight downward trend for hard maple (*Acer saccharum*), a statistical test of significance for the standard deviation was not conducted given the small sample sizes, unequal sample sizes, and normality could not be assumed.

The process location (X-bar) of "finished blank" thickness as represented by the average and median varied over time (Figure 12). The median was not stable and there was evidence of a statistical difference in the median at an $\alpha = 0.05$ for the three species studied (Tables 6-8, pages 53-54). Hard maple (*Acer saccharum*), white oak (*Quercus alba*) and red oak (*Quercus rubra*) were the three predominate wood species manufactured and represented approximately 75% of the annual production.

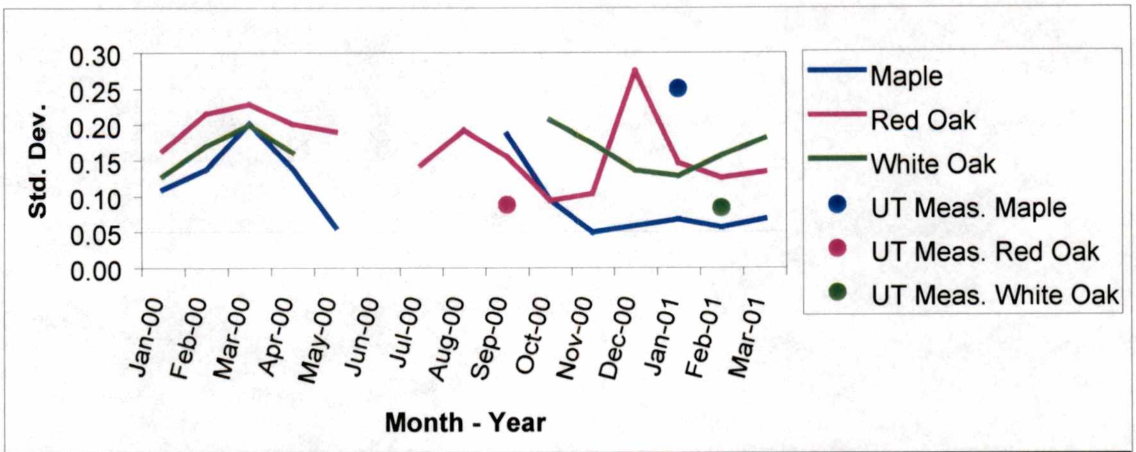

Figure 11. Standard deviations (mm) for "finished blank" thickness for target length 270 mm.

Table 5. Standard deviations, *s*, and sample sizes, *n*, by month for "finished blank" thickness for target length 270 mm.

Month-Year	**Sample Sizes (*n*)**	**hard maple *s* in mm**	**Sample Sizes (*n*)**	**Red Oak *s* in mm**	**Sample Sizes (*n*)**	**white oak *s* in mm**
January-2000	20	0.110	60	0.164	55	0.128
February-2000	15	0.137	35	0.215	10	0.170
March-2000	25	0.201	70	0.228	80	0.199
April-2000	25	0.138	70	0.201	55	0.161
May-2000	10	0.056	50	0.190	--*	--*
June-2000	--*	--*	--*	--*	--*	--*
July-2000	--*	--*	20	0.143	--*	--*
August-2000	--*	--*	90	0.192	10	0.039
September-2000	30	0.186	40 (160)**	0.154 (0.086)**	--*	--*
October-2000	10	0.094	10	0.094	30	0.206
November-2000	10	0.049	10	0.103	40	0.174
December-2000	10	0.058	30	0.275	30	0.136
January-2001	45 (330)**	0.068 (0.249)**	50	0.146	30	0.128
February-2001	60	0.056	30	0.125	40 (138)**	0.156 (0.083)**
March-2001	65	0.068	50	0.134	60	0.181

* *Blank cells indicate that no data were available.*

** *Statistics in parenthesis were estimates that were taken as part of a sampling study.*

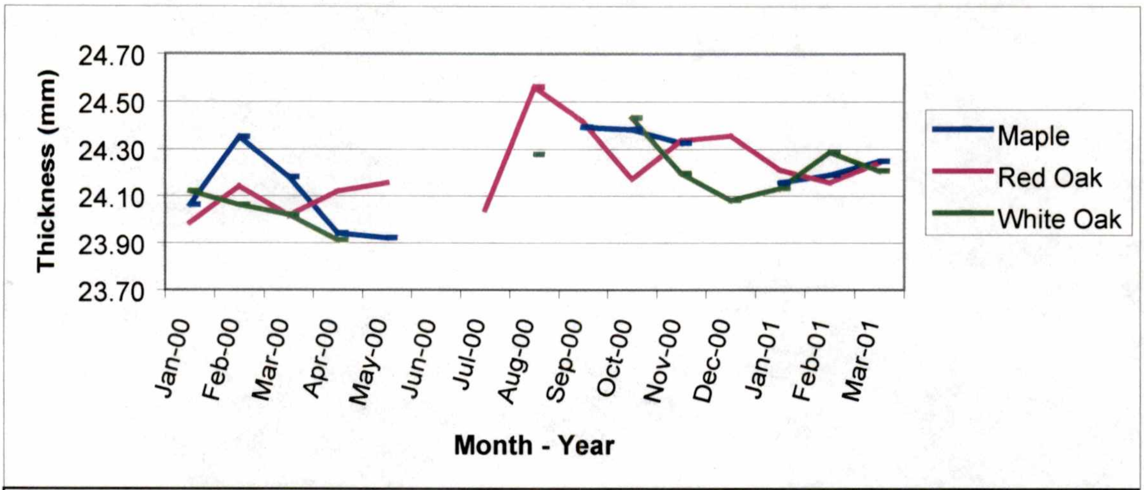

Figure 12. Medians for "finished blank" thickness for target length 270 mm.

There was statistical evidence that the process location for "finished blank" thickness was not stable month-to-month. Instability in "finished blank" thickness may result in lower production yields when thin "finished blanks" result in unacceptably thin "veneer-slat" thickness. Thick "finished blanks" may result in lower production yields by causing excessive tool wear at the planer and may cause slower line speeds.

"Finished Blank" Length for Target Length 270 mm

The sample standard deviation, *s*, was also used as an estimate of process variability for "finished blank" length. The sample averages and medians were used as estimates of the process location. The variability as represented by the standard deviation in "finished blank" length varied from 0.04 mm to 0.25 mm from January 2000 to March 2001 (Figure 13, page 54). The line graph in Figure 13 represented samples taken by the manufacturer. The standard deviation in Table 9, page 55, displays the amount of dispersion for "finished blank" length 270 mm. A statistical test of significance for the standard deviation was not conducted given small sample sizes, unequal sample sizes, and normality could not be assumed.

Table 6. Averages and medians by month for hard maple (*Acer saccharum*) "finished blank" thickness for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median (M) in mm	Non-parametric Wilcoxon Rank Sums Test
January-2000	20	24.06	24.06	a
February-2000	15	24.32	24.35	b
March-2000	25	24.20	24.18	c
April-2000	38	23.98	23.94	d
May-2000	12	24.03	23.92	de
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--*	--*	--*	--*
September-2000	10	24.46	24.39	fghi
October-2000	20	24.43	24.38	b fghij
November-2000	10	24.33	24.33	bc fgh k
December-2000	--*	--*	--*	--*
January-2001	11 (330)**	24.17 (24.20)**	24.16 (24.29)**	a c fgh k lm
February-2001	20	24.15	24.19	a c efgh k lmn
March-2001	23	24.20	24.25	bc fgh k mno

** Blank cells indicate that no data were available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter; "b" is for February-2000 and is compared with each month thereafter.*

Table 7. Averages and medians by month for red oak (*Quercus rubra*) "finished blank" thickness for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median (M) in mm	Non-parametric Wilcoxon Rank Sums Test
January-2000	60	24.03	23.99	a
February-2000	35	24.13	24.14	ab
March-2000	70	24.05	24.02	c
April-2000	120	24.13	24.12	d
May-2000	50	24.22	24.16	abcde
June-2000	--*	--*	--*	--*
July-2000	20	24.11	24.04	ab efg
August-2000	90	24.48	24.56	abcdefgh
September-2000	40 (160)**	24.41 (24.42)**	24.42 (24.43)**	abcdefghi
October-2000	10	24.18	24.17	a cd f hij
November-2000	10	24.31	24.34	abcd fghijk
December-2000	30	24.42	24.36	abcdefg j l
January-2001	20	24.19	24.21	a cd f hi klm
February-2001	30	24.16	24.16	cd f hi k mn
March-2001	140	24.25	24.24	abcd lmno

**Blank cells indicate that no data were available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter; "b" is for February-2000 and is compared with each month thereafter.*

Table 8. Averages and medians by month for white oak (*Quercus alba*) "finished blank" thickness for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median (M)in mm	Non-parametric Wilcoxon Rank Sums Test
January-2000	55	24.14	24.12	a
February-2000	10	24.08	24.06	ab
March-2000	80	24.02	24.02	bc
April-2000	55	23.97	23.91	d
May-2000	--*	--*	--*	--*
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	10	24.27	24.28	h
September-2000	--*	--*	--*	--*
October-2000	30	24.40	24.43	j
November-2000	40	24.18	24.20	b h k
December-2000	30	24.09	24.08	b l
January-2001	30	24.05	24.13	abc lm
February-2001	80 (138)**	24.27 (24.17)**	24.29 (24.19)**	h j n
March-2001	30	24.23	24.21	h k o

**Blank cells indicate that no data were available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter; "b" is for February-2000 and is compared with each month thereafter.*

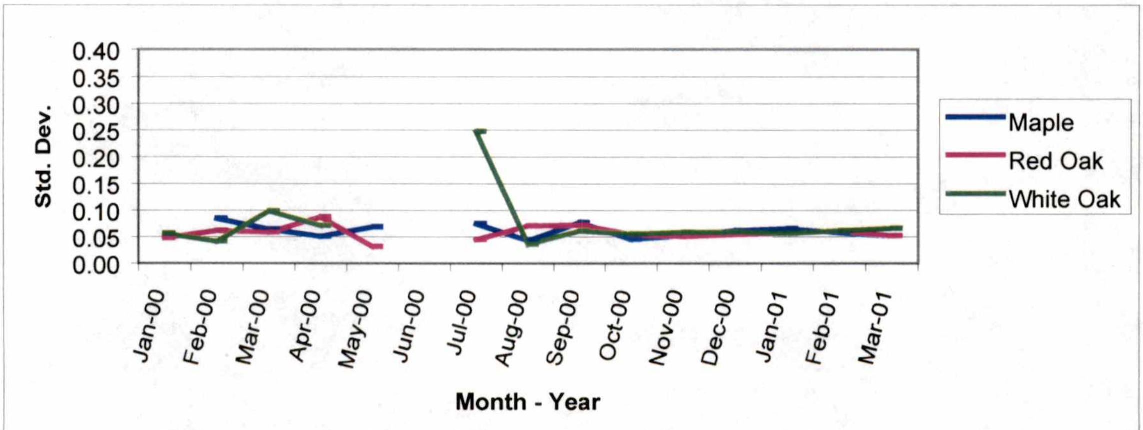

Figure 13. Standard deviations (mm) for "finished blank" length for target length 270 mm.

Table 9. Standard deviations, *s*, and sample sizes, *n*, by month for "finished blank" length for target length 270 mm.

Month-Year	Sample Sizes (*n*)	hard maple (*s*) in mm	Sample Sizes (*n*)	red oak (*s*) in mm	Sample Sizes (*n*)	white oak (*s*) in mm
January-2000	--*	--*	104	0.047	107	0.057
February-2000	15	0.084	50	0.061	25	0.041
March-2000	15	0.064	125	0.058	50	0.098
April-2000	10	0.051	73	0.086	55	0.071
May-2000	120	0.068	10	0.031	--*	--*
June-2000	--*	--*	--*	--*	--*	--*
July-2000	10	0.075	10	0.044	15	0.247
August-2000	5	0.043	55	0.070	10	0.036
September-2000	30	0.077	40 (80)**	0.072 (0.068)**	15	0.061
October-2000	10	0.045	40	0.054	20	0.055
November-2000	10	0.052	20	0.050	20	0.059
December-2000	10	0.062	15	0.054	10	0.059
January-2001	20 (110)**	0.066 (0.478)**	20	0.056	20	0.056
February-2001	20	0.057	40	0.061	20 (46)**	0.062 (0.047)**
March-2001	30	0.052	40	0.052	30	0.066

**Blank cells indicate that no data were available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

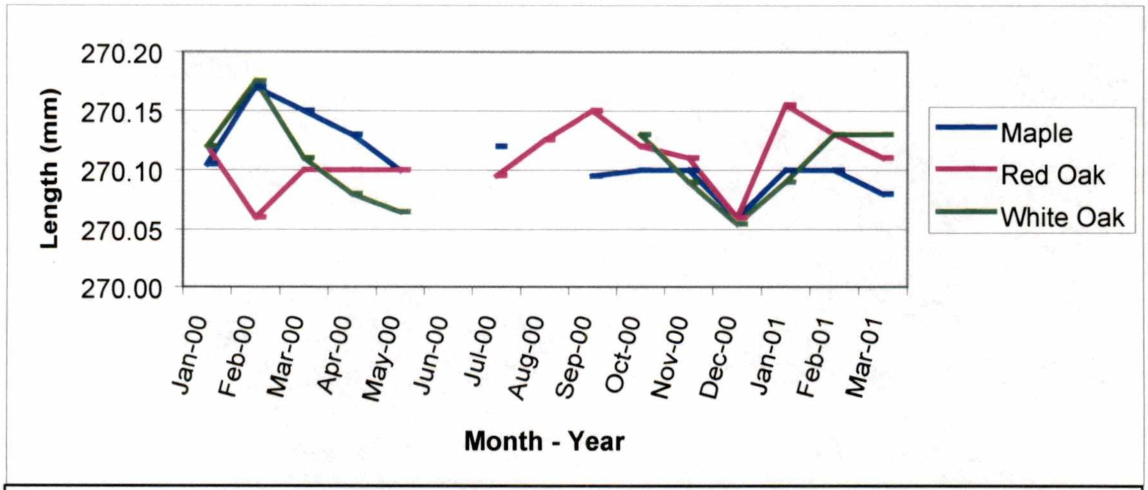

Figure 14. Medians for "finished blank" lengths for target length 270 mm.

Table 10. Averages and medians by month for hard maple (*Acer saccharum*) "finished blank" length for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median (M) in mm	Non-parametric Wilcoxon Rank Sums Test
January-2000	10	270.11	270.11	a
February-2000	15	270.16	270.17	b
March-2000	25	270.14	270.15	abc
April-2000	55	270.13	270.13	abcd
May-2000	25	270.10	270.10	a e
June-2000	--*	--*	--*	--*
July-2000	5	270.12	270.12	abcdefg
August-2000	--*	--*	--*	--*
September-2000	24	270.10	270.10	a efghi
October-2000	20	270.10	270.10	a efghij
November-2000	20	270.11	270.10	a c efghijk
December-2000	5	270.07	270.06	a efghijkl
January-2001	10 (110)**	270.10 (270.32)**	270.10 (270.18)**	a c efghijklm
February-2001	15	270.11	270.10	a c efghijklmn
March-2001	30	270.08	270.08	a efghijklmno

** Blank cells indicate that no data were available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter; "b" is for February-2000 and is compared with each month thereafter.*

Table 11. Averages and medians by month for red oak (*Quercus rubra*) "finished blank" length for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median (M) in mm	Non-parametric Wilcoxon Rank Sums Test
January-2000	65	270.12	270.12	a
February-2000	35	270.06	270.06	b
March-2000	80	270.09	270.10	c
April-2000	99	270.10	270.10	ce
May-2000	30	270.11	270.10	a cde
June-2000	--*	--*	--*	--*
July-2000	10	270.10	270.10	abcde g
August-2000	80	270.12	270.13	a d fgh
September-2000	45 (80)**	270.12 (270.13)**	270.15 (270.13)**	a efghi
October-2000	29	270.12	270.12	a c efghij
November-2000	10	270.10	270.11	abcdefghijk
December-2000	15	270.08	270.06	bcdefg i kl
January-2001	10	270.16	270.16	hij m
February-2001	5	270.12	270.13	abcde ghijkl n
March-2001	105	270.11	270.11	a c e g jk no

** Blank cells indicate that no data were available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter; "b" is for February-2000 and is compared with each month thereafter.*

Table 12. Averages and medians by month for white oak (*Quercus alba*) "finished blank" length for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median (M) in mm	Non-parametric Wilcoxon Rank Sums Test
January-2000	45	270.12	270.12	a
February-2000	10	270.18	270.18	b
March-2000	80	270.11	270.11	a c
April-2000	105	270.09	270.08	cd
May-2000	50	270.08	270.07	de
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--*	--*	--*	--*
September-2000	--*	--*	--*	--*
October-2000	40	270.11	270.13	a cd j
November-2000	20	270.08	270.09	cde jk
December-2000	10	270.06	270.06	e kl
January-2001	25	270.10	270.09	a cd jk m
February-2001	15 (46)**	270.13 (270.10)**	270.13 (270.10)**	a c j n
March-2001	45	270.12	270.13	a j no

* *Blank cells indicate that no data were available.*

** *Statistics in parenthesis were estimates that were taken as part of a sampling study.*

*** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter; "b" is for February-2000 and is compared with each month thereafter.

The process location of "finished blank" length as represented by the average and median varied over time (Figure 14). The medians, in some cases, were significantly different from month-to-month at a $\alpha = 0.05$ for all three species studied (Tables 10-12, pages 56-57).

There was evidence that the process locations for "finished blank" length were not stable month-to-month, *e.g., results from Non-parametric Wilcoxon Rank Sums Test.* "Finished blank" lengths were longer than the 270 mm target lengths, which were necessary given the variation of the process. Recall the Taguchi Loss Function and the effect of variation and deviations from target on manufacturing costs (Taguchi, 1993). Taguchi penalizes for the process location (X-bar) deviating from the target specification.

“Finished Blank” Width for Target Length 270 mm

The sample standard deviation, *s*, was used as an estimate of process variability for “finished blank” width. The sample average and medians were used as estimates of process location for “finished blank” width. The variability as represented by the standard deviation in “finished blank” width varied from 0.02 mm to 0.08 mm from January 2000 to March 2001 (Figure 15, page 60). The line graph in Figure 15 represented samples taken by the manufacturer. The sample points in Figure 15 represents samples taken as part of the thesis sampling plan. The thesis sampling plan estimates of standard deviation and the manufacturers estimate of standard deviation were almost identical, indicating accuracy for both measurements taken (Figure 15, page 60, and Table 13, page 62). A statistical test of significance for the standard deviation was not conducted given small sample sizes, unequal sample sizes, and normality could not be assumed. In a non-stochastic sense, the dispersion of “finished blank” width appears to be stable.

The process location of “finished blank” width as represented by the median can be seen in Figure 16, page 63. There was a significant difference, in some cases, in the medians from month-to month at a $\alpha = 0.05$ for the three species studied (Tables 14-16, pages 61-62).

Instability in “finished blank” width may have a direct relationship with the number of blanks that can be cut from rough lumber as related to the width of the rough lumber. This relationship may affect production yield.

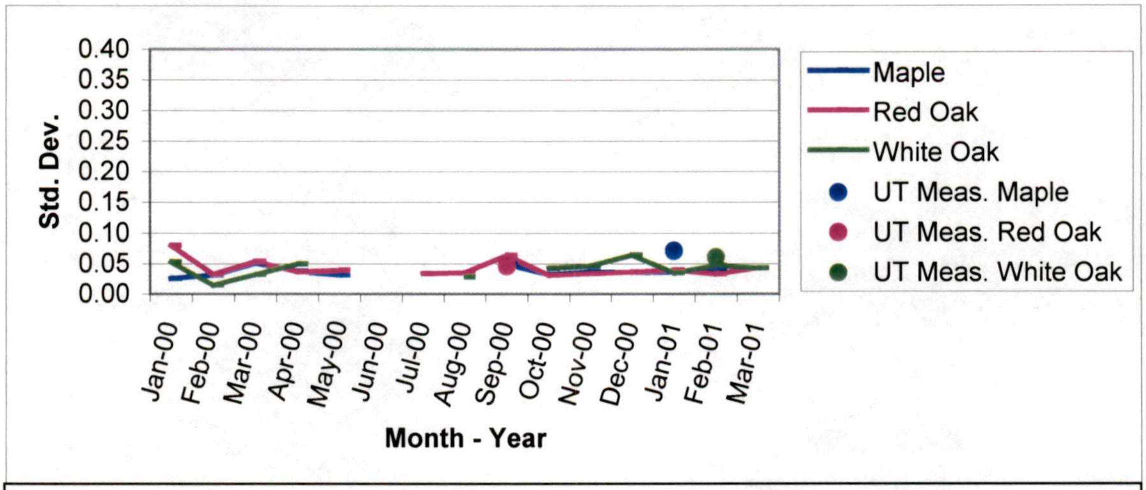

Figure 15. Standard deviation of "finished blank" width for target length 270 mm.

Table 13. Standard deviations, *s*, and sample sizes, *n*, by month for "finished blank" width for target length 270 mm.

Month-Year	**Sample Sizes (*n*)**	**hard maple (s) in mm**	**Sample Sizes (*n*)**	**Red Oak (s) in mm**	**Sample Sizes (*n*)**	**white oak (s) in mm**
January-2000	20	0.0254	60	0.0791	55	0.0523
February-2000	15	0.0310	35	0.0322	10	0.0145
March-2000	25	0.0510	70	0.0530	80	0.0316
April-2000	38	0.0360	120	0.0391	55	0.0492
May-2000	12	0.0287	50	0.0387	--*	--*
June-2000	--*	--*	--*	--*	--*	--*
July-2000	--*	--*	20	0.0327	--*	--*
August-2000	--*	--*	90	0.0343	10	0.0275
September-2000	10	0.0477	40 (160)**	0.0630 (0.044)**	--*	--*
October-2000	20	0.0484	10	0.0302	30	0.0424
November-2000	10	0.0370	10	0.0329	40	0.0463
December-2000	--*	--*	30	0.0358	30	0.0636
January-2001	20 (165)**	0.0350 (0.071)**	20	0.0474	30	0.0195
February-2001	20	0.0504	30	0.0461	80 (69)**	0.0493 (0.048)**
March-2001	23	0.0941	140	0.0423	30	0.0395

** Blank cells indicate that no data were available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

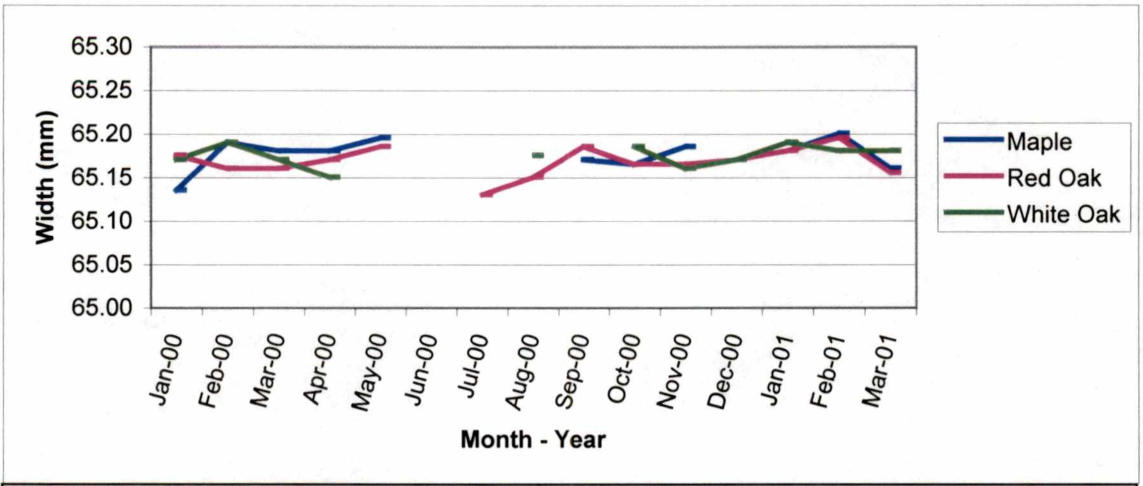

Figure 16. Medians for "finished blank" width for target length 270 mm.

Table 14. Averages and medians by month for hard maple (*Acer saccharum*) "finished blank" width for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median (M) in mm	Non-parametric Wilcoxon Rank Sums Test
January-2000	20	65.14	65.14	a
February-2000	15	65.19	65.19	b
March-2000	25	65.17	65.18	bc
April-2000	38	65.17	65.18	cd
May-2000	12	65.19	65.20	bcde
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--*	--*	--*	--*
September-2000	10	65.17	65.17	bcdefghi
October-2000	20	65.15	65.17	bcdefghij
November-2000	10	65.17	65.19	a cd fghijk
December-2000	--*	--*	--*	--*
January-2001	20 (165)**	65.16 (65.20)**	65.18 (65.19)**	bcdefghijklm
February-2001	20	65.20	65.20	bcdefghijklmn
March-2001	23	65.19	65.16	bcdefghijklmno

* *Blank cells indicate that no data were available.*

** *Statistics in parenthesis were estimates that were taken as part of a sampling study.*

*** *Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter; "b" is for February-2000 and is compared with each month thereafter.*

Table 15. Averages and medians by month for red oak (*Quercus rubra*) "finished blank" width for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median (M) in mm	Non-parametric Wilcoxon Rank Sums Test
January-2000	60	65.19	65.18	a
February-2000	35	65.16	65.16	ab
March-2000	70	65.15	65.16	bc
April-2000	120	65.17	65.17	bcd
May-2000	50	65.18	65.19	a e
June-2000	--*	--*	--*	--*
July-2000	20	65.13	65.13	b g
August-2000	90	65.15	65.15	a d h
September-2000	40 (160)**	65.20 (65.20)**	65.19 (65.20)**	a e i
October-2000	10	65.15	65.17	abcd g j
November-2000	10	65.16	65.17	abcde k
December-2000	30	65.16	65.17	abcde hi kl
January-2001	20	65.19	65.18	a e j m
February-2001	30	65.20	65.20	a e j mn
March-2001	140	65.15	65.16	bcd kl o

** Blank cells indicate that no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter; "b" is for February-2000 and is compared with each month thereafter.*

Table 16. Averages and medians for white oak (*Quercus alba*) "finished blank" width for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median (M) in mm	Non-parametric Wilcoxon Rank Sums Test
January-2000	55	65.17	65.17	a
February-2000	10	65.19	65.19	ab
March-2000	80	65.17	65.17	abc
April-2000	55	65.14	65.15	d
May-2000	--*	--*	--*	--*
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	10	65.17	65.18	abcd h
September-2000	--*	--*	--*	--*
October-2000	30	65.18	65.19	abcd hj
November-2000	40	65.16	65.16	a cd hjk
December-2000	30	65.16	65.17	ab d hj l
January-2001	30	65.19	65.19	bc hj lm
February-2001	78 (69)**	65.18 (65.20)**	65.18 (65.19)**	abc hjklmn
March-2001	30	65.17	65.18	abc hjklmno

** Blank cells indicate that no data were available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter; "b" is for February-2000 and is compared with each month thereafter.*

"Veneer-Slat" Thickness for Target Length 270 mm

The sample standard deviation, *s*, was used as an estimate of process variability for "veneer-slat" thickness. The sample average and median were used as estimates of the process location for "veneer-slat" thickness. The variability as represented by the standard deviation in "veneer-slat" thickness varied from 0.04 mm to 0.10 mm from January 2000 to March 2001 (Figure 17, page 64). The line graph in Figure 17, page 64, represented samples taken by the manufacturer. The sample points in Figure 17, page 64, represented samples taken as part of the thesis sampling plan. The thesis sampling plan estimates of standard deviation and the manufacturers estimate of standard deviation were close in value, indicating accuracy with both sets of data (Figure 17, page 64, Table 17, page 64). A statistical test of significance for the standard deviation was not conducted given small sample sizes, unequal sample sizes, and normality could not be assumed. In a non-stochastic sense, the dispersion of "veneer-slat" thickness appeared to be stable.

The process location of "veneer-slat" thickness as represented by the median varied over time (Figure 18, page 65). There was a significant difference, in some cases, in the medians from month-to month at a $\alpha = 0.05$ for the three species studied (Tables 18-20, pages 65-66).

Differences in "veneer-slat" thickness may represent serious quality problems in that they affect the final product (composite wood flooring), which is used by the customer. They may also represent a direct loss to the company if the "veneer-slat" thickness is thinner than the minimum "veneer-slat" thickness specification. "Veneer-slats" that are too thick may represent additional tool wear during sanding.

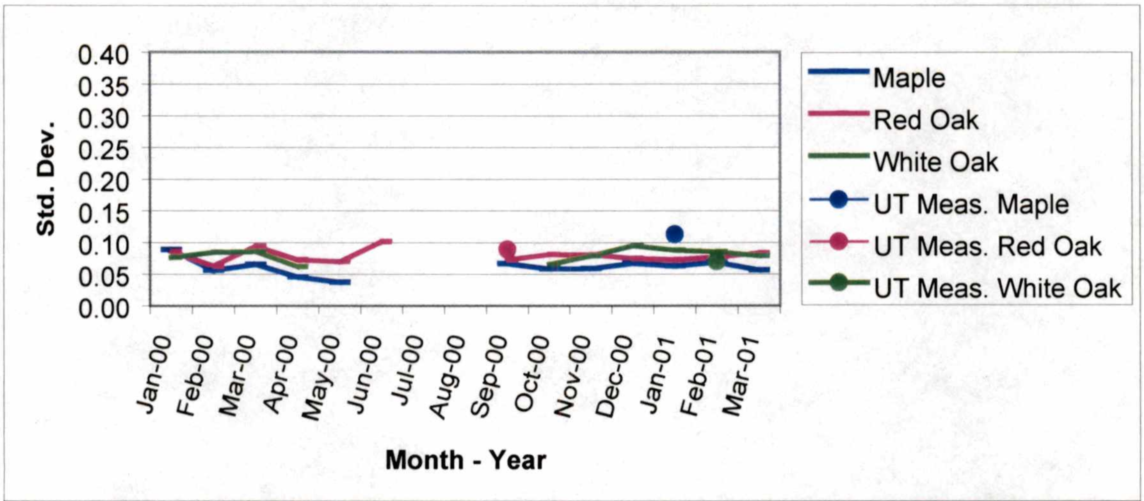

Figure 17. Standard deviation (mm) for "veneer-slat" thickness for target length 270 mm.

Table 17. Standard deviations, *s*, and sample sizes, *n*, by month for "veneer-slat" thickness for target length 270 mm.

Month-Year	Sample Sizes (n)	hard maple (s) in mm	Sample Sizes (n)	red oak (s) in mm	Sample Sizes (n)	white oak (s) in mm
January-2000	29	0.089	139	0.086	120	0.077
February-2000	30	0.056	80	0.063	20	0.085
March-2000	40	0.066	160	0.094	160	0.086
April-2000	60	0.046	180	0.073	100	0.062
May-2000	10	0.037	50	0.070	--*	--*
June-2000	--*	--*	30	0.101	--*	--*
July-2000	--*	--*	--*	--*	--*	--*
August-2000	--*	--*	--*	--*	--*	--*
September-2000	60	0.067	90 (160)**	0.073 (0.089)**	--*	--*
October-2000	50	0.058	69	0.081	79	0.065
November-2000	40	0.059	20	0.080	39	0.079
December-2000	10	0.067	40	0.075	50	0.095
January-2001	18 (328)**	0.063 (0.113)**	60	0.073	80	0.088
February-2001	18	0.069	20	0.077	60 (138)**	0.086 (0.069)**
March-2001	24	0.056	80	0.083	110	0.079

** Blank cells indicate that no data were available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

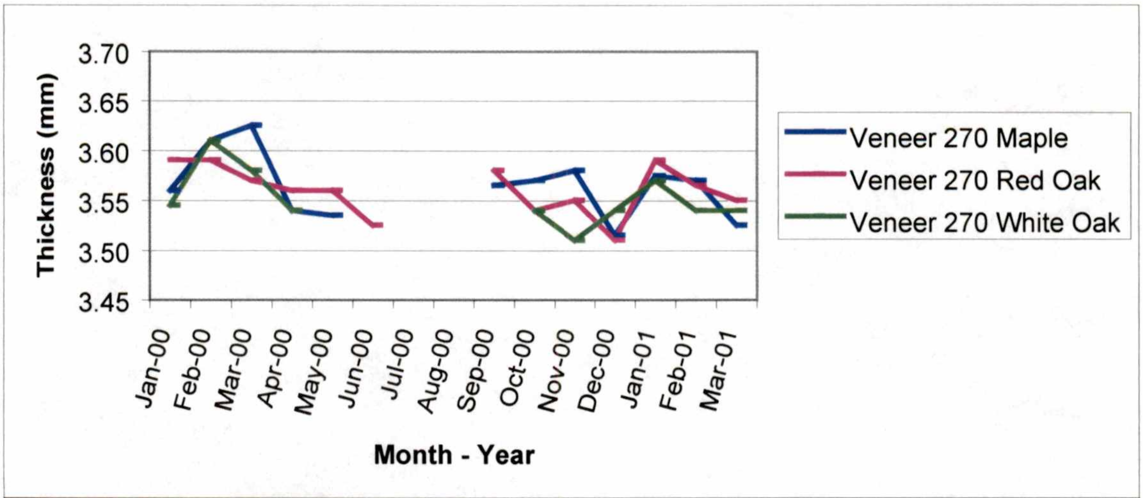

Figure 18. Medians for "veneer-slat" thickness for target length 270 mm.

Table 18. Averages and medians by month for hard maple (*Acer saccharum*) "veneer-slat" thickness for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median (M) in mm	Non-parametric Wilcoxon Rank Sums Test
January-2000	29	3.54	3.56	a
February-2000	30	3.62	3.61	b
March-2000	40	3.62	3.63	bc
April-2000	60	3.55	3.54	a d
May-2000	10	3.54	3.54	a de
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--*	--*	--*	--*
September-2000	60	3.56	3.57	a defghi
October-2000	50	3.56	3.57	a defghij
November-2000	40	3.57	3.58	a efghijk
December-2000	10	3.52	3.52	a defgh l
January-2001	18 (328)**	3.57 (3.60)**	3.58 (3.60)**	a defghijk m
February-2001	18	3.57	3.57	a defghijk mn
March-2001	24	3.53	3.53	a defgh l o

** Blank cells indicate that no data were available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter; "b" is for February-2000 and is compared with each month thereafter.*

Table 19. Averages and medians by month for red oak (*Quercus rubra*) "veneer-slat" thickness for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median (M) in mm	Non-parametric Wilcoxon Rank Sums Test
January-2000	139	3.59	3.59	a
February-2000	80	3.58	3.59	ab
March-2000	160	3.56	3.57	bc
April-2000	180	3.55	3.56	cd
May-2000	50	3.54	3.56	cde
June-2000	30	3.54	3.53	cdef
July-2000	--*	--*	--*	--*
August-2000	--*	--*	--*	--*
September-2000	90 (160)**	3.56 (3.58)**	3.58 (3.59)**	abcd f i
October-2000	69	3.55	3.54	cdef j
November-2000	20	3.52	3.55	bcdef jk
December-2000	40	3.51	3.51	f kl
January-2001	60	3.60	3.59	ab i m
February-2001	20	3.57	3.57	abcdef i k mn
March-2001	80	3.55	3.55	def jk o

** Blank cells indicate that no data were available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter; "b" is for February-2000 and is compared with each month thereafter.*

Table 20. Averages and medians by month for white oak (*Quercus alba*) "veneer-slat" thickness for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median (M) in mm	Non-parametric Wilcoxon Rank Sums Test
January-2000	120	3.54	3.55	a
February-2000	20	3.61	3.61	b
March-2000	160	3.58	3.58	bc
April-2000	100	3.54	3.54	a d
May-2000	--*	--*	--*	--*
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--*	--*	--*	--*
September-2000	--*	--*	--*	--*
October-2000	79	3.54	3.54	a d j
November-2000	39	3.50	3.51	k
December-2000	50	3.53	3.54	a d jkl
January-2001	80	3.57	3.57	bc m
February-2001	60 (138)**	3.54 (3.53)**	3.54 (3.54)**	a d j l n
March-2001	110	3.53	3.54	a d j l no

** Blank cells indicate that no data were available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter; "b" is for February-2000 and is compared with each month thereafter.*

Capability Analysis - Objective 2

A capability analysis was conducted by using the following capability indices: C_p, C_{pk}, C_{pm}.[10,11,12] C_p and C_{pk} were used for the capability analysis in the thesis because the two indices are widely used by practitioners in capability studies (Breyfogle 1999). Taguchi's C_{pm} capability index was used because the result penalizes the manufacturer from deviating from target. Taguchi's penalty for deviating from the target is important because deviations from target may represent a direct loss to the organization. Note that the $C_{pm} = C_p$ if the process average is equal to the target. The C_{pm} is an extension of Taguchi's philosophy (Taguchi 1993) of reducing variability around the target and is also consistent with Harry's (2000) philosophy of obtaining "Six Sigma" quality relative to the target.

The process is considered to be capable of meeting specifications if each capability index has a value greater than or equal to one (Juran 1992). Recall Deming's views on capability indices presented in Chapter 2, *i.e., capability indices may be a hindrance to continuous improvement when it is used as a static quality goal.* Also recall (Harry 2000) views that a capability index of one produces 2,700 parts per million that are defective. Due to the significant differences, in some cases, from month-to-month in the medians a $\alpha = 0.05$ may be a reason for the majority of the capability indices

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[10] $C_p = (USL - LSL) / 6s$, where USL = upper specification limit, LSL = lower specification limit and s = sample standard deviation.

[11] $C_{pk} = \min \{[(USL - \text{X-bar}) / 3s], [(\text{X-bar} - LSL) / 3s]\}$, where "X-bar" is the sample average.

[12] $C_{pm} = (USL - LSL) / 6[(\text{X-bar} - T)^2 + s^2]^{1/2}$, where T = target.

indicating processes not capable of meeting specification (Appendix C, Figures 1c to 25c, page 180-189).

For all products and species that were studied over the 15-month study period there were only 10 cases out of the possible 405 opportunities where the C_p value was greater than one. There was one incident out of the possible 405 where the C_{pk} value was greater than one. Taguchi's C_{pm} capability index was never greater than one for all 405 possible opportunities. One may question the manufacturer's process capability rationale in the context of the defined specifications, *i.e., are the specifications realistic and helpful for the employees in process improvement efforts?* The specification limits the manufacturer are trying to hold are unrealistic because the largest specification was eight hundredths (0.08) of an inch to the tightest specification of four thousandths (0.004) of an inch. The tightest specification, on average, is the thickness of a piece of paper. Four thousandths of an inch is generally seen as specification for manufacturing of metal pieces.

"Finished Blank" Thickness for Target Lengths 215 mm, 270 mm, and 325 mm

A capability analsysis was not conducted for "finished blank" thickness because this product did not have complete specifications as defined by the manufacturer. There was a minimum specification (LSL), but a target (T) and upper specification limit (USL) were not defined. The manufacturer may be missing a significant cost savings opportunity by not defining a target or USL for "finished blank" thickness. If the manufacturer allows "finished blanks" to be processed at extreme thicknesses, optimization of blank recovery from lumber may not be obtained. Excessive thickness and thickness variation of within and between "finished blanks" may lead to additional tool-wear and final "veneer-slat" thickness variation.

"Finished Blank" Lengths for Target Lengths 215 mm, 270 mm, and 325 mm

The capability indices for "finished blank" lengths of 215 mm, 270 mm, and 325 mm suggested that the process was not consistently capable of meeting specifications from January 2000 thru March 2001 (Figures 19-21, pages 69-70). The C_{pk} capability index for the "finished blank" length of 215 mm for white oak (*Quercus alba*) during the month of July 2001 (Table 21, page 72) was equal to one, *i.e., process variation was within specification.*

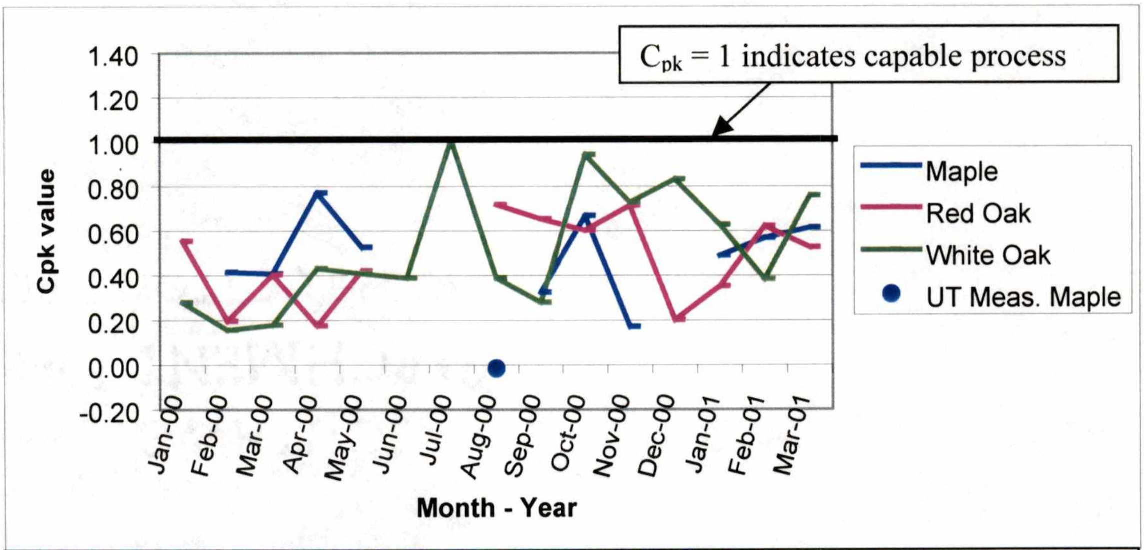

Figure 19. Capability C_{pk} index for "finished blank" length for target length 215 mm.

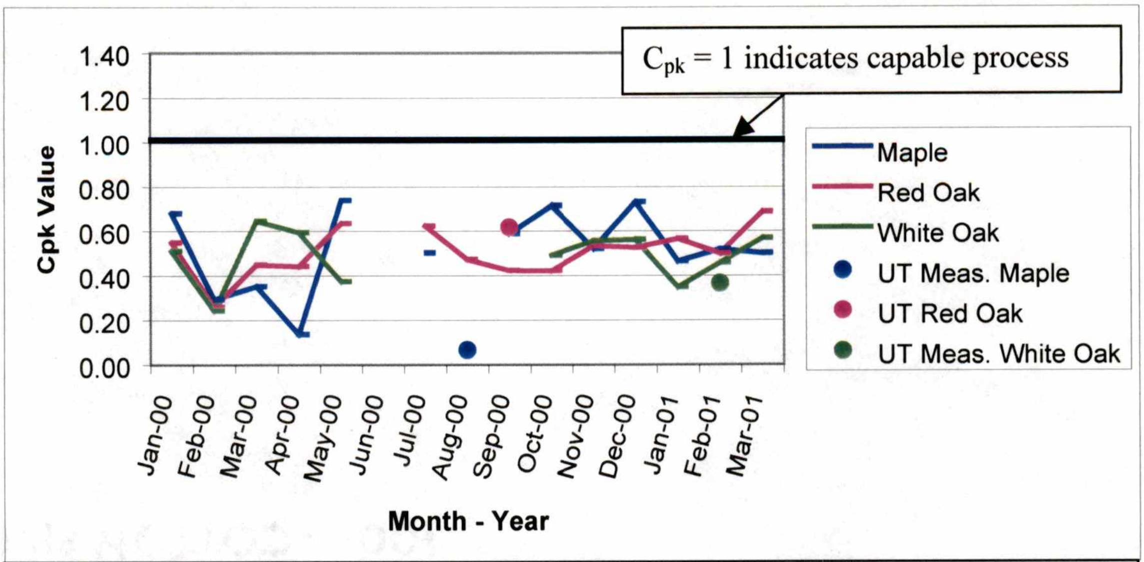

Figure 20. Capability C_{pk} index for "finished blank" length for target length 270 mm.

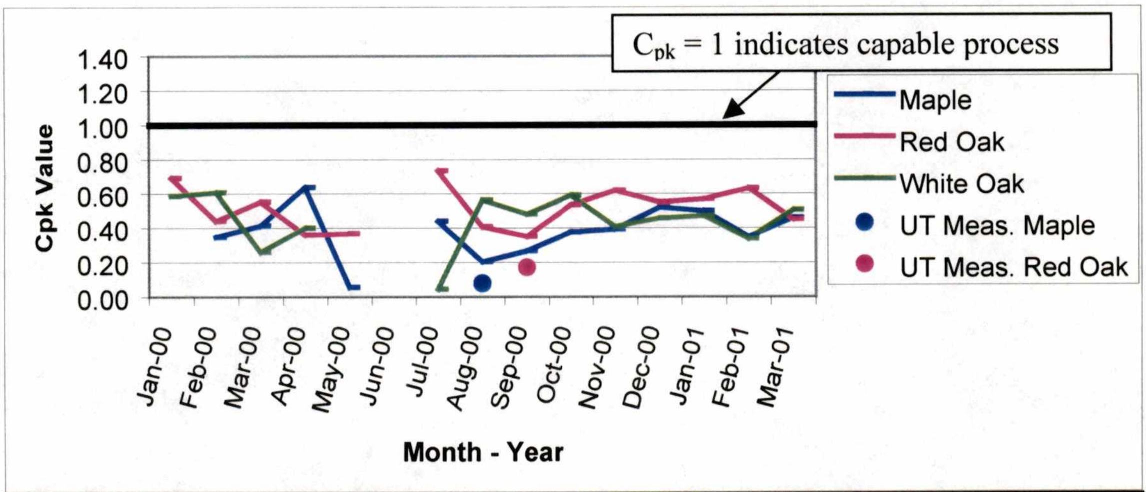

Figure 21. Capability C_{pk} index for "finished blank" length for target length 325 mm.

The capability statistics for "finished blank" length for target lengths of 270 mm and 325 mm indicated only a few months that had a C_p value greater than one (Tables 22 and 23, page 71-72). There were no months where the C_{pk} or C_{pm} values were greater than one. The months where the C_p value was greater than one for target length 270 mm were December 2000 (hard maple), February and November 2000 (white oak). For the target length of 325 mm, $C_p > 1$ for May 2000 (red oak). The manufacturer has an opportunity to investigate the months where C_p was capable. They would investigate reason why their process was capable that month to potentially learn ways to continually hold there process within their specifications. Fishbone diagrams may help identify reasons for C_p being capable. For most months $C_p \neq C_{pk}$ which further indicated that the process location was not stable.

Harry's (2000) philosophy indicates that a long term "Six Sigma" quality level produces only 3.4 defective parts per million. The approximate number of defects produced for "finished blank" length for all target lengths and the three species studied were 300,000 defective parts per million. This may equate to a 30% loss rate for the hardwood-flooring manufacturer. However, most process averages and medians were greater than the target value, which would imply that not all products were produced as reject but that yield and recovery was not being optimized. Capability indices for "finished blank" length for target lengths 215 mm, 270 mm, and 325 mm suggested that the manufacturer was not capable of meeting specifications (Table 21, page 71).

Table 21. Capability indices for "finished blank" length for target length 215 mm.

	hard maple (*Acer saccharum*)			red oak (*Quercus rubra*)			white oak (*Quercus alba*)		
Month-Year	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}
Jan-00	--*	--*	--*	0.575	0.552	0.574	0.289	0.276	0.288
Feb-00	0.457	0.413	0.453	0.882	0.194	0.385	0.506	0.155	0.349
Mar-00	0.555	0.405	0.507	0.598	0.401	0.514	0.320	0.177	0.294
Apr-00	0.823	0.770	0.813	0.218	0.173	0.216	0.613	0.429	0.537
May-00	0.845	0.524	0.609	0.565	0.417	0.517	0.525	0.406	0.494
Jun-00	--*	--*	--*	--*	--*	--*	**1.101**	0.385	0.465
Jul-00	--*	--*	--*	--*	--*	--*	**1.328**	**1.009**	0.960
Aug-00	--* (0.71)	--* (-0.21)	--* (0.24)	0.733	0.715	0.732	0.568	0.385	0.498
Sep-00	0.477	0.321	0.432	0.672	0.650	0.671	0.365	0.277	0.353
Oct-00	0.833	0.667	0.745	0.715	0.601	0.676	**1.252**	0.941	0.916
Nov-00	0.545	0.169	0.361	0.857	0.710	0.784	0.826	0.726	0.791
Dec-00	--*	--*	--*	0.901	0.198	0.386	**1.093**	0.831	0.859
Jan-01	0.562	0.488	0.463	0.785	0.348	0.464	0.864	0.626	0.346
Feb-01	0.497	0.567	0.514	0.565	0.619	0.516	0.749	0.382	0.457
Mar-01	0.683	0.613	0.365	0.648	0.523	0.499	0.813	0.757	0.565

** Blank cells indicate that no data were available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 22. Capability indices for "finished blank" length for target length 270 mm.

	hard maple (*Acer saccharum*)			red oak (*Quercus rubra*)			white oak (*Quercus alba*)		
Month-Year	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}
Jan-00	0.738	0.679	0.727	0.690	0.547	0.634	0.637	0.508	0.594
Feb-00	0.654	0.292	0.443	0.434	0.258	0.384	**1.054**	0.242	0.400
Mar-00	0.554	0.350	0.473	0.493	0.448	0.488	0.682	0.643	0.677
Apr-00	0.322	0.135	0.281	0.456	0.441	0.456	0.638	0.591	0.632
May-00	0.759	0.734	0.757	0.675	0.632	0.670	0.442	0.373	0.432
Jun-00	--*	--*	--*	--*	--*	--*	--*	--*	--*
Jul-00	0.596	0.500	0.573	0.620	0.620	0.620	--*	--*	--*
Aug-00	--*	--*	--*	0.623	0.471	0.567	--*	--*	--*
Sep-00	0.587	0.585	0.587	0.526 (0.48)	0.421 (0.36)	0.502 (0.45)	--*	--*	--*
Oct-00	0.725	0.711	0.725	0.532	0.420	0.504	0.546	0.490	0.539
Nov-00	0.579	0.519	0.570	0.547	0.531	0.546	0.659	0.553	0.628
Dec-00	**1.070**	0.728	0.746	0.670	0.523	0.613	**1.018**	0.560	0.599
Jan-01	0.463 (0.07)	0.464 (-0.08)	0.348 (0.06)	0.488	0.562	0.785	0.626	0.346	0.490
Feb-01	0.514	0.516	0.619	0.567	0.497	0.565	0.382 (0.70)	0.457 (0.67)	0.562 (0.69)
Mar-01	0.365	0.499	0.523	0.613	0.683	0.648	0.757	0.565	0.679

** Blank cells indicate that no data were available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 23. Capability indices for "finished blank" length for target length 325 mm.

	hard maple (*Acer saccharum*)			red oak (*Quercus rubra*)			white oak (*Quercus alba*)		
Month-Year	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}
Jan-00	--*	--*	--*	0.711	0.690	0.710	0.590	0.586	0.590
Feb-00	0.397	0.346	0.392	0.546	0.437	0.519	0.810	0.606	0.691
Mar-00	0.520	0.413	0.495	0.574	0.550	0.573	0.342	0.257	0.331
Apr-00	0.656	0.637	0.655	0.386	0.358	0.385	0.470	0.398	0.459
May-00	0.489	0.054	0.297	**1.076**	0.366	0.457	--*	--*	--*
Jun-00	--*	--*	--*	--*	--*	--*	--*	--*	--*
Jul-00	0.447	0.438	0.447	0.754	0.731	0.752	0.135	0.042	0.130
Aug-00	0.779 (0.28)	0.203 (0.07)	0.390 (0.24)	0.474	0.404	0.464	0.937	0.562	0.623
Sep-00	0.434	0.266	0.387	0.465	0.348	0.439	0.549	0.479	0.537
Oct-00	0.735	0.375	0.499	0.616	0.531	0.597	0.602	0.590	0.601
Nov-00	0.642	0.391	0.513	0.666	0.616	0.659	0.569	0.407	0.512
Dec-00	0.540	0.519	0.539	0.619	0.549	0.606	0.562	0.455	0.535
Jan-01	0.509	0.498	0.562	0.594	0.565	0.623	0.591	0.467	0.513
Feb-01	0.583	0.347	0.513	0.544	0.629	0.579	0.540	0.335	0.498
Mar-01	0.645	0.457	0.480	0.647	0.447	0.684	0.505	0.503	0.556

** Blank cells indicate that no data were available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

<u>"Finished Blank" Width for Target Lengths 215 mm, 270 mm, and 325 mm</u>

The capability indices for "finished blank" width for target lengths 215 mm, 270 mm, and 325 mm suggested that the process was not consistently capable of meeting specifications from January 2000 thru March 2001 (Figures 22-24, pages 73-74). The C_p capability index for the "finished blank" width for the target length of 215 mm for hard maple (*Acer saccharum*) during May 2000 and 270 mm for white oak (*Quercus alba*) during February 2000 (Tables 24 and 25, page 75) were greater than one. The C_{pk} and C_{pm} capability indices for these months were not greater than one. This indicated that even though the process dispersion was capable of meeting the engineering tolerance, the process was not on target or centered within the specifications.

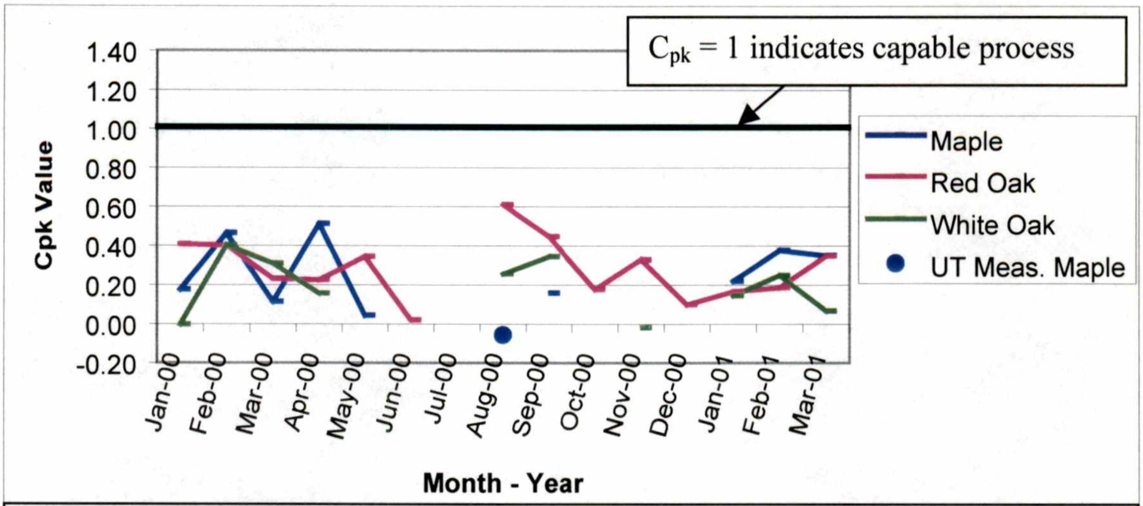

Figure 22. Capability C_{pk} index for "pre-finished blank" width for target length 215 mm.

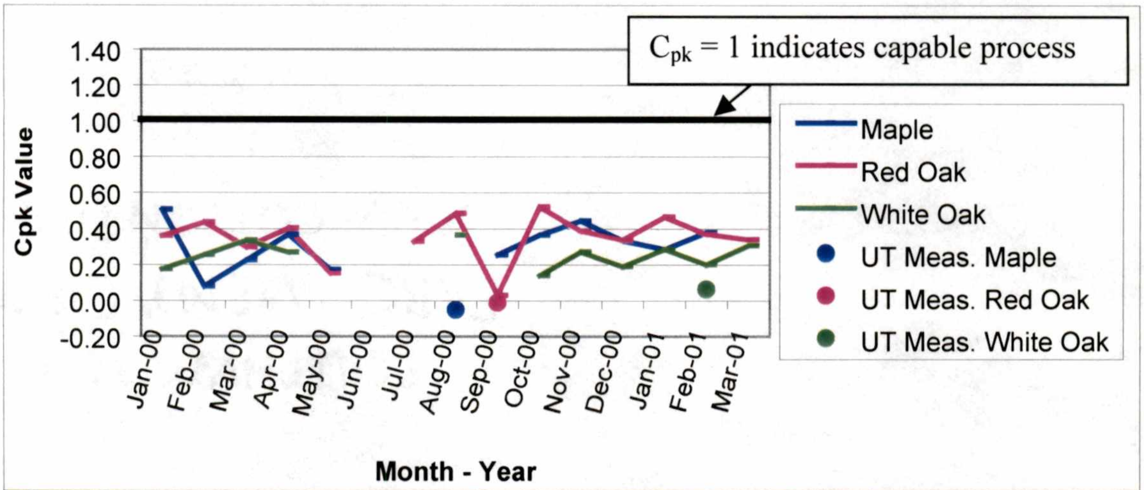

Figure 23. Capability C_{pk} index for "pre-finished blank" width for target length 270 mm.

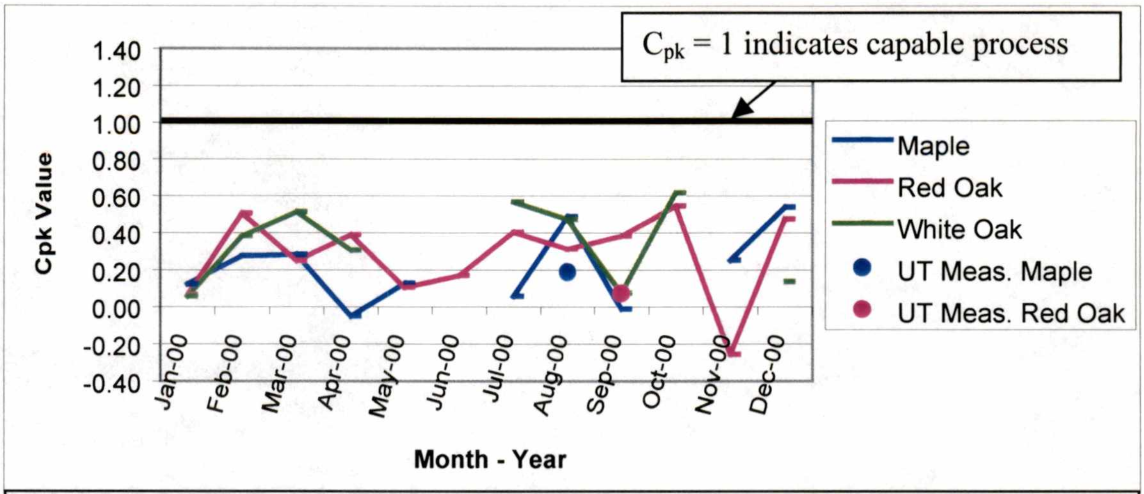

Figure 24. Capability C_{pk} index for "pre-finished blank" width for target length 325 mm.

There were only two occurrences where the natural disperion of "finished blank" width was capable of meeting the engineering tolerance, hard maple (May 2000) and white oak (February 2000), see Tables 24-26, pages 75-76. These occurances may be due to the specification limits allowing only a 0.05 mm movement around the average. The specification tolerance only allows the width of a "veneer-slat" to vary by the thickness of a piece of paper, which is on average four thousandths (0.004) of an inch. A "veneer-slat" width There were no months where the C_{pk} or C_{pm} values were greater than one for any "finished blank" width for any species and target length. In some cases the C_{pk} values were negative, *i.e., the process average was above the USL.* In this study the manufacturer was processing their material wider than the USL.

The approximate number of defects produced for "finished blank" width for all species and target lengths were approximately 350,000 defective parts per million. Note a defective part may not necessary equate to reject. Even though the manufacturer feels a part is acceptable, it still may have a negative effect on yield and recovery.

Table 24. Capability indices for "finished blank" width for target length 215 mm.

	hard maple (*Acer saccharum*)			red oak (*Quercus rubra*)			white oak (*Quercus alba*)		
Month-Year	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}
Jan-00	0.244	0.175	0.239	0.223	0.405	0.196	0.322	-0.004	0.230
Feb-00	0.510	0.464	0.504	0.596	0.400	0.514	0.495	0.402	0.477
Mar-00	0.513	0.113	0.328	0.504	0.230	0.389	0.483	0.309	0.428
Apr-00	0.546	0.511	0.544	0.331	0.223	0.315	0.345	0.156	0.300
May-00	**1.076**	0.043	0.330	0.349	0.342	0.349	--*	--*	--*
Jun-00	--*	--*	--*	0.469	0.019	0.279	--*	--*	--*
Jul-00	--*	--*	--*	--*	--*	--*	--*	--*	--*
Aug-00	--* (0.34)	--* (-0.6)	--* (0.21)	0.614	0.606	0.614	0.491	0.255	0.401
Sep-00	0.254	0.158	0.244	0.452	0.443	0.452	0.556	0.345	0.470
Oct-00	--*	--	--	0.544	0.174	0.364	--*	--*	--
Nov-00	0.370	0.326	0.367	0.348	0.327	0.348	0.339	-0.020	0.230
Dec-00	--*	--*	--*	0.184	0.096	0.178	--*	--*	--*
Jan-01	0.365	0.218	0.218	0.219	0.164	0.203	0.468	0.144	0.316
Feb-01	0.345	0.375	0.306	0.342	0.184	0.138	0.426	0.248	0.214
Mar-01	0.461	0.349	0.502	0.219	0.347	0.355	0.362	0.067	0.200

* *Blank cells indicate that no data were available.*

** *Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 25. Capability indices for "finished blank" width for target length 270 mm.

	hard maple (*Acer saccharum*)			red oak (*Quercus rubra*)			white oak (*Quercus alba*)		
Month-Year	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}
Jan-00	0.656	0.505	0.303	0.211	0.358	0.193	0.318	0.174	0.292
Feb-00	0.537	0.079	0.323	0.517	0.434	0.502	**1.150**	0.253	0.401
Mar-00	0.327	0.225	0.423	0.315	0.296	0.314	0.527	0.335	0.457
Apr-00	0.450	0.367	0.187	0.465	0.401	0.457	0.339	0.268	0.331
May-00	0.532	0.170	0.289	0.430	0.150	0.329	--*	--*	--*
Jun-00	--*	--*	--*	--*	--*	--*	--*	--*	--*
Jul-00	--*	--*	--*	0.510	0.326	0.446	--*	--*	--*
Aug-00	--*	--*	--*	0.485	0.482	0.485	0.606	0.364	0.490
Sep-00	0.342	0.253	0.144	0.265 (0.37)	0.026 (-0.01)	0.215 (0.24)	--*	--*	--*
Oct-00	--*	--*	--*	0.552	0.519	0.549	0.393	0.139	0.313
Nov-00	0.461	0.443	0.460	0.506	0.385	0.476	0.360	0.270	0.347
Dec-00	0.476	0.333	0.437	0.466	0.335	0.434	0.262	0.189	0.256
Jan-01	0.580 (0.23)	0.285 (-0.01)	0.346 (0.19)	0.289	0.463	0.514	0.350	0.285	0.414
Feb-01	0.348	0.378	0.486	0.427	0.367	0.325	0.286 (0.35)	0.200 (0.01)	0.346 (0.25)
Mar-01	--*	--*	--*	0.395	0.336	0.335	0.342	0.306	0.268

* *Blank cells indicate that no data were available.*

** *Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 26. Capability indices for "finished blank" width for target length 325 mm.

	hard maple (*Acer saccharum*)			red oak (*Quercus rubra*)			white oak (*Quercus alba*)		
Month-Year	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}
Jan-00	0.385	0.123	0.303	0.223	0.063	0.232	0.225	0.057	0.201
Feb-00	0.327	0.274	0.323	0.596	0.503	0.550	0.511	0.380	0.476
Mar-00	0.521	0.281	0.423	0.504	0.246	0.388	0.554	0.512	0.549
Apr-00	0.253	-0.051	0.187	0.331	0.385	0.503	0.342	0.305	0.340
May-00	0.347	0.126	0.289	0.349	0.103	0.324	--*	--*	--*
Jun-00	--*	--*	--*	0.469	0.166	0.352	--*	--*	--*
Jul-00	0.311	0.056	0.247	--*	--*	--*	0.806	0.564	0.652
Aug-00	0.515 (0.32)	0.485 (0.19)	0.513 (0.30)	0.614	0.310	0.327	0.491	0.471	0.490
Sep-00	0.162	-0.013	0.144	0.452 (0.39)	0.379 (0.07)	0.488 (0.28)	0.373	0.075	0.278
Oct-00	--*	--*	--*	0.544	0.541	0.615	0.852	0.614	0.693
Nov-00	0.320	0.249	0.313	0.403	-0.258	0.182	--*	--*	--*
Dec-00	0.553	0.536	0.552	0.562	0.472	0.542	0.363	0.134	0.299
Jan-01	0.365	0.319	0.427	0.481	0.205	0.368	0.355	0.255	0.206
Feb-01	0.517	0.416	0.216	0.389	0.184	0.207	0.325	0.364	0.365
Mar-01	0.452	0.265	0.036	0.516	0.350	0.487	0.561	0.227	0.303

* *Blank cells indicate that no data were available.*

** *Statistics in parenthesis were estimates that were taken as part of a sampling study.*

"Veneer-Slat" Thickness for Target Lengths 215 mm, 270 mm, and 325 mm

The capability indices for "veneer-slat" thickness lengths of 215 mm, 270 mm, and 325 mm suggested that the process was not consistently capable of meeting specifications from January 2000 thru March 2001 (Figures 25-27, pages 77-78). The C_p, C_{pk}, and C_{pm} indices for the "veneer-slat" thickness did not have any value greater than one for all species and length categories (Tables 27-29, pages 78-79).

The capability C_{pk} indice for "veneer-slat" thickness in some cases was negative which indicated in this study that the process average was above the USL (Figures 25-27, pages 77-78 and Tables 27-29, pages 78-79). The approximate number of defects produced for "veneer-slat" thickness was 350,000 defective parts per million.

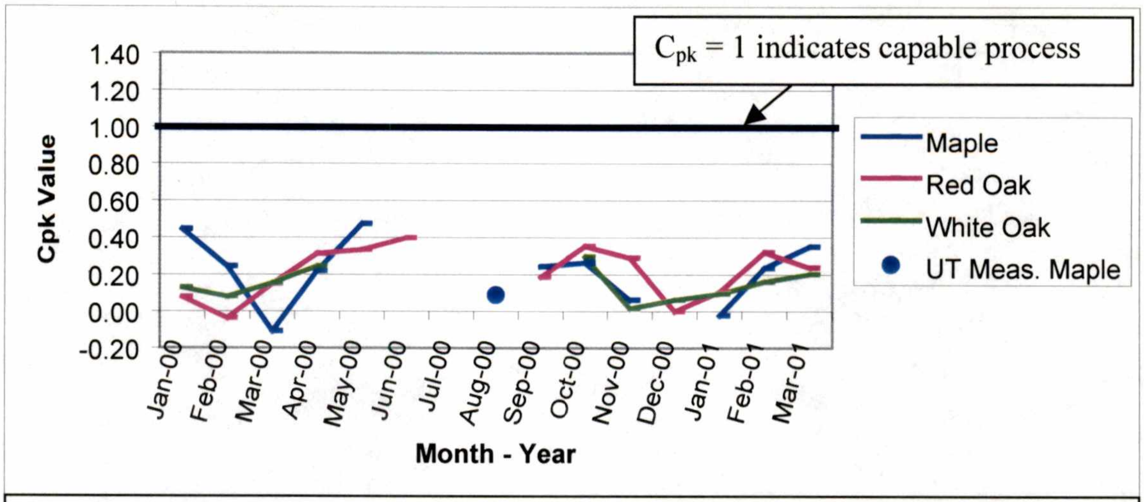

Figure 25. Capability C_{pk} index for "veneer-slat" thickness for target length 215 mm.

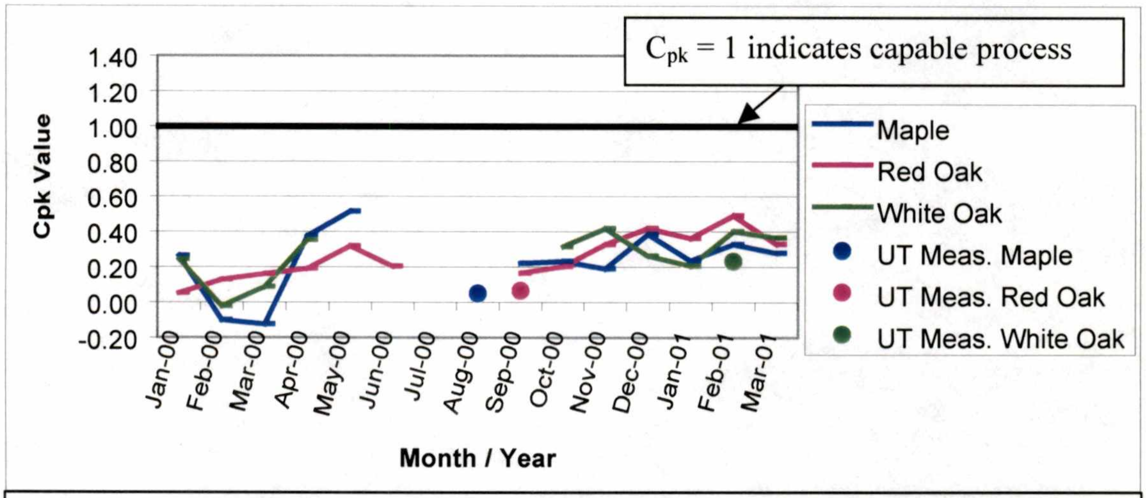

Figure 26. Capability C_{pk} index for "veneer-slat" thickness for target length 270 mm.

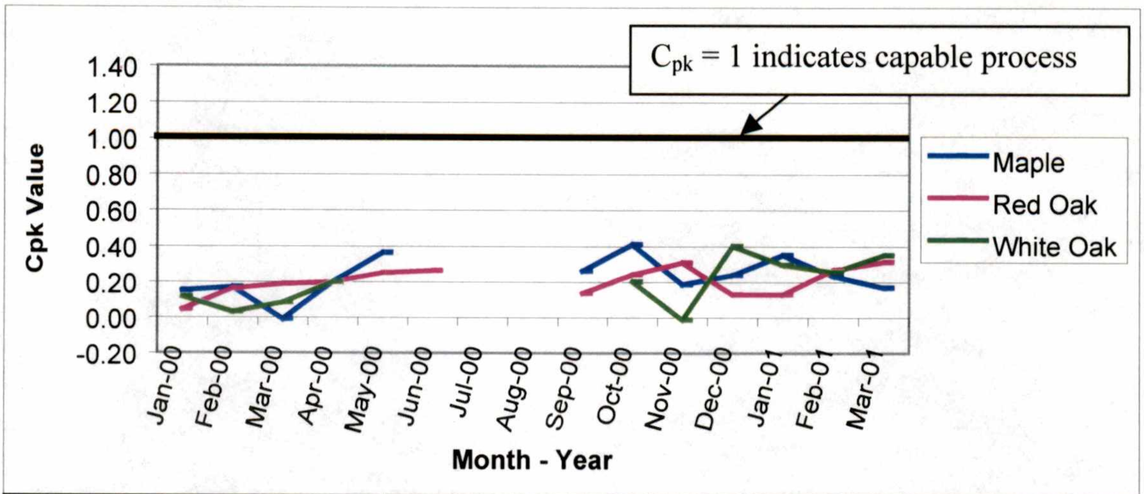

Figure 27. Capability C_{pk} index for "veneer-slat" thickness for target length 325 mm.

Table 27. Capability indices for "veneer-slat" thickness for target length 215 mm.

	hard maple (*Acer saccharum*)			**red oak (*Quercus rubra*)**			**white oak (*Quercus alba*)**		
Month-Year	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}
Jan-00	0.616	0.443	0.547	0.494	0.074	0.307	0.470	0.128	0.328
Feb-00	0.553	0.243	0.405	0.376	-0.041	0.235	0.442	0.078	0.299
Mar-00	0.524	-0.110	0.244	0.387	0.146	0.314	0.451	0.153	0.336
Apr-00	0.506	0.216	0.383	0.481	0.310	0.428	0.574	0.243	0.407
May-00	0.844	0.473	0.564	0.399	0.331	0.391	--*	--*	--*
Jun-00	--*	--*	--*	0.557	0.395	0.501	--*	--*	--*
Jul-00	--*	--*	--*	--*	--*	--*	--*	--*	--*
Aug-00	--* (0.29)	--* (0.09)	--* (0.25)	--*	--*	--*	--*	--*	--*
Sep-00	0.349	0.241	0.332	0.462	0.182	0.354	--*	--*	--*
Oct-00	0.455	0.262	0.395	0.469	0.350	0.442	0.435	0.295	0.401
Nov-00	0.758	0.061	0.327	0.618	0.286	0.438	0.421	0.014	0.267
Dec-00	--*	--*	--*	0.407	-0.004	0.256	0.507	0.061	0.303
Jan-01	0.509	-0.025	0.368	0.594	0.102	0.417	0.591	0.095	0.356
Feb-01	0.583	0.232	0.390	0.544	0.316	0.385	0.540	0.159	0.278
Mar-01	0.645	0.348	0.345	0.647	0.235	0.365	0.505	0.198	0.316

** Blank cells indicate that no data were available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 28. Capability indices for "veneer-slat" thickness for target length 270 mm.

	hard maple (*Acer saccharum*)			red oak (*Quercus Rubra*)			white oak (*Quercus Alba*)		
Month-Year	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}
Jan-00	0.374	0.261	0.355	0.389	0.050	0.273	0.435	0.242	0.377
Feb-00	0.595	-0.101	0.257	0.530	0.125	0.337	0.394	-0.024	0.246
Mar-00	0.509	-0.126	0.236	0.355	0.159	0.306	0.388	0.085	0.287
Apr-00	0.733	0.374	0.499	0.458	0.188	0.356	0.541	0.351	0.470
May-00	0.898	0.512	0.587	0.480	0.316	0.430	--*	--*	--*
Jun-00	--*	--*	--*	0.329	0.200	0.307	--*	--	--*
Jul-00	--*	--*	--*	--*	--*	--*	--*	--*	--*
Aug-00	--*	--*	--*	--*	--*	--*	--*	--*	--*
Sep-00	0.500	0.219	0.383	0.459 (0.37)	0.162 (0.06)	0.343 (0.27)	--*	--*	--*
Oct-00	0.571	0.230	0.398	0.412	0.198	0.347	0.510	0.313	0.439
Nov-00	0.565	0.188	0.374	0.416	0.325	0.402	0.424	0.415	0.424
Dec-00	0.497	0.383	0.471	0.446	0.415	0.444	0.350	0.260	0.338
Jan-01	0.053 (0.29)	0.233 (0.01)	0.489 (0.22)	0.460	0.359	0.385	0.380	0.203	0.319
Feb-01	0.487	0.327	0.395	0.436	0.486	0.456	0.390 (0.47)	0.398 (0.33)	0.322 (0.44)
Mar-01	0.059	0.276	0.404	0.404	0.326	0.421	0.424	0.365	0.301

* *Blank cells indicate that no data were available.*

** *Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 29. Capability indices for "veneer-slat" thickness for length 325 mm.

	hard maple (*Acer saccharum*)			red oak (*Quercus rubra*)			white oak (*Quercus alba*)		
Month-Year	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}	C_p	C_{pk}	C_{pm}
Jan-00	0.245	0.152	0.264	0.337	0.041	0.252	0.388	0.115	0.300
Feb-00	0.470	0.169	0.349	0.492	0.159	0.348	0.390	0.031	0.265
Mar-00	0.394	-0.012	0.250	0.416	0.185	0.342	0.362	0.083	0.277
Apr-00	0.350	0.199	0.319	0.518	0.196	0.372	0.480	0.200	0.367
May-00	0.404	0.362	0.400	0.527	0.248	0.404	--*	--*	--*
Jun-00	--*	--*	--*	0.416	0.261	0.377	--*	--*	--*
Jul-00	--*	--*	--*	--*	--*	--*	--*	--*	--*
Aug-00	--* (0.19)	--* (0.09)	--* (0.18)	--*	--*	--*	--*	--*	--*
Sep-00	0.395	0.260	0.367	0.505 (0.32)	0.134 (-0.07)	0.337 (0.21)	--*	--*	--*
Oct-00	0.674	0.408	0.524	0.540	0.238	0.400	0.487	0.202	0.370
Nov-00	0.368	0.186	0.323	0.390	0.306	0.378	0.389	-0.015	0.248
Dec-00	0.584	0.237	0.405	0.457	0.125	0.324	0.418	0.399	0.417
Jan-01	0.530	0.349	0.504	0.436	0.125	0.356	0.494	0.295	0.266
Feb-01	0.566	0.232	0.340	0.491	0.265	0.368	0.438	0.255	0.456
Mar-01	0.499	0.168	0.425	0.044	0.308	0.317	0.051	0.349	0.427

* *Blank cells indicate that no data were available.*

** *Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Production Yield And Manufacturing Costs - Objective 3

The third objective of the thesis was partially satisfied. Even though the senior management of the hardwood-flooring manufacturer agreed early in the study to provide production yield and manufacturing cost data on a monthly basis, the data were never provided, *e.g., monthly production yield data were not provided even though it was requested.* The species red oak (*Quercus rubra*), white oak (*Quercus alba*), and hard maple (*Acer saccharum*) represented about 75% of total production. Red oak represented about 50% of total production, white oak 16% and hard maple 9%.

Monthly Lumber Usage by Species

The average monthly lumber usage from January 2000 to December 2000 for the three species studied was approximately 560 MBF. The average monthly usage for red oak was 286 MBF, white oak 163 MBF, and hard maple 112 MBF (Table 30, Figure 28, page 82).

Table 30. Monthly production by species (board feet).

Month-Year	hard maple	red oak	white oak
Jan-00	125,815	253,872	166,357
Feb-00	45,435	295,529	62,440
Mar-00	158,164	217,473	193,344
Apr-00	65,055	353,949	318,675
May-00	107,242	282,207	185,482
Jun-00	88,105	316,500	83,242
Jul-00	123,975	334,327	201,943
Aug-00	59,575	255,137	99,040
Sep-00	128,535	330,060	123,212
Oct-00	141,315	378,835	195,580
Nov-00	122,025	210,875	130,020
Dec-00	180,162	202,157	201,355
Average	**112,117**	**285,910**	**163,391**
Total	**1,345,403**	**3,430,921**	**1,960,690**

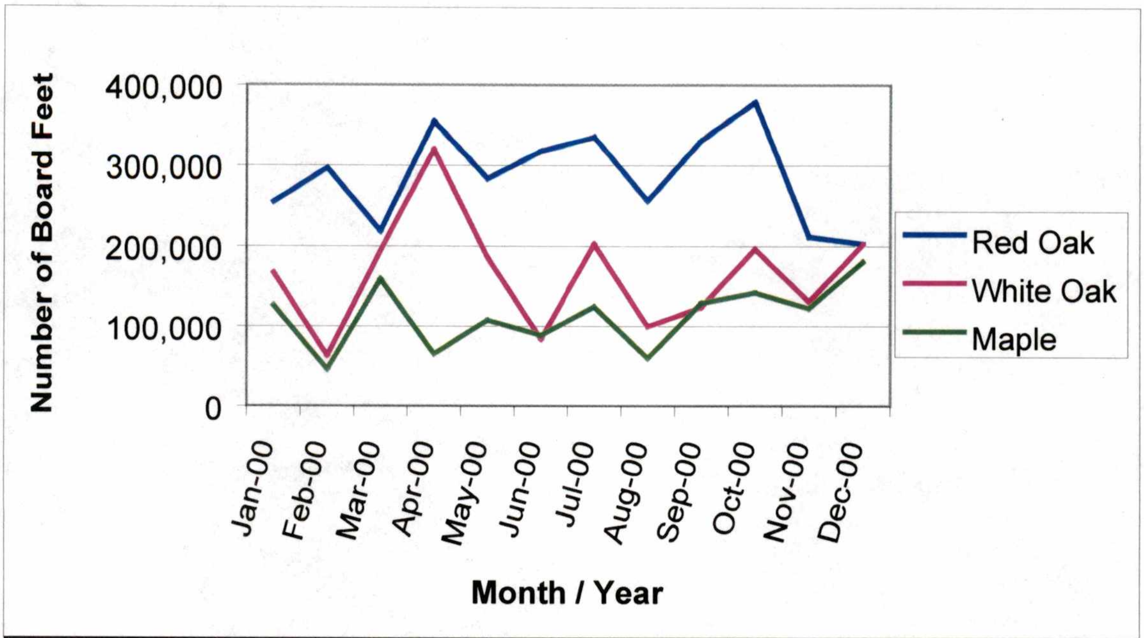

Figure 28. Monthly usage by species in board feet.

"Finished Blank" Production

Approximately 15,000,000 "finished blanks" were produced from January 2000 to February 2001. Average "finished blank" production on a monthly basis by species was as follows: 183,000 (red oak); 107,000 (white oak); and 70,000 (hard maple), (Table 31-33, page 86-87).

The predominate target length for each species studied was 325 mm (Figure 29). The reason for the greater number of blanks at length 325 mm might be due to a higher rejection rate for longer blanks or the blank can be recovered at a shorter length. Some of the rejected longer blanks were recovered and re-manufactured into smaller blank sizes depending on defect location, also low grade lumber allows more shorter parts to be cut.

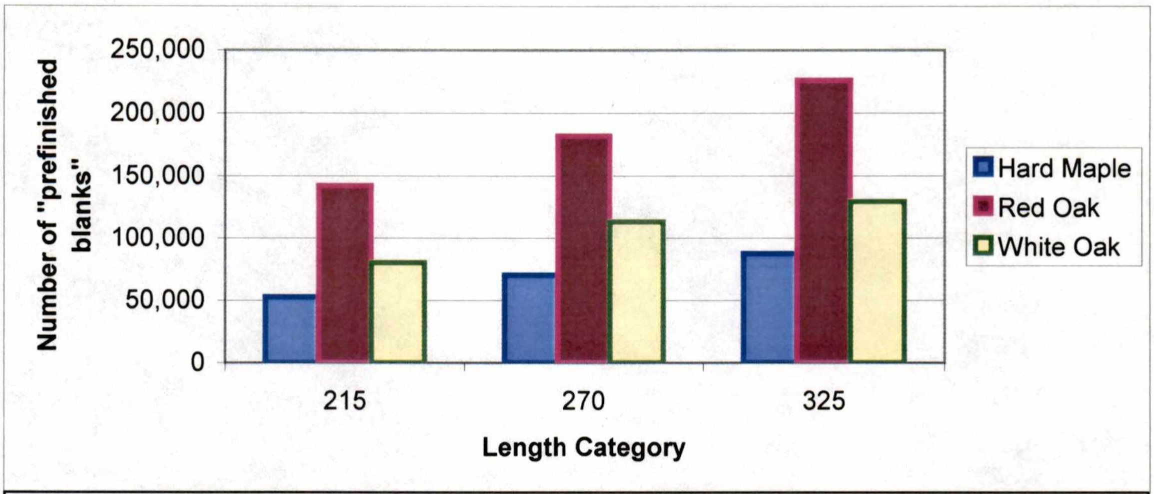

Figure 29. Average monthly "finished blank" production by species and target length.

Table 31. "Finished blank" production for hard maple target lengths.

	hard maple (# of blanks)		
Month - Year	**215 mm**	**270 mm**	**325 mm**
Jan-00	27,117	44,997	48,689
Feb-00	35,706	64,724	59,315
Mar-00	43,191	53,601	69,276
Apr-00	31,275	37,942	48,944
May-00	59,865	76,141	93,657
Jun-00	58,572	80,410	90,827
Jul-00	35,251	44,624	52,528
Aug-00	29,401	38,894	48,455
Sep-00	83,145	94,093	116,149
Oct-00	98,540	122,819	164,857
Nov-00	54,857	78,768	103,581
Dec-00	51,961	78,388	107,391
Jan-01	79,021	102,266	139,985
Feb-01	--	--	--
Average	**52,916**	**70,590**	**87,973**
Total	**687,902**	**917,667**	**1,143,654**

Table 32. "Finished blank" production for red oak target lengths.

	red oak (# of blanks)		
Month - Year	**215 mm**	**270 mm**	**325 mm**
Jan-00	145,503	178,376	200,989
Feb-00	166,988	224,039	293,814
Mar-00	107,166	186,633	226,751
Apr-00	147,688	183,075	217,033
May-00	157,222	210,418	242,703
Jun-00	164,858	182,136	257,812
Jul-00	121,360	158,029	185,386
Aug-00	213,527	270,639	345,547
Sep-00	201,578	249,278	305,234
Oct-00	142,119	173,056	241,461
Nov-00	127,236	166,948	205,566
Dec-00	61,870	95,857	120,557
Jan-01	119,668	138,176	158,981
Feb-01	117,937	136,089	167,627
Average	**142,480**	**182,339**	**226,390**
Total	**1,994,720**	**2,552,749**	**3,169,461**

Table 33. "Finished blank" production for white oak target lengths.

	white oak (# of blanks)		
Month - Year	**215 mm**	**270 mm**	**325 mm**
Jan-00	79,584	112,498	135,498
Feb-00	64,292	79,474	89,068
Mar-00	104,974	129,225	160,981
Apr-00	107,126	149,812	178,731
May-00	87,864	114,312	141,138
Jun-00	62,583	72,765	101,000
Jul-00	97,309	126,127	162,938
Aug-00	69,090	83,147	103,783
Sep-00	80,253	107,435	126,668
Oct-00	71,697	213,957	101,864
Nov-00	59,056	80,411	102,377
Dec-00	101,093	129,403	159,131
Jan-01	57,774	78,036	99,223
Feb-01	81,461	108,767	146,276
Average	**80,297**	**113,241**	**129,191**
Total	**1,124,156**	**1,585,369**	**1,808,676**

“Veneer-Slat” Production

Approximately 62,000,000 “veneer-slats” were produced from January 2000 to February 2001 for all species and lengths. The average number of “veneer-slats” produced per month by species were as follows: 775,000 (red oak), 425,000 (white oak), and 315,000 (hard maple) (Tables 34-36, pages 85-86, Figure 30, page 87).

Even though more “finished blanks” at a target length of 325 mm were produced on a monthly basis, the average number of “veneer-slats” produced per month were similar for all three target lengths. The data suggested for hard maple that it takes more “finished blanks” to produce “veneer-slats” for target length 325 mm relative to the 215 mm and 270 mm target lengths.

Table 34. Monthly production of hard maple “veneer-slats.”

	hard maple (# of “veneer-slats”) (*Acer sacchrum*)		
Month-Year	**215 mm**	**270 mm**	**325 mm**
Jan-00	154,396	224,738	201,386
Feb-00	221,283	322,623	245,527
Mar-00	270,158	232,962	260,345
Apr-00	124,582	160,350	184,327
May-00	272,085	335,732	310,800
Jun-00	325,357	357,809	302,055
Jul-00	197,750	181,825	189,036
Aug-00	153,594	158,678	156,745
Sep-00	430,014	351,268	355,873
Oct-00	595,473	542,257	614,527
Nov-00	333,251	385,721	397,586
Dec-00	319,218	392,366	412,805
Jan-01	449,781	509,399	541,545
Feb-01	--	--	--
Average	**295,919**	**319,671**	**320,966**
Total	**3,846,942**	**4,155,728**	**4,172,557**

Table 35. Monthly production of red oak "veneer-slats."

	red oak (# of "veneer-slats") (*Quercus rubra*)		
Month-Year	**215 mm**	**270 mm**	**325 mm**
Jan-00	973,621	794,033	709,950
Feb-00	1,011,303	961,831	1,061,927
Mar-00	626,132	763,661	738,759
Apr-00	807,860	747,464	669,782
May-00	750,206	803,344	965,941
Jun-00	827,901	762,765	868,927
Jul-00	539,630	628,508	607,764
Aug-00	1,034,410	1,033,699	1,118,141
Sep-00	844,177	972,940	924,909
Oct-00	807,579	789,240	876,045
Nov-00	749,719	756,607	772,618
Dec-00	378,134	458,754	467,545
Jan-01	708,573	650,574	616,073
Feb-01	728,436	648,142	648,827
Average	**770,549**	**769,397**	**789,086**
Total	**10,787,681**	**10,771,562**	**11,047,208**

Table 36. Monthly production of white oak "veneer-slats."

	white oak (# of "veneer-slats") (Quercus alba)		
Month-Year	**215 mm**	**270 mm**	**325 mm**
Jan-00	433,532	461,240	447,145
Feb-00	335,940	333,432	381,950
Mar-00	538,299	562,273	536,836
Apr-00	593,649	584,421	612,055
May-00	416,351	454,743	434,245
Jun-00	304,328	297,792	320,891
Jul-00	509,904	542,787	555,009
Aug-00	311,001	328,169	335,236
Sep-00	372,003	370,322	388,164
Oct-00	353,347	308,350	316,855
Nov-00	336,433	364,104	394,555
Dec-00	508,786	486,000	504,545
Jan-01	331,975	360,530	361,927
Feb-01	469,150	490,164	531,455
Average	**415,336**	**424,595**	**437,205**
Total	**5,814,698**	**5,944,327**	**6,120,868**

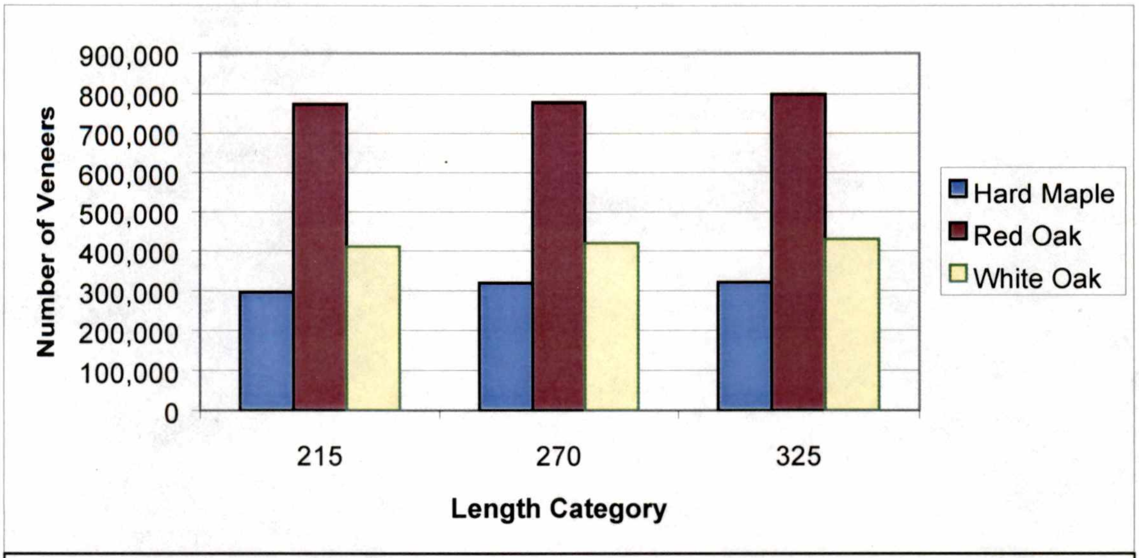

Figure 30. Average monthly "veneer-slat" production by species and target length.

"Veneer-Slat" Yield

An analysis of the "veneer-slat" yield at the grading station suggested that the manufacturer was rejecting approximately 20% of good "veneer-slats." The analysis consisted of taking a random sample of white oak "veneer-slats" over a four-hour period for target lengths 215 mm and 270 mm ($n = 371$). The data also included "veneer-slat" production from two shifts. The second shift rejected more "veneer-slats" that were good than the first shift (Figure 31, page 88). Discussions with supervisors and quality control staff indicated that the estimate of 20% rejection of good "veneer-slats" may be representative.

The incorrect grading of "veneer-slats" represented a substantial finding during the production yield study because this was an area of greatest loss to the manufacturer. The potential costs savings from correcting this problem of rejecting good "veneer-slats" is a savings of $500,000 per year. One of the limitations of the "veneer-slat" yield study

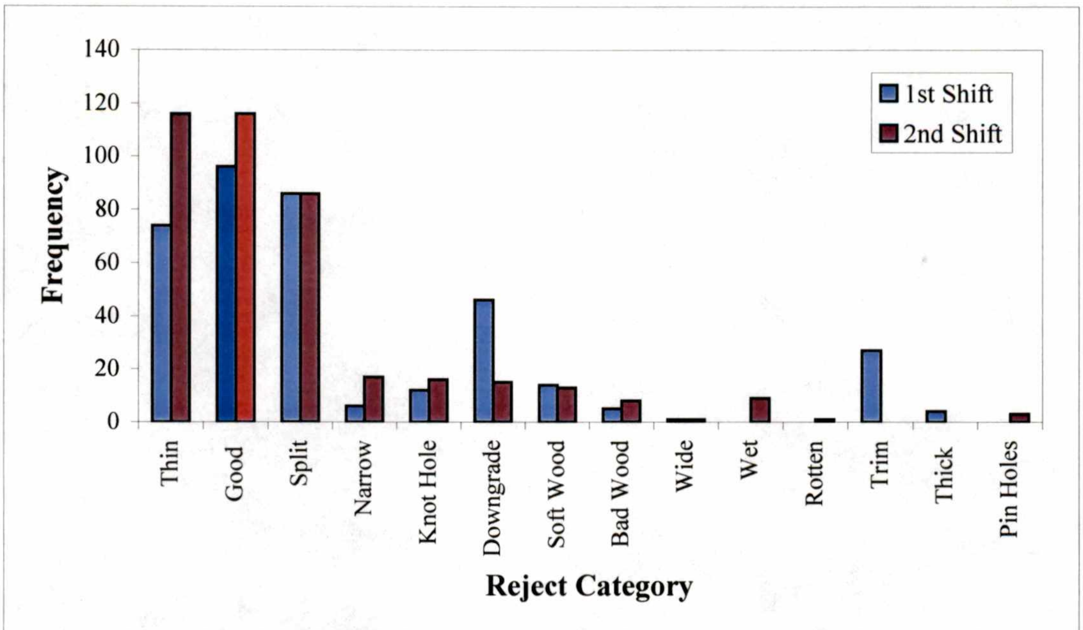

Figure 31. "Veneer-slat" reject categories for white oak target length 270 mm.

was that it was only conducted once for each shift. More "veneer-slat" yield studies were planned but the hardwood-flooring manufacture did not allow further investigation of "veneer-slat" yield. This represented a serious limitation of accomplishing the third objective because yield statistics could not be developed for the thesis. The hardwood flooring manufacturer did not have any existing yield statistics for "finished blanks" or "veneer-slats."

Manufacturing Costs

The total manufacturing costs from January 2000 to February 2001 for "finished blanks" by species were: red oak ($6,462,167), white oak ($3,782,956), and hard maple ($2,308,905), see Table 37, page 89. "Finished blanks" for target length 325 mm cost more to manufacture than the other target lengths.

Table 37. Total manufacturing costs for "finished blanks" by species and target length from January 2000 to February 2001.

Target Length	hard maple	red oak	white oak	Total
215 mm	$433,378	$1,256,674	$708,218	**$2,398,270**
270 mm	$743,310	$2,067,727	$1,284,149	**$4,095,186**
325 mm	$1,132,217	$3,137,766	$1,790,589	**$6,060,572**
Total	**$2,308,905**	**$6,462,167**	**$3,782,956**	**$12,554,028**

Table 38. Total manufacturing costs for "veneer-slats" by species and target length from January 2000 to February 2001.

Target Length	hard maple	red oak	white oak	Total
215 mm	$269,286	$755,138	$407,029	**$1,431,452**
270 mm	$374,015	$969,441	$534,990	**$1,878,446**
325 mm	$458,982	$1,215,193	$673,296	**$2,347,470**
Total	**$1,102,283**	**$2,939,771**	**$1,615,314**	**$5,657,368**

The total manufacturing costs from January 2000 to February 2001 for "veneer-slats" by species were: red oak ($2,939,771), white oak ($1,615,314), and hard maple ($1,102,283), see Table 38. The manufacturer's accounting staff indicated that it cost manufacturing cost $0.09 to manufacture a "veneer-slat."

Sources Of Variation - Objective 4

<u>Ishikawa Diagrams</u>

Ishikawa diagrams (fishbone diagrams) were developed as the first step in identifying sources of variability that influence product attribute variability. The Ishikawa diagrams were developed from discussions with senior management, quality control staff and operators. Potential sources of variability were initially investigated using the results of the interviewers with senior management, quality control staff and operators. Sources of variability for the following product attributes were investigated:

- "Veneer-slat" thickness variation;
    - Measurement Error;
    - "Finished blank" thickness;

        - Lumber Thickness Variation.
- "Veneer-slat" width variation;
    - Lumber moisture content variation.
- "Lumber rip" width variation;
    - Rip width location.

Sources of variability were identified for product attributes other than the product attributes initially studied. The other product attributes were identified to help reduce variability and improve production yields, *e.g., "veneer-slat" width and "lumber rip."* After the sources of variability were defined for the additional product attributes, management at the hardwood flooring plant indicated that the additional product attributes were important, *i.e., the thesis study improved the management's awareness of other important product attributes.*

In lieu of the thesis and in an effort to develop a better understanding of the hardwood-flooring "veneer-slat" process, a process flow was developed before the Ishikawa diagrams were developed. The process flow diagram was invaluable in developing a better understanding of the process was essential for initial discussions with plant personal (refer to Figure 7, pages 45 to 47).

Ishikawa diagrams were developed for each key product attribute (*e.g., "veneer-slat" thickness*). Once a key process parameter was identified for a given product attribute, another Ishikawa diagram was developed. This process of developing Ishikawa diagrams within Ishikawa diagrams led to a detailed root cause analysis of sources of variability (Figure 32, page 91). The use of Ishikawa diagrams for root cause analysis is consistent with Harry's (2000) philosophy.

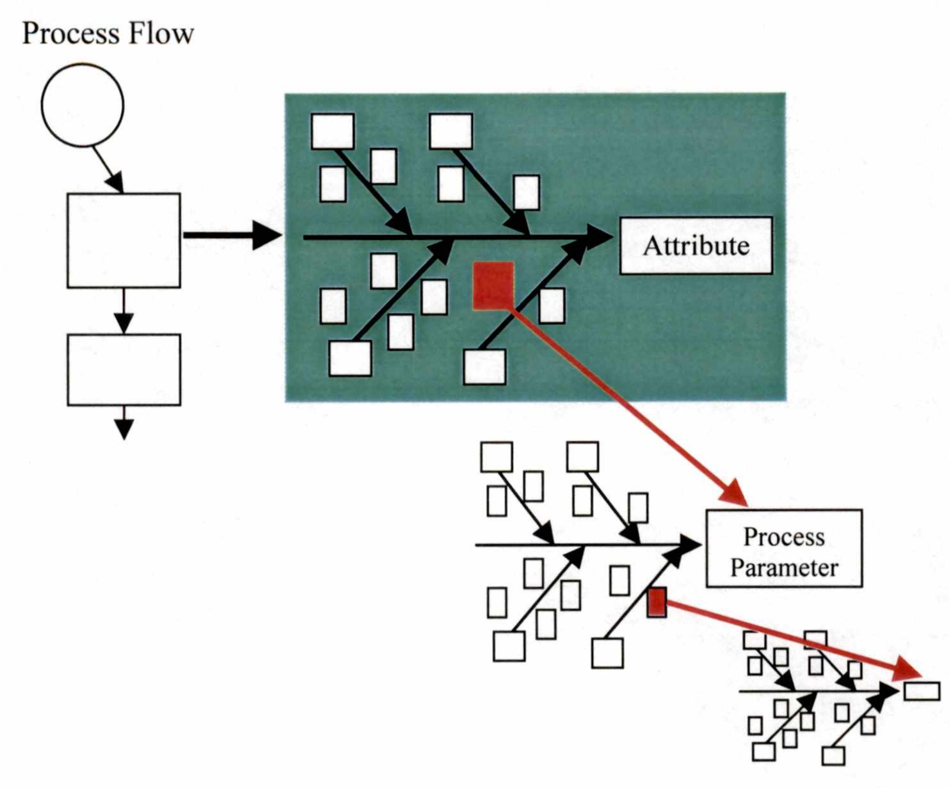

Figure 32. Illustration of Ishikawa diagram within Ishikawa diagram.

"Veneer-Slat" Thickness Variation

The first fishbone was completed for sources of "veneer-slat" thickness variation (Figure 33, page 93). The scope of the thesis did not allow for all potential sources of variability to be investigated. However, significant sources of variability for "veneer-slat" thickness were discovered. The following sources of variability for "veneer-slat" thickness were investigated:

- "blank" molder setup,
- "finished blank" thickness,
- moisture content,

- feed rate of slat molder,
- measurement variation,
- slat molder setup,
- and “veneer-slat” molder blade alignment.

“Finished Blank” Thickness Variation

An Ishikawa diagram was developed for “finished blank” thickness variation (Figure 34, page 94). Possible factors that were investigated for “finished blank” thickness variation were:

- lumber thickness,
- moisture content,
- planer blade setup,
- misalignment of planer blades,
- groove depth of blank,
- measurement variation.

“Blank Molder” Machine Variability

An Ishikawa diagram was developed for “blank molder” machine variability (Figure 35, page 95). Possible factors that were investigated for “blank molder” machine variability were:

- machine setup,
- groove depth setup,
- feed rate,
- thickness setup,
- width setup.

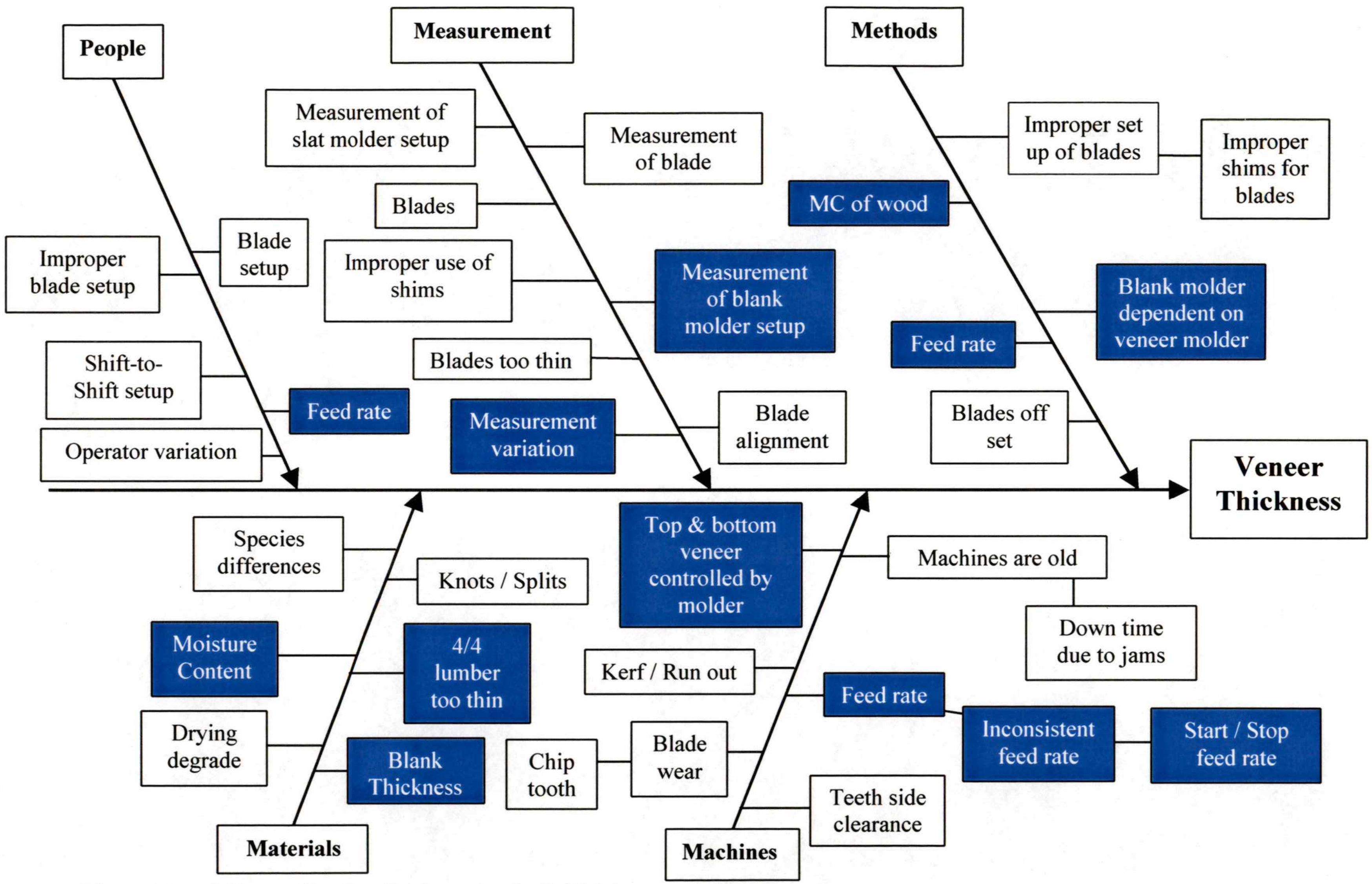

Figure 33. Fishbone diagram for “veneer-slat” thickness variation.

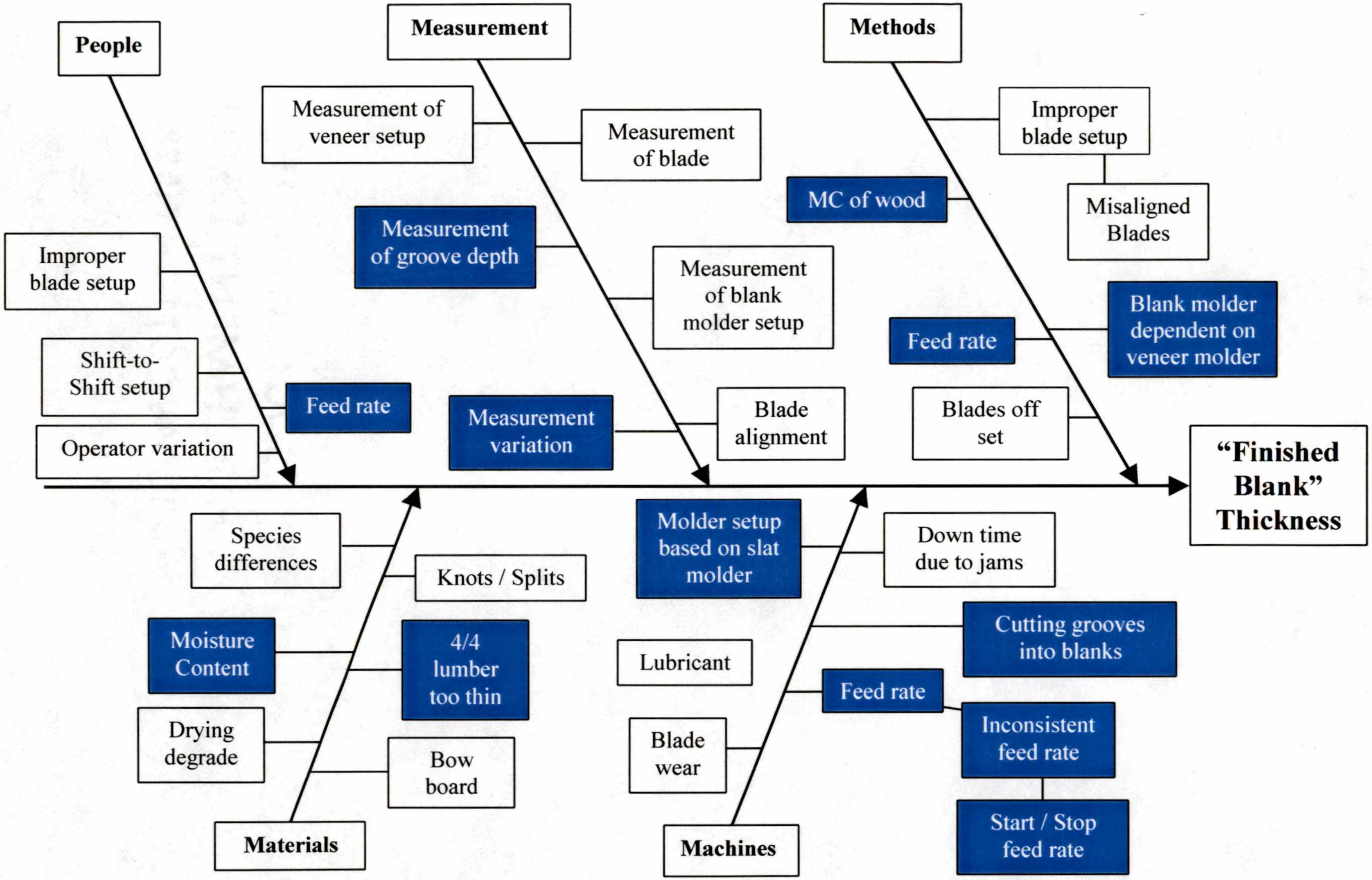

Figure 34. Fishbone diagram for "finished blank" thickness variation.

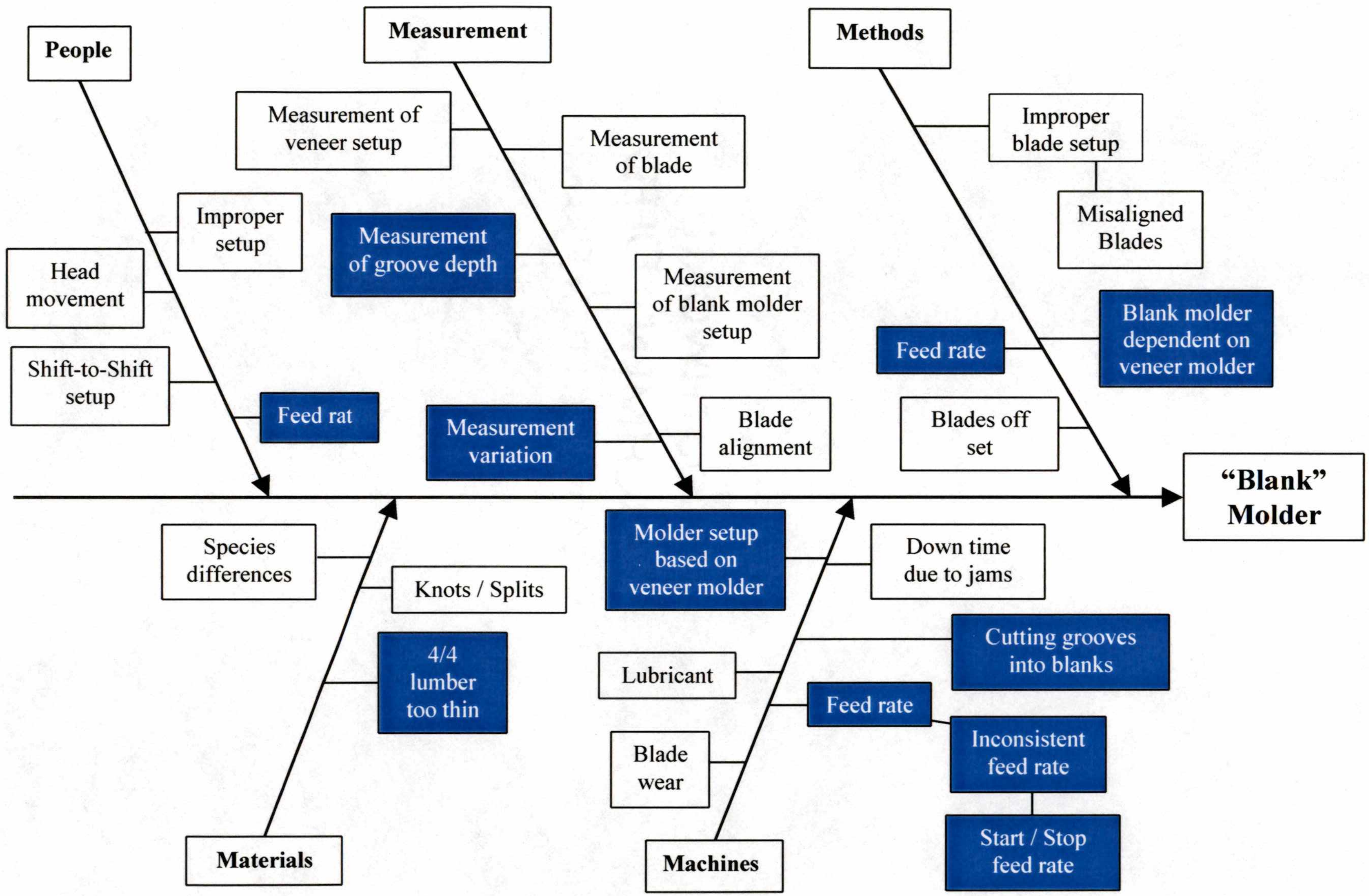

Figure 35. Fishbone diagram for "blank" molder machine variability.

Lumber Thickness Variation

In order to conduct a controlled study that may identify the effect that lumber thickness has on "finished blank" thickness, three categories of lumber thickness were developed: thin (0.9" to 1.1" – category 1), target (1.1" to 1.3" – category 2), and thick (>1.4" to 1.5" – category 3), (Figure 36, page 97). The lumber thickness variation study was conducted in January 2001 for hard maple. Each piece of lumber was coded and followed through each process and measured. The process follows the process flow (Figure 7, page 44-46).

There was evidence lumber thickness effects "finished blank" thickness. Lumber thickness category 3 was significantly greater (p-value = 0.0001) than lumber thickness categories 1 and 2 (Figure 36, page 97). Lumber with thickness between 25.5 mm and 27 mm will have more variation than lumber with thickness between 28 mm and 33 mm. Discussions with operators concerning this relationship indicated that the "blank molder" for this particular day was setup for thicker incoming lumber due to the new blades on the "veneer-slat" molder. New blades result in a larger saw kerf than usual. Lumber thickness category three (s = 0.047) had less "finished blank" thickness variation lumber thickness categories one (s = 0.25) and two (s = 0.18).

Additional analyses were conducted on the relationship between lumber thickness and "finished blank" length and "finished blank" width. There was no statistical evidence that suggested lumber thickness affected "finished blank" length or "finished blank" width.

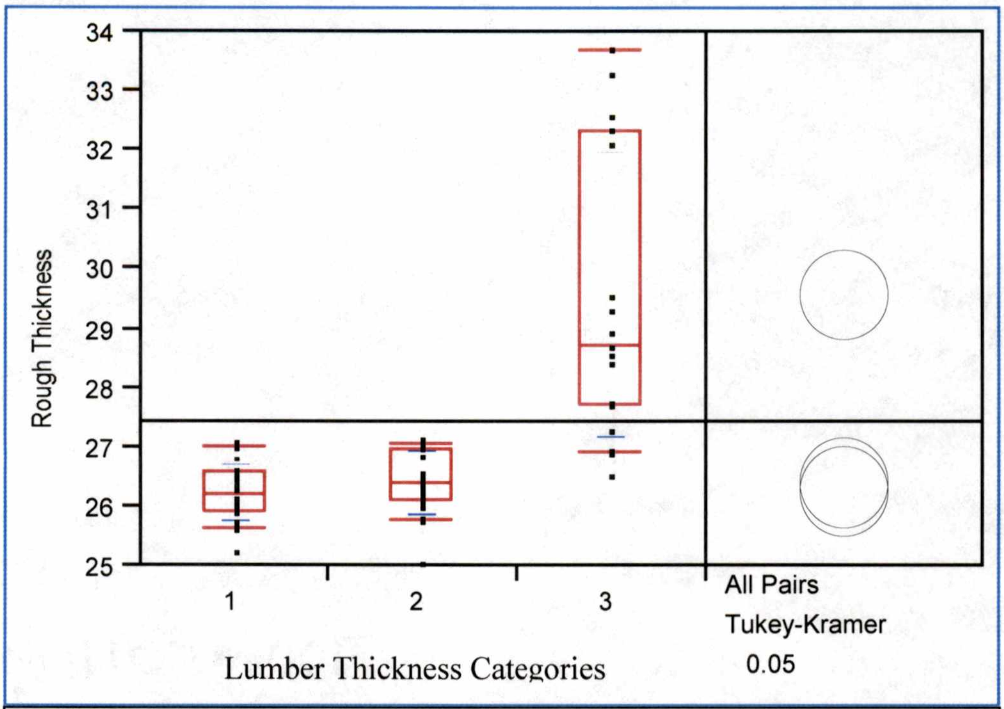

Figure 36. Box-Whisker plot of rough lumber thickness (mm) by lumber thickness category (n=60).

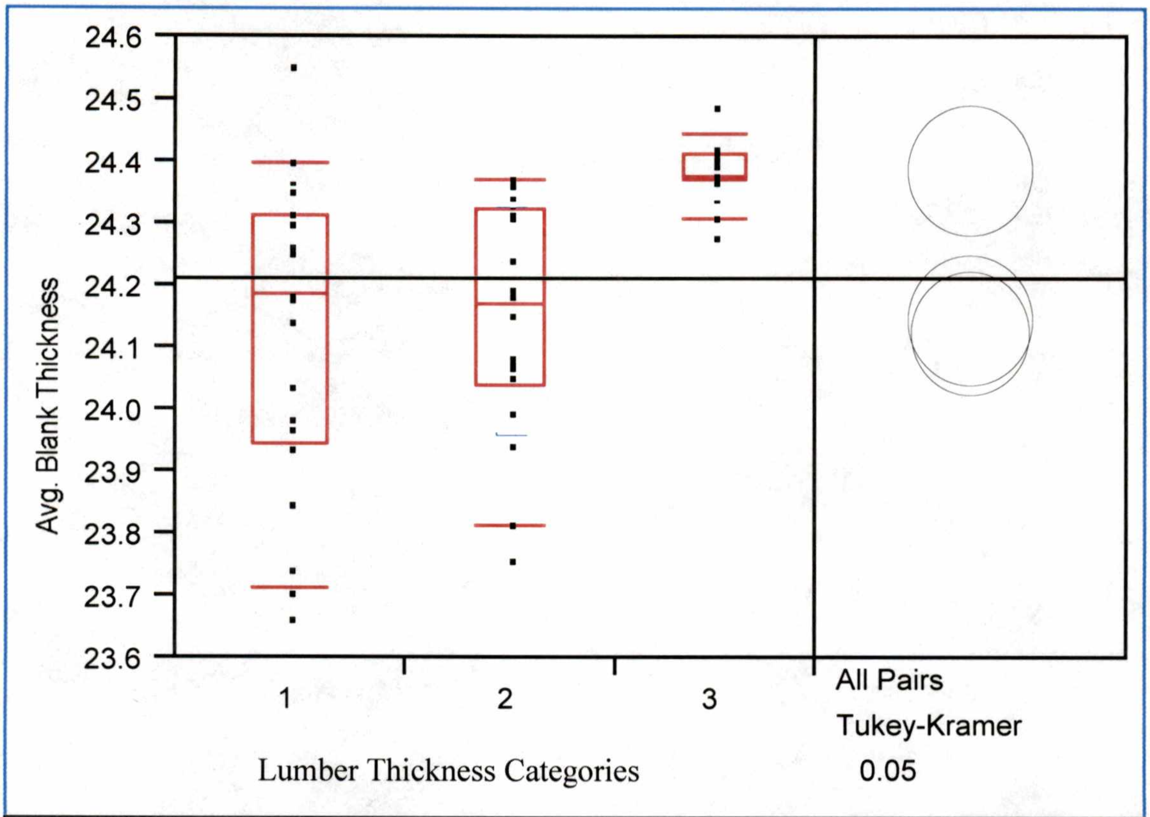

Figure 37. Box-Whisker plot of "finished blank" thickness (mm) by lumber thickness category (n=60).

<u>Individual "Veneer-Slat" Thickness Variation (Top "Veneer-Slat").</u> -- The average thickness for the top "veneer-slat" was effected by lumber thickness (Figure 38, page 98). There was statistical evidence that a linear relationship existed between top "veneer-slat" thickness and lumber thickness, *i.e., the thicker the lumber the thicker the top "veneer-slat."* The correlation between the top "veneer-slat" thickness and "finished blank" thickness was 0.46 (Figure 39, page 99). The variation in "finished blank" thickness is absorbed partially in the top "veneer-slat" because the process flow has been established in this fashion.

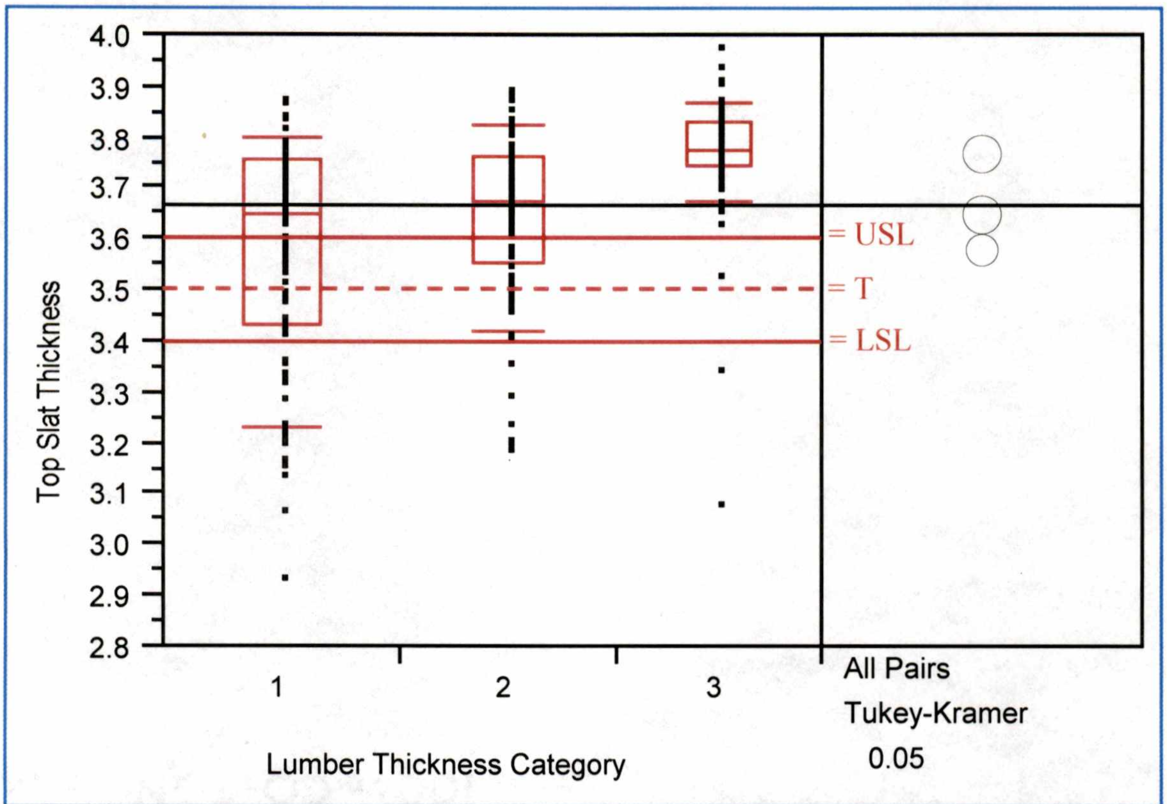

Figure 38. Box-Whisker plot of top "veneer-slat" thickness (mm) by lumber thickness category (n=330).

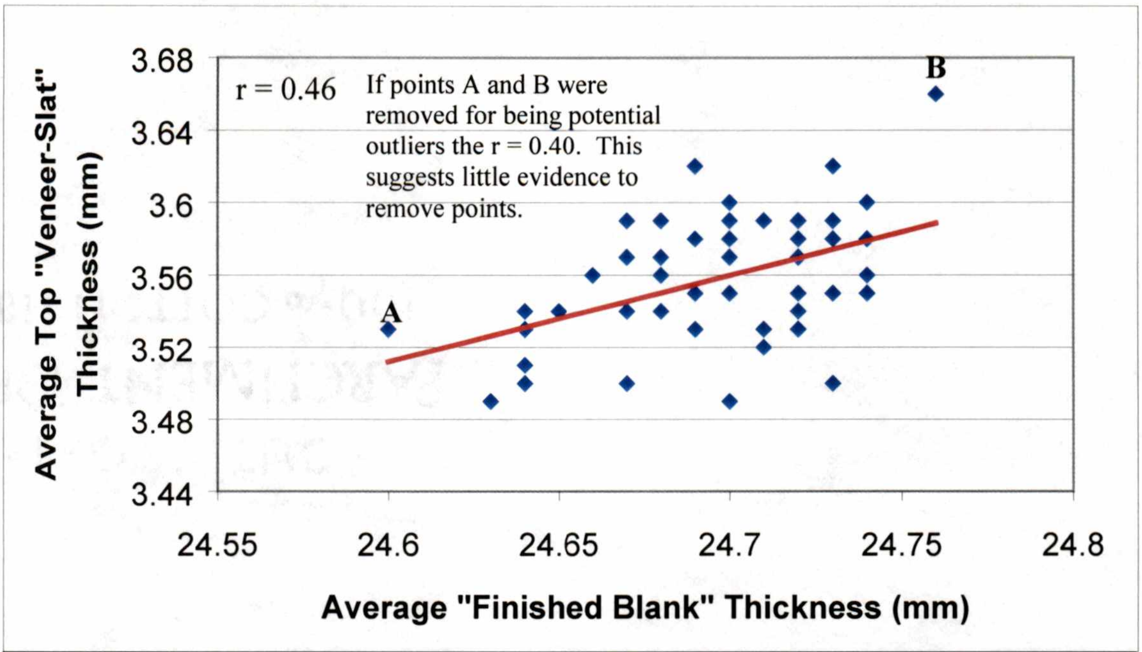

Figure 39. Correlation between top "veneer-slat" thickness (mm) and "finished blank" thickness (mm) (n=50).

<u>Individual "Veneer-Slat" Thickness Variation (Middle "Veneer-Slat")</u>.-- There were no significant differences between middle "veneer-slat" thickness by lumber thickness category (Figure 40, page 100). The correlation between the middle "veneer-slat" thickness and "finished blank" thickness was 0.13 (Figure 41, page 101).

<u>Individual "Veneer-Slat" Thickness Variation (Bottom "Veneer-Slat")</u>. -- There was statistical evidence at an $\alpha = 0.05$ that the average thickness for the bottom "veneer-slat" was effected by lumber thickness (Figure 42, page 102). The correlation between the bottom "veneer-slat" thickness and "finished blank" thickness was 0.34 (Figure 43, page 103).

The data also indicated that the top and bottom "veneer-slat" had more variation than the middle location "veneer-slat" (Table 39, page 102). The top "veneer-slat" had more variation than the bottom "veneer-slat."

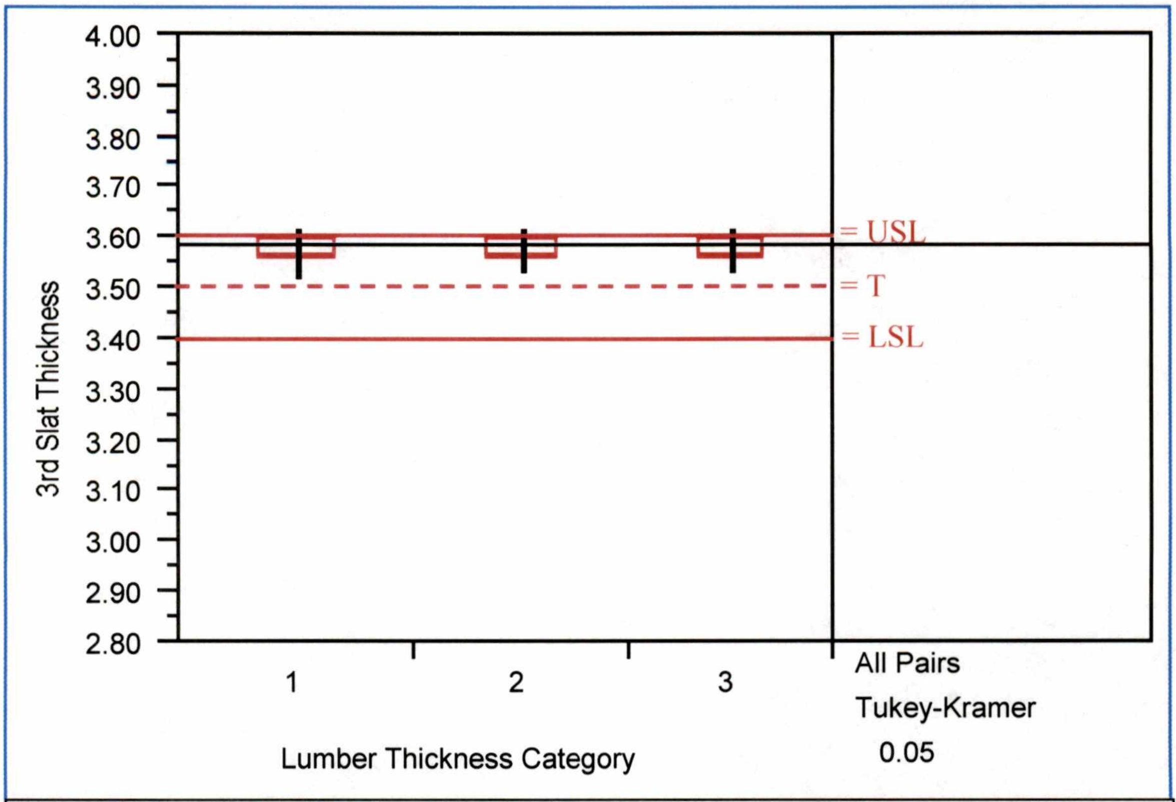

Figure 40. Box-Whisker plot of middle “veneer-slat” thickness (mm) by lumber thickness category (n=330).

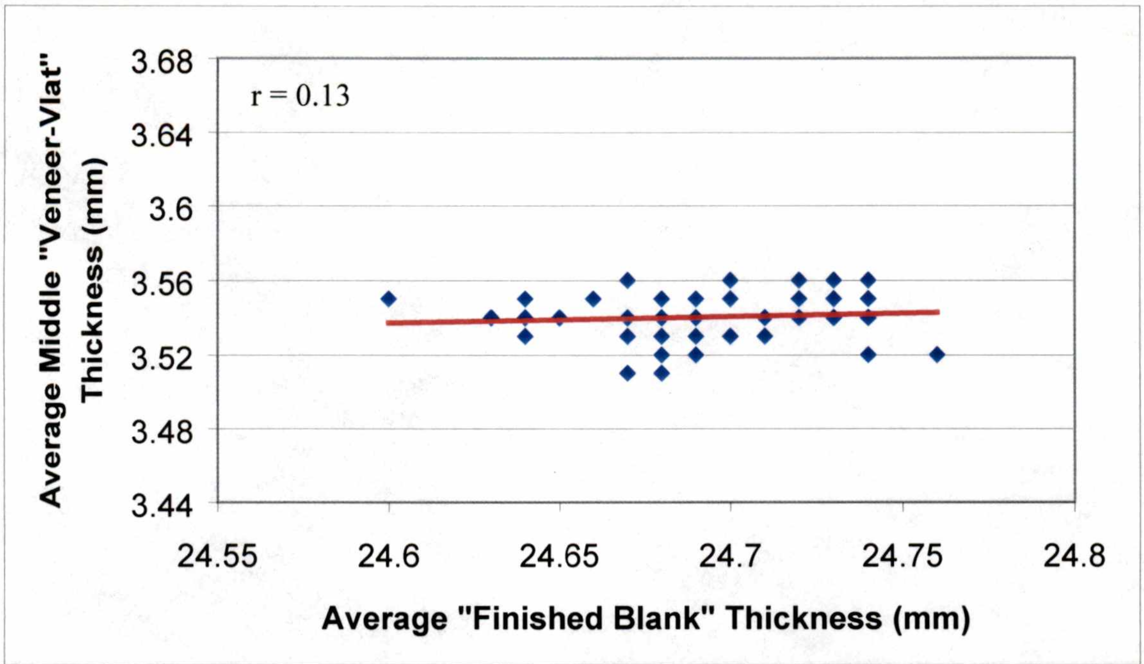

Figure 41. Correlation between middle "veneer-slat" thickness (mm) and "finished blank" thickness (mm).

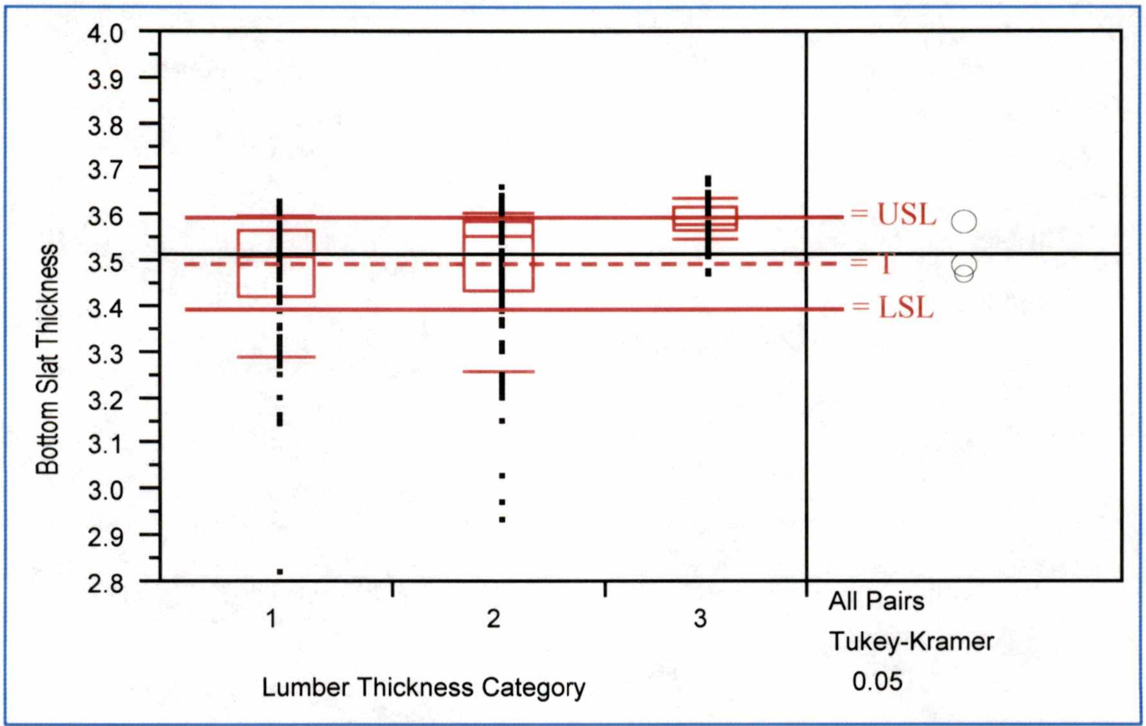

Figure 42. Box-Whisker plot of bottom "veneer-slat" thickness (mm) by lumber thickness category (n=330).

Table 39. Standard deviation by "veneer-slat" location.

Lumber Thickness Category	Top "veneer-slat" Standard Deviation (mm)	2nd "veneer-slat" Standard Deviation (mm)	Middle "veneer-slat" Standard Deviation (mm)	4th "veneer-slat" Standard Deviation (mm)	Bottom "veneer-slat" Standard Deviation (mm)
1	0.2134	0.0182	0.0197	0.0196	0.1336
2	0.1599	0.0228	0.0180	0.0221	0.1430
3	0.1077	0.0192	0.0193	0.0203	0.0378

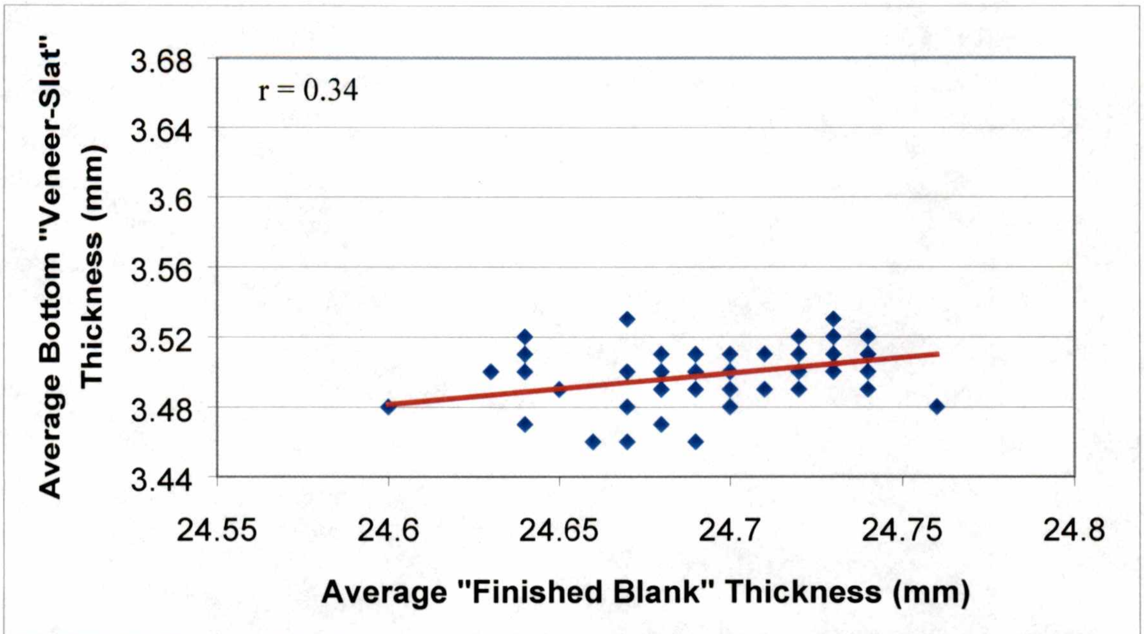

Figure 43. Correlation between middle "veneer-slat" thickness (mm) and "finished blank" thickness (mm).

Talking to operators, management, and analysis of a fishbone diagram indicated that "finished blank" thickness variation can be caused by lumber thickness variation and "blank molder" setup. By reducing "blank molder" setup variation improvements can occur with "finished blank" thickness variation and top and bottom "veneer-slat" thickness variation.

"Veneer-Slat" Width Variation

Lumber Moisture Content. -- The moisture content was identified as potential causes for variation with product attribute by senior management and fishbone diagrams. A drying study was conducted for three different lumber moisture content categories: low (4.0% to 5.2%- category 1), target (5.2% to 6.4%- category 2), and high moisture content

(6.4% to 7.6%- category 3). The study consisted of selecting three white oak boards at the different moisture content categories and following them through the process taking measurement after each station (Figure 7, page 44 - 46). All the "blanks" were selected from each of the boards, measured, and followed through the process.

Stress samples were taken to identify if the variation in product attributes were more related to moisture content and/or stresses. Stresses within the wood add to the variation. Evaluation of internal lumber stresses was determined by a "stress test" in which individual samples were cut from sample boards for each moisture category (Figure 44, page 105). Four stress samples were taken for each board and stresses were excessive stresses were identified in two of the boards or 8 of the 16 samples. Stresses in wood are often caused by improper drying schedule and conditioning in the dry kiln.[13] "Honeycombing" was also found to be present in the wood, which indicated poor drying practices (Figure 45, page 105).

There was statistical evidence at an $\alpha = 0.05$ that suggested that the moisture content of lumber effected "veneer-slat" width variation. The top and bottom "veneer-slat" widths were greater than the middle "veneer-slat" width due to moisture content.

Analyses were conducted on lumber moisture content and "veneer-slat" thickness and length. There was no significant statistical evidence that indicated a relationship existed between lumber moisture content and "veneer-slat" thickness and length.

[13] Conditioning – following the final stage of a lumber drying schedule a conditioning treatment is done which causes a redistribution of moisture into the faces for the lumber in order to relieve some of the stresses that are in compression (Simpson 1997).

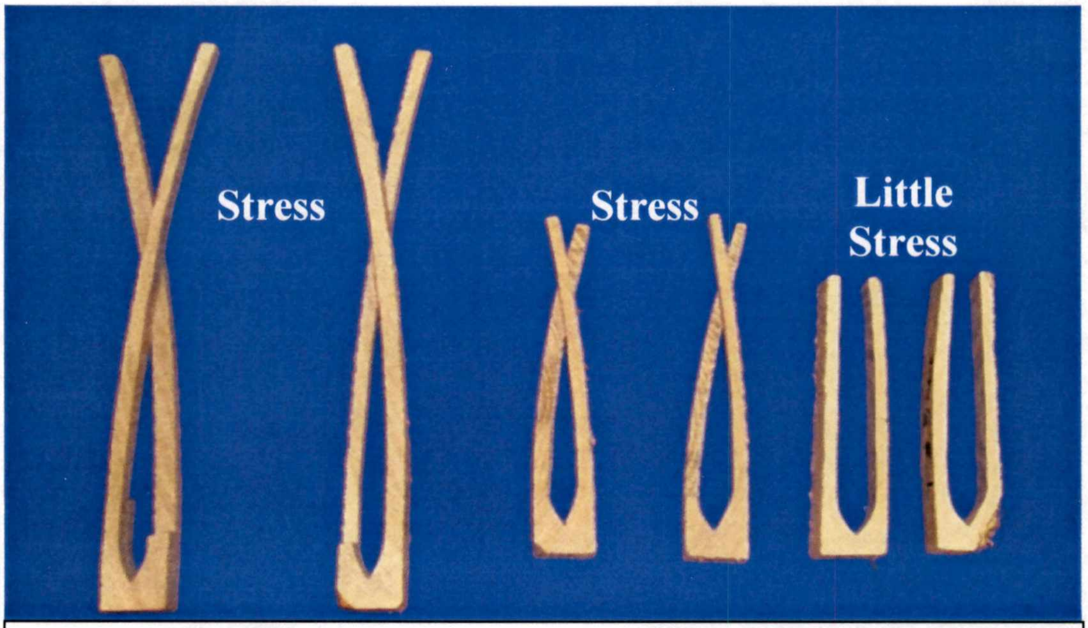

Figure 44. Stress test sample from manufacturers kiln dried lumber.

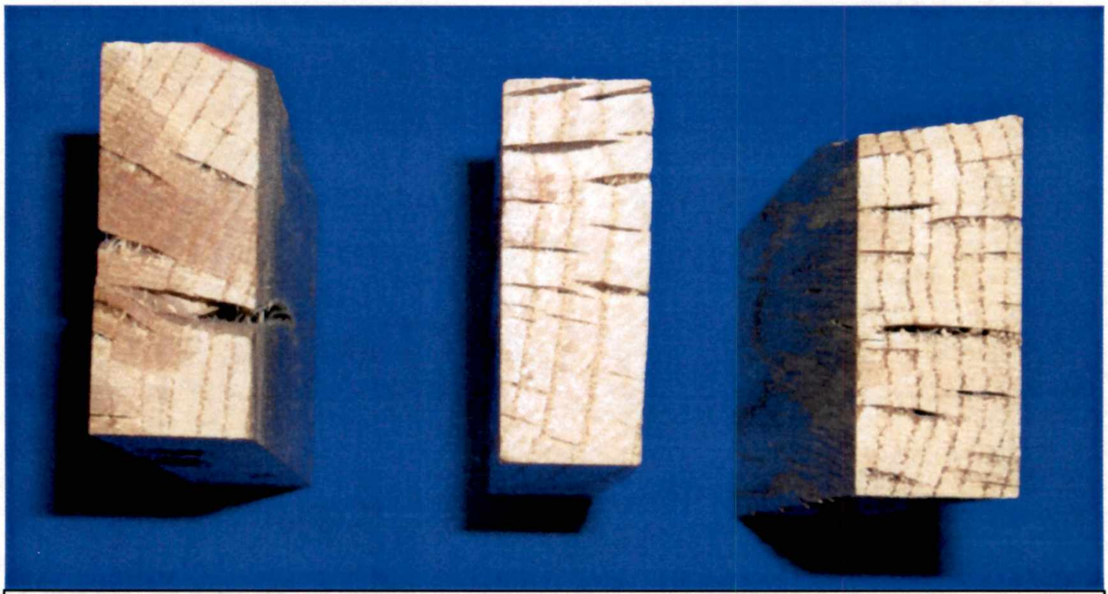

Figure 45. Example of honeycomb sample from manufacturer.

Individual "Veneer-Slat" Width Variation (Top "Veneer-Slat"). -- The top "veneer-slat" width by moisture content category indicated that moisture content was a cause for the variation in the widths. A nonlinear relationship was identified for moisture content categories and "veneer-slat" width (Figure 46). The variations present in the "veneer-slat" width due to moisture content variations were unexplainable. Typically, as wood increases in moisture content wood swells and the reverse occurs when the moisture content decreases. The reason for the nonlinear pattern may be due to the conditions the lumber was exposed to after removed from the dry kiln.

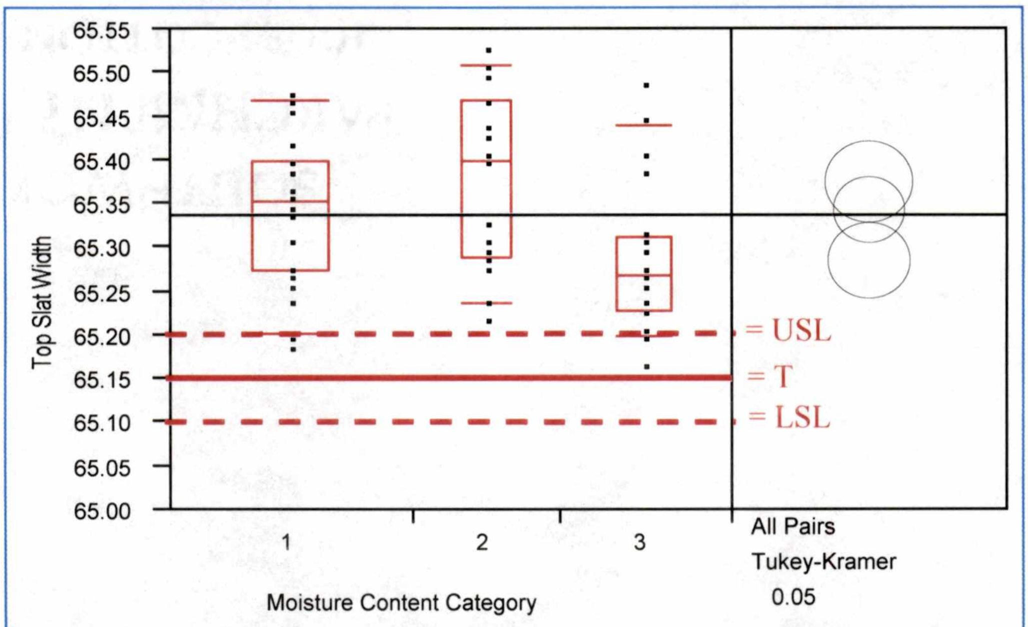

Figure 46. Box-Whisker plot of top "veneer-slat" width (mm) by moisture content category (n=165).

Individual "Veneer-Slat" Width Variation (Middle "Veneer-Slat"). -- The middle "veneer-slat" width was not significantly different by moisture content category at an $\alpha = 0.05$ (Figure 47). Most middle "veneer-slats" widths were within the specification limits (Figure 47).

Individual "Veneer-Slat" Width Variation (Bottom "Veneer-Slat"). -- The bottom "veneer-slat" width by moisture content category indicated that moisture content for category one was statistically different than the moisture content for category three at an $\alpha = 0.05$ (Figure 48, page 108). There was an indication of a linear relationship between bottom "veneer-slat" width and moisture content, *i.e., the higher the moisture content, the wider the bottom "veneer-slat."*

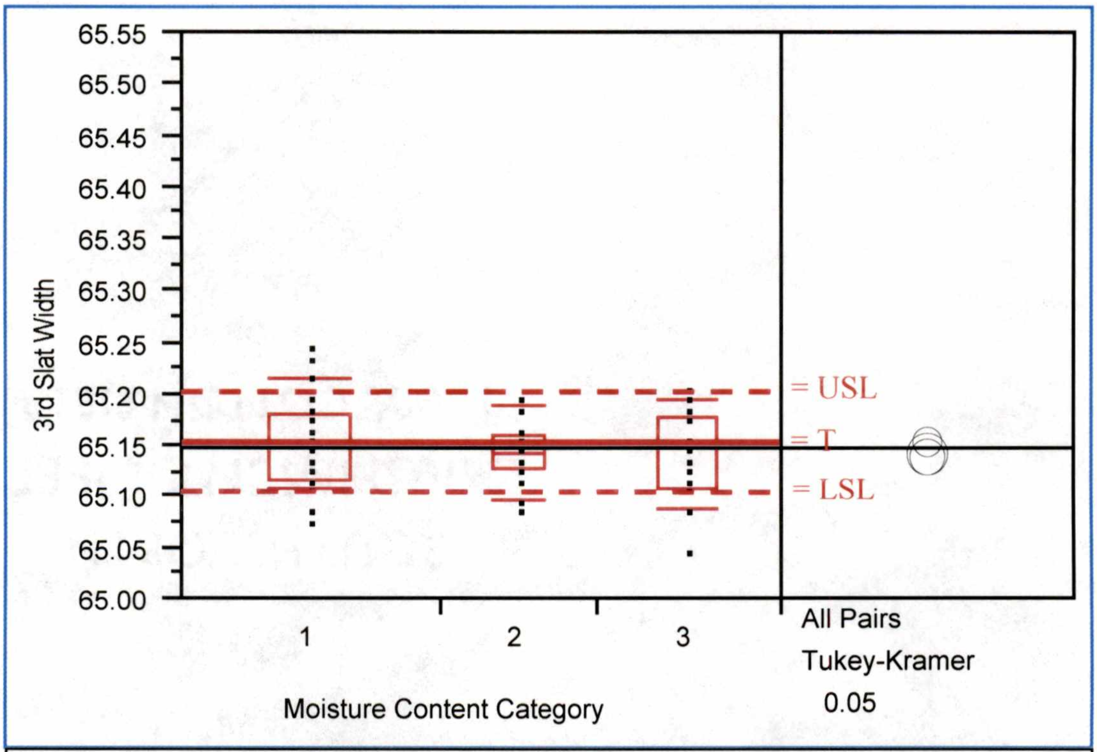

Figure 47. Box-Whisker plot of middle "veneer-slat" width (mm) by moisture content category (n=165).

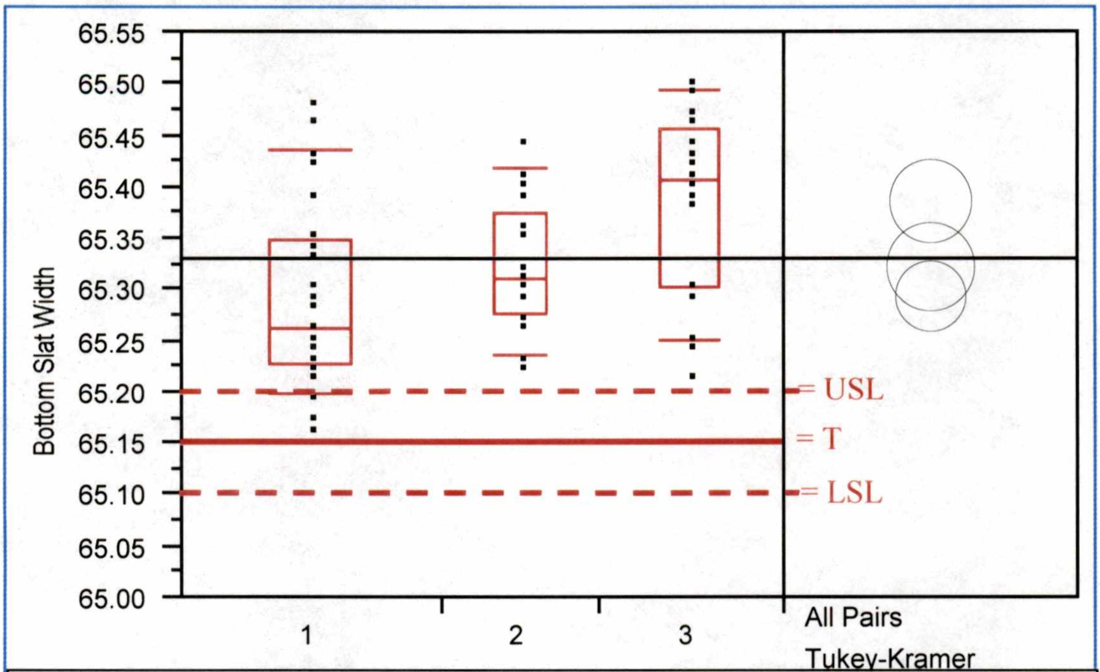

Figure 48. Box-Whisker plot of bottom "veneer-slat" width (mm) by moisture content category (n=165).

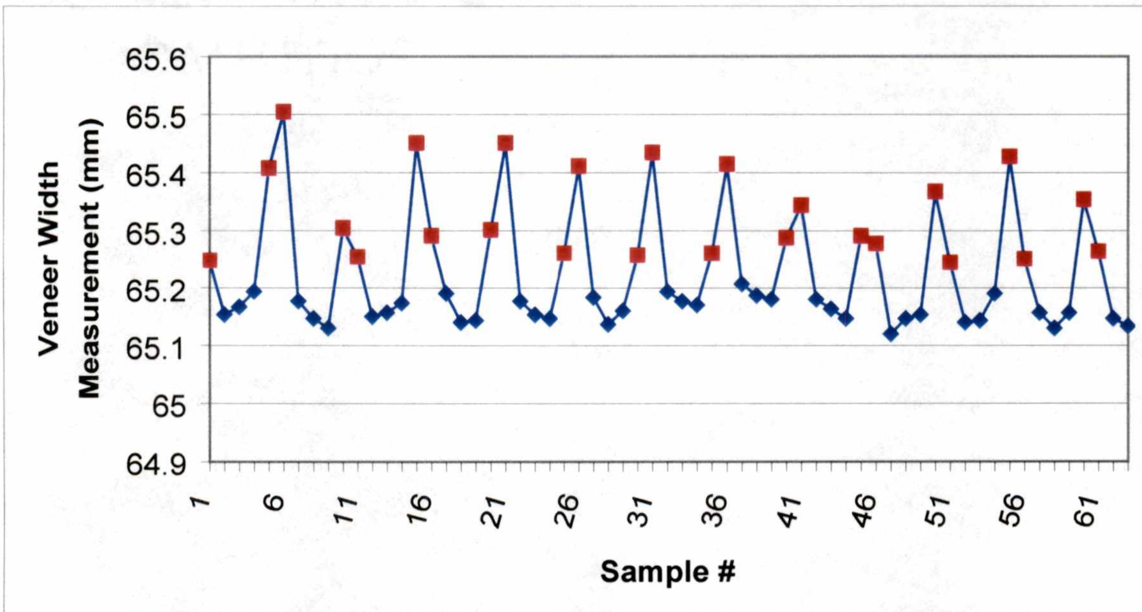

Figure 49. Top, middle, and bottom "veneer-slat" width (mm).

It was evident in the thesis study that moisture content had an effect on the top and bottom "veneer-slats" widths. There was evidence that the hardwood-flooring manufacturer may be able to reduce "veneer-slat" width variation by reducing variability in the moisture content of dried lumber by implementing better drying practices.

"Veneer-Slat" Thickness Measurement Error

There was evidence that indicated that measurement error for "veneer-slat" thickness was a significant source of variability. A Gauge Repeatability[14] and Reproducibility[15] (Gauge R&R) was conducted three different times for two shifts in the thesis study. The six Gauge R&R studies had three different appraisers with the exception of 2nd shift 4/4/01 which had two appraisers. The measurement device used for the Gauge R&R was the hardwood manufacturer's Mitutoyo 0" to 1" caliper that was the typical device used for measuring "veneer-slat" thickness, (Figure 10, page 51). The Gauge R&R studies attempted to estimate "appraiser error," "gauge error," and a "discrimination ratio."[16]

The predominate source of measurement error for both shifts was due to "appraiser error" (Tables 40-41, page 110). The percent of total measurement error due to "appraiser error" varied from 71% to 94% when three appraisers were assessed. The sources of variability for "appraiser error" that were observed during the Gauge R&R study were:

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[14] Repeatability – the variation in measurements obtained with one measurement instrument when used several times by one appraiser, while measuring the identical characteristic on the same part.
[15] Reproducibility – the variation in the average of the measurements made by different appraisers using the same measuring instrument when measuring the identical characteristic on the same part.
[16] The "discrimination ratio" represents the number of discrete intervals in which the measurement device is capable of defining (Wheeler 1989).

Table 40. Gauge R&R results for first shift.

Gauge Repeatability and Reproducibility First Shift				
Date	**Appraiser (σ_e)**	**Gauge (σ_m)**	**Discrimination Ratio (D_R)**	**σ R&R**
6/28/00	94%	6%	3	0.055
8/22/00	71%	29%	12	0.026
4/4/01	85%	15%	8	0.049

Table 41. Gauge R&R results for second shift.

Gauge Repeatability and Reproducibility Second Shift				
Date	**Appraiser (σ_e)**	**Gauge (σ_m)**	**Discrimination Ratio (D_R)**	**σ R&R**
6/28/00	81%	19%	5	0.058
8/22/00	78%	22%	8	0.031
4/4/01	40%	60%	8	0.014

- no zero calibration of caliper before starting measurement;
- no gauge calibration for 12.7 mm and 25.4 mm intervals;
- appraisers varied the angle of caliper feet when measurements were taken;
- appraisers applied different pressures to the caliper feet when measurements were taken.

The "discrimination ratio" varied from 5 to 12 for "veneer-slat" thickness, e.g., a "discrimination ratio" of 3 implies that the measurement device is capable of distinguishing between low, medium and high intervals.

"Rip-Saw" Width

Another source of variability identified in the thesis was "rip-saw" width. A potential improvement in yield may be realized if the manufacturer reduces the "rip-saw" width of incoming lumber.

The "rip-saw" cuts lumber into long, thin strips (Figure 50). The specifications of the manufacturer for "rip-saw" width were: LSL = 69 mm; target = 70 mm; and USL = 71 mm.

For 120 samples of "rip-saw" strips, the standard deviation of "rip-saw" width was 0.0714 mm. The natural tolerance of "rip-saw" width was 0.428 mm and the average width was 71.16 mm (Figure 51, page 111). Note that the engineering tolerance of "rip-saw" width was 2 mm.

It may be possible to lower the target "rip-saw" width given the low amount of variation and its highly capable state, *i.e.*, $NT < ET$. If the process target was lowered to 68.5 mm and the saw-kerf was reduced by 1 mm there would be a 3.5 mm savings for each "rip-saw" strip. An increase in yield of approximately 8% may be realized from the reduction in target and saw-kerf.

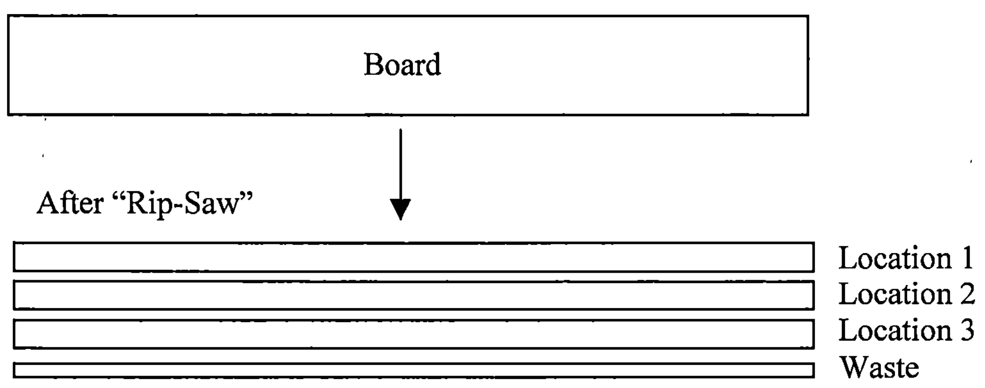

Figure 50. Illustration of "rip-saw" width.

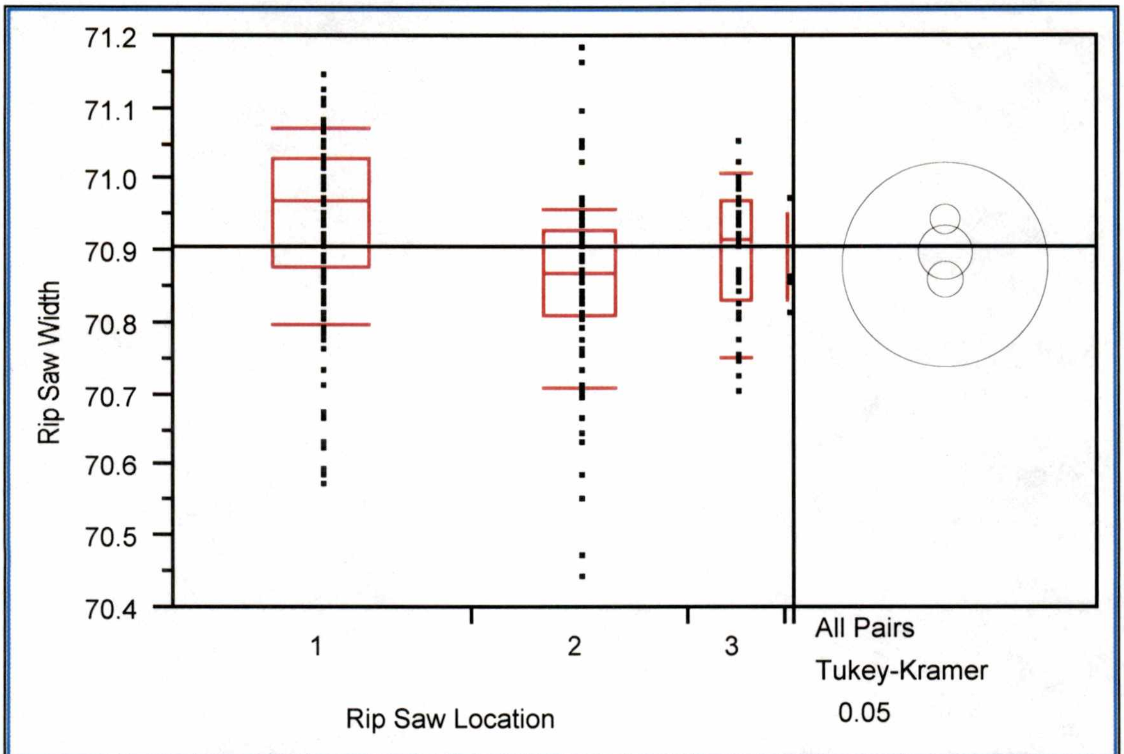

Figure 51. Box-Whisker plot of "rip-saw" width (mm) by "rip-saw" location.

Recommendation – Objective 5

Recommendations were made to the hardwood flooring manufacturer management on April 11, 2001. Recommendations were:

<u>"Finished Blank" and "Veneer-Slat" Thickness Variation</u>

The conclusions identified from evaluation of the "finished blank" and "veneer-slat" studies were that the top and bottom "veneer-slats" had more variation than the middle "veneer-slats." The variation in the top and bottom "veneer-slats" was correlated to "finished blank" thickness. Variations within the "finished blank" thickness were partially due to inconsistent molder setup. The recommendation was to establish standard operating procedures and develop a systematic sampling plan to ensure proper molder setup based on discussions with operators, management, and fishbone diagram analysis.

Drying Practices

Drying stresses and honeycomb were present in the wood indicating improper drying. The top and bottom "veneer-slat" width was greater than the middle "veneer-slat" width indicating improper conditioning of lumber. The recommendation was that all lumber should be conditioned and an appropriate drying schedule should be followed along with a systematic sampling plan to ensure proper moisture content.

Measurement Error

There was a large amount of measurement error that was due to appraiser error. Appraiser error was due to improper use of the measurement device. A recommendation was made to retrain operators on proper use of calipers.

Sampling Plan

A stratified random sampling plan was recommended to senior management to help identify proper sampling plans for "finished blank" thickness and "veneer-slat" thickness (Levy and Lemeshow 1991). Three different levels of certainty were recommended as potential choices, *e.g., 90%, 95%, and 99% with a 5% error level.* Sampling plans were estimated for "finished blank" thickness (Tables 42-44, pages 114) and "veneer-slat" thickness (Tables 45-47, pages 115) using the most recent data from the companies database. A sampling plan was recommended because in some cases the manufacturer had not taken an adequate number of samples. The best sampling plan to implement would be the 99% certainty level sampling plan. This would allow the company to have more confidence in the data and sampling plan is not excessive.

Table 42. Sampling scheme for "finished blank" thickness for a 5% error level and 90% certainty level.

Species / Product	Average Monthly Production	"Finished Blank" Thickness (mm)	"Finished Blank" Variance (mm^2)	Monthly Sample Size
red oak - 215 mm	142,480	24.23	0.0119	71
red oak - 270 mm	182,339	24.25	0.0178	90
red oak - 325 mm	226,390	24.22	0.0193	112
white oak - 215 mm	80,297	24.17	0.0095	40
white oak - 270 mm	113,241	24.23	0.0095	56
white oak - 325 mm	129,191	24.21	0.0067	64
hard maple - 215 mm	52,916	24.15	0.0279	26
hard maple - 270 mm	70,590	24.20	0.0361	35
hard maple - 325 mm	87,973	24.09	0.0200	44

Table 43. Sampling scheme for "finished blank" thickness for a 5% error level and 95% certainty level.

Species / Product	Average Monthly Production	"Finished Blank" Thickness (mm)	"Finished Blank" Variance (mm^2)	Monthly Sample Size
red oak - 215 mm	142,480	24.23	0.0119	101
red oak - 270 mm	182,339	24.25	0.0178	129
red oak - 325 mm	226,390	24.22	0.0193	160
white oak - 215 mm	80,297	24.17	0.0095	57
white oak - 270 mm	113,241	24.23	0.0095	80
white oak - 325 mm	129,191	24.21	0.0067	91
hard maple - 215 mm	52,916	24.15	0.0279	37
hard maple - 270 mm	70,590	24.20	0.0361	50
hard maple - 325 mm	87,973	24.09	0.0200	62

Table 44. Sampling scheme for "finished blank" thickness for a 5% error level and 99% certainty level.

Species / Product	Average Monthly Production	"Finished Blank" Thickness (mm)	"Finished Blank" Variance (mm^2)	Monthly Sample Size
red oak - 215 mm	142,480	24.23	0.0119	173
red oak - 270 mm	182,339	24.25	0.0178	222
red oak - 325 mm	226,390	24.22	0.0193	275
white oak - 215 mm	80,297	24.17	0.0095	98
white oak - 270 mm	113,241	24.23	0.0095	138
white oak - 325 mm	129,191	24.21	0.0067	157
hard maple - 215 mm	52,916	24.15	0.0279	64
hard maple - 270 mm	70,590	24.20	0.0361	86
hard maple - 325 mm	87,973	24.09	0.0200	107

Table 45. Sampling scheme for “veneer-slat” thickness for a 5% error level and 90% certainty level.

Species / Product	Average Monthly Production	"Finished Blank" Thickness (mm)	"Finished Blank" Variance (mm^2)	Monthly Sample Size
red oak - 215 mm	770,549	3.54	0.0029	91
red oak - 270 mm	769,397	3.55	0.0018	91
red oak - 325 mm	789,086	3.53	0.0026	93
white oak - 215 mm	415,336	3.56	0.0044	49
white oak - 270 mm	424,595	3.53	0.0024	50
white oak - 325 mm	437,205	3.53	0.0024	52
hard maple - 215 mm	295,919	3.53	0.0031	35
hard maple - 270 mm	319,671	3.53	0.0029	38
hard maple - 325 mm	320,966	3.54	0.0026	38

Table 46. Sampling scheme for “veneer-slat” thickness for a 5% error level and 95% certainty level.

Species / Product	Average Monthly Production	"Finished Blank" Thickness (mm)	"Finished Blank" Variance (mm^2)	Monthly Sample Size
red oak - 215 mm	770,549	3.54	0.0029	130
red oak - 270 mm	769,397	3.55	0.0018	130
red oak - 325 mm	789,086	3.53	0.0026	133
white oak - 215 mm	415,336	3.56	0.0044	70
white oak - 270 mm	424,595	3.53	0.0024	72
white oak - 325 mm	437,205	3.53	0.0024	74
hard maple - 215 mm	295,919	3.53	0.0031	50
hard maple - 270 mm	319,671	3.53	0.0029	54
hard maple - 325 mm	320,966	3.54	0.0026	54

Table 47. Sampling scheme for “veneer-slat” thickness for a 5% error level and 99% certainty level.

Species / Product	Average Monthly Production	"Finished Blank" Thickness (mm)	"Finished Blank" Variance (mm^2)	Monthly Sample Size
red oak - 215 mm	770,549	3.54	0.0029	224
red oak - 270 mm	769,397	3.55	0.0018	224
red oak - 325 mm	789,086	3.53	0.0026	229
white oak - 215 mm	415,336	3.56	0.0044	121
white oak - 270 mm	424,595	3.53	0.0024	123
white oak - 325 mm	437,205	3.53	0.0024	127
hard maple - 215 mm	295,919	3.53	0.0031	86
hard maple - 270 mm	319,671	3.53	0.0029	93
hard maple - 325 mm	320,966	3.54	0.0026	93

"Rip-Saw" Width

An evaluation of the "rip-saw" width suggested that a decrease in the "rip" width to 69 mm and a decrease in the saw kerf from 3/16 inch to 1/8 inch could have an approximate 8% increase in yield. If these ideas were implemented for the first rip there would be a 3.5 mm "rip" width reduction at "rip" location one. The extra material gained by lowering the target and saw kerf would leave more opportunities for the "rip" width to clean up better in the other "rip" locations. An extra "rip" cannot be expected for each board. The studies conducted indicated on three different occasions boards had the potential to increase yields of 12.5%, 9.7%, and 7.7% for a for a random sample size of four-hundred. The recommendations were to conduct additional studies to validate the potential gains.

"Veneer-Slat" Grading Line

Approximately 20% of rejected "veneer-slats" were identified as good "veneer-slats" and 10% were "down-gradable." In order to improve yield due to the improved grading of "veneer-slats," retraining of graders and posting of visual grading standards were recommended.

Potential Financial Savings and Measurement Improvements - Objective 6

The total potential cost savings from the elimination of thin "veneer-slats" was estimated to be $520,000 dollars per year. The total potential cost savings for recovering 20% of rejected "veneer-slats" that were good was estimated to be approximately $500,000 dollars per year. If the manufacturer were to operate at a "Six Sigma" quality level they would increase their number of "veneer-slats" by at least 7,500,000.

Measurement variation was excessive and could be improved. A lab study was conducted to determine a theoretical measurement error level for the measurement device. In a controlled lab environment with proper instruction in the use of Mitutoyo calipers appraiser error consumed 15% of the total measurement error and the gauge consumed 85% of the total measurement error (Table 48). Note that the $\sigma_{R\&R}$ was reduced form 0.043 (1^{st} shift) and 0.034 (2^{nd} shift) to 0.004 (lab study).

Table 48. Gauge R&R results for lab-controlled study.

Date	**Appraiser (σ_e)**	**Gauge (σ_m)**	**Discrimination Ratio (D_R)**	**σ R&R**
Average 1^{st} Shift	83%	17%	8	0.043
Average 2^{nd} Shift	66%	34%	7	0.034
Lab Study	**15%**	**85%**	**12**	**0.004**

CHAPTER 5

CONCLUSIONS

Forest products companies enjoyed the benefits of inexpensive raw material and low labor costs in the early 20th century. As competition increased, the demand for quality products increased. Given the increased demand for companies to improve quality, industries have reached out to statistical methods.

As the U.S. forest products industry enters the 21st century, they are faced with a panacea of issues. Environmental regulation and preservation interests have reduced the availability of wood fiber and resulted in higher raw material costs. Air quality restrictions, are forcing many forest products companies to invest in expensive air-quality control equipment. Labor costs are higher in the U.S. relative to labor costs in developing countries. The U.S. forest products industry is also faced with increasing domestic and international market competition from non-wood products such as plastic, aluminum, and concrete. The scenario faced by most U.S. forest products companies is lower profit margins due to higher raw material and manufacturing costs in the context of stable real-prices for final wood products. Some U.S. forest products companies have started reassessing the importance of continuous improvement. The "Six Sigma" quality philosophy provides the forest products industry with a contemporary approach to continuous improvement.

The hypothesis of this thesis was to determine if a modified "Six Sigma" quality philosophy can improve the quality of hardwood flooring manufactured by a Tennessee producer in a 6-month time frame. The hypothesis of the thesis could not be rejected given the lack of quantifiable evidence in the 6-month time frame. However, there was enough evidence to confirm that if more time was allowed improvements can be made.

There were six research objectives: 1) define the current-state of product variability for the specific attributes of "finished blank" length, width, and thickness and "veneer-slat" thickness; 2) determine the capability of the product attributes "finished blank" length, width, and thickness and "veneer-slat" thickness as related to engineering specifications; 3) determine the current production yield and manufacturing costs associated with the manufacture of "veneer-slats;" 4) define the sources of variability that influence the "finished blank" length, width, and thickness and "veneer-slats;" 5) recommend to senior management the improvements necessary to enhance the overall quality of "veneer-slat" and; 6) if any of the recommendations were adopted from objective five, the first four objectives would be repeated to determine if the quality of the product attributes improved. Four of the six objectives were completely satisfied. The sixth objective was not satisfied because of a senior management change, which did not support the study. The "Six Sigma" philosophy strongly emphasizes the importance of senior management support for continuous improvement.

All of the objectives were satisfied except objective six. In regard to objective one the current state of product variability was defined. For each product attribute and each species there was, in some cases, a significant difference from month-to-month for the medians indicating the process location was not stable. Objective two was satisfied when the capability indices were defined for each product attribute. The capability analysis indicated that the manufacturer was not capable of meeting product specifications. There was only one case out of 405 opportunities for all species and product attributes where the process variability was within specification. This resulted in product being produced outside of specification limits, which resulted in excessive sanding or defective product. Objective three was completed when yield statistics were developed for the product attributes and species studied. Additional analysis as related to objective three indicated that approximately 20% of the rejected "veneer-slats" were good, and 10% "veneer-slats" were usable or "down-gradable." The cost of rejecting good or "down-gradable" "veneer-slats" was approximately $500,000 per year. Significant sources of variability were defined in objective four. Top and bottom "veneer-slat" thickness represented most of the variation in total "veneer-slat" thickness variation. There was a greater correlation present between "finished blank" thickness and top and bottom "veneer-slat" thickness than the thickness of middle "veneer-slats." Moisture content had the largest influence on "veneer-slat" width. Most of the measurement error was due to appraiser error. It was determined that an 8% yield increase for incoming lumber may be obtained by lowering the target and saw kerf for the "rip" width. The fifth objective was completed when recommendations were made to senior management on April 11, 2001. No recommendations were adopted by senior management given a management change and the senior management's unwillingness to continue the study.

Support of senior management is essential for the survival of any quality improvement initiative. The thesis was evidence of the importance of management support. For future studies on this topic it is advised that the researchers have strong support from senior management. In this study good relationships were maintained with the company, but a change in senior management resulted in a redirection of company quality initiatives.

The thesis has demonstrated that no risk investments in continuous improvements may result in cost savings of almost $1,000,000 per year. The "Six Sigma" philosophy provides forest products manufacturers with an accepted and structured framework for continuous improvement.

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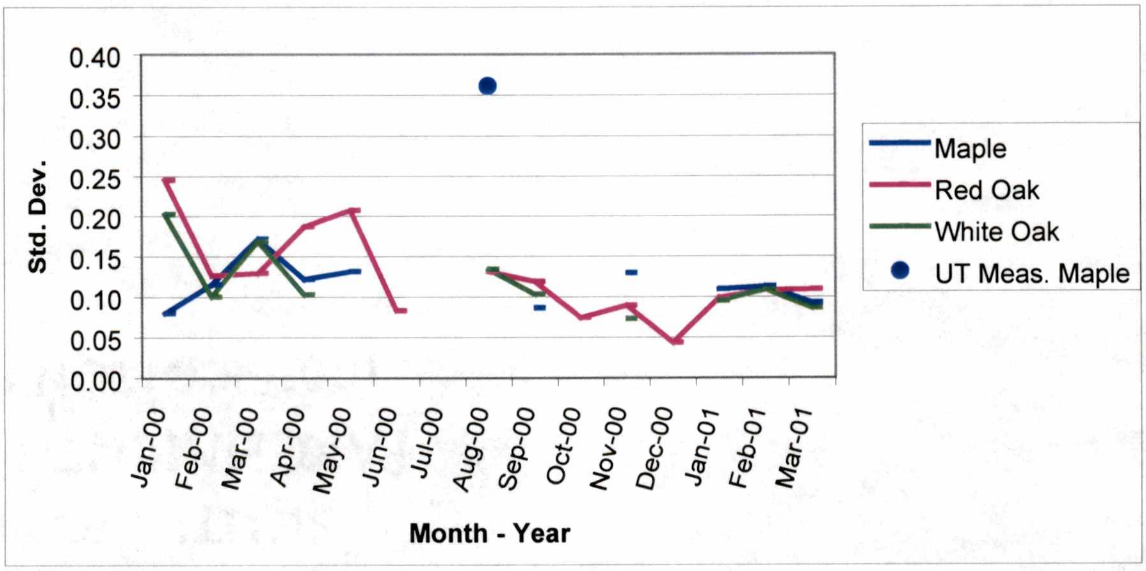
APPENDICES

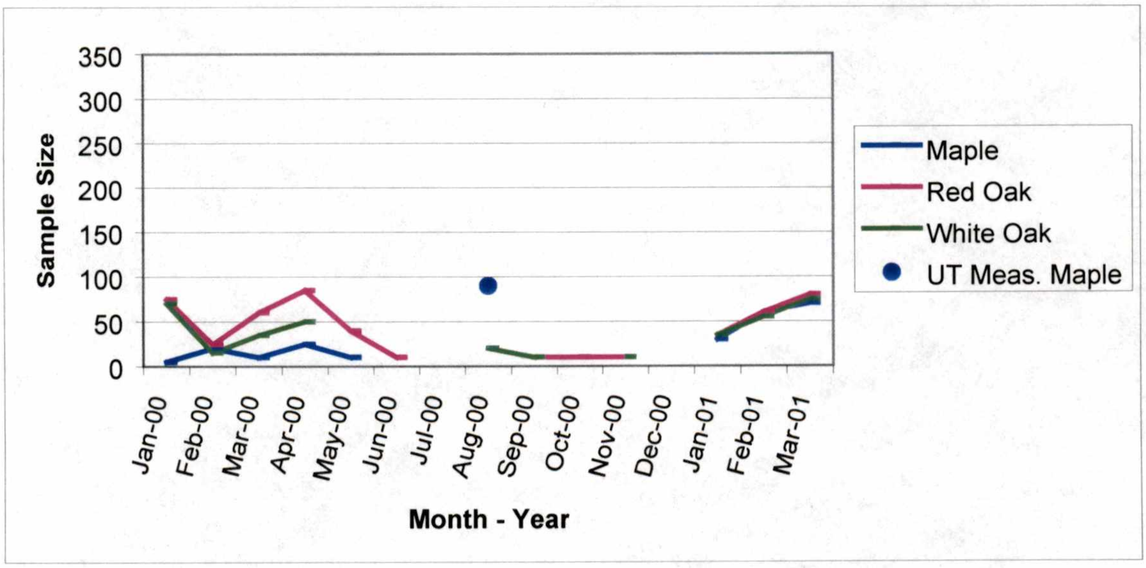
Appendix A

(Graphs 1a to 24a)

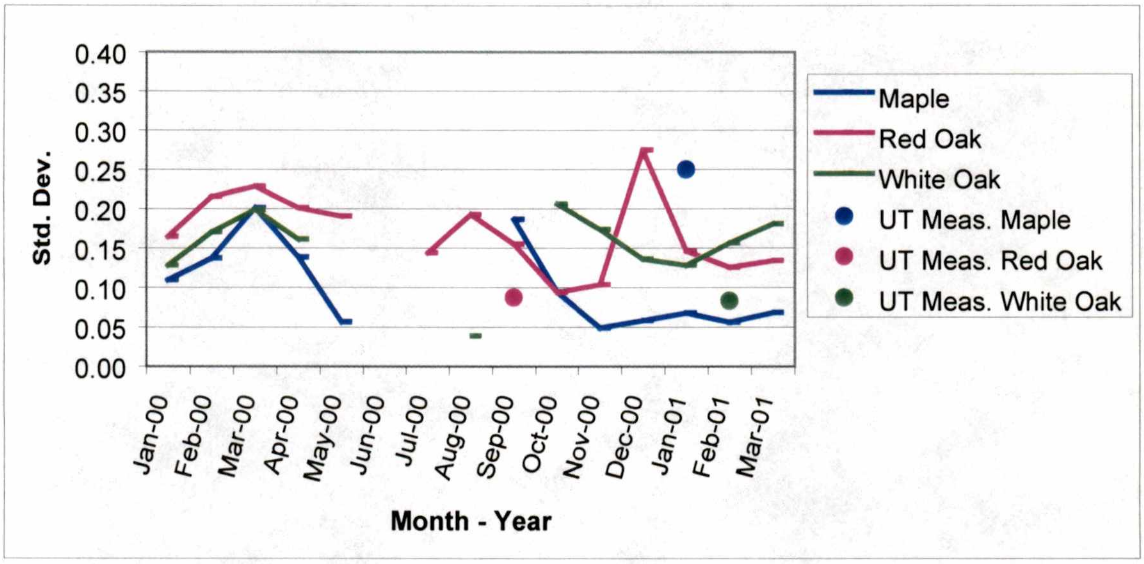
Graph 1a. Standard deviations (mm) for "finished blank" thickness for target length 215 mm.



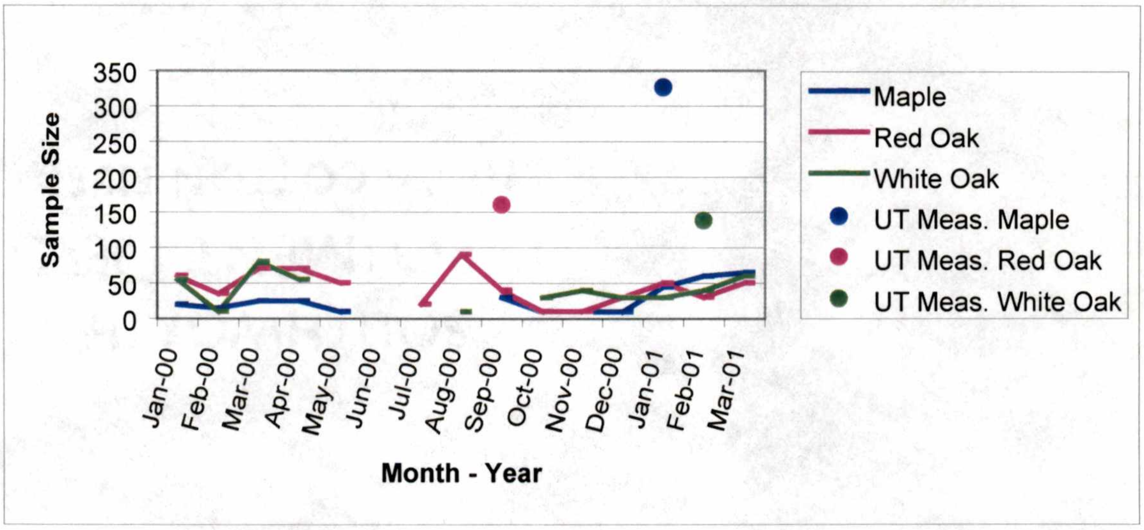
Graph 2a. Sample size for "finished blank" thickness for target length 215 mm.



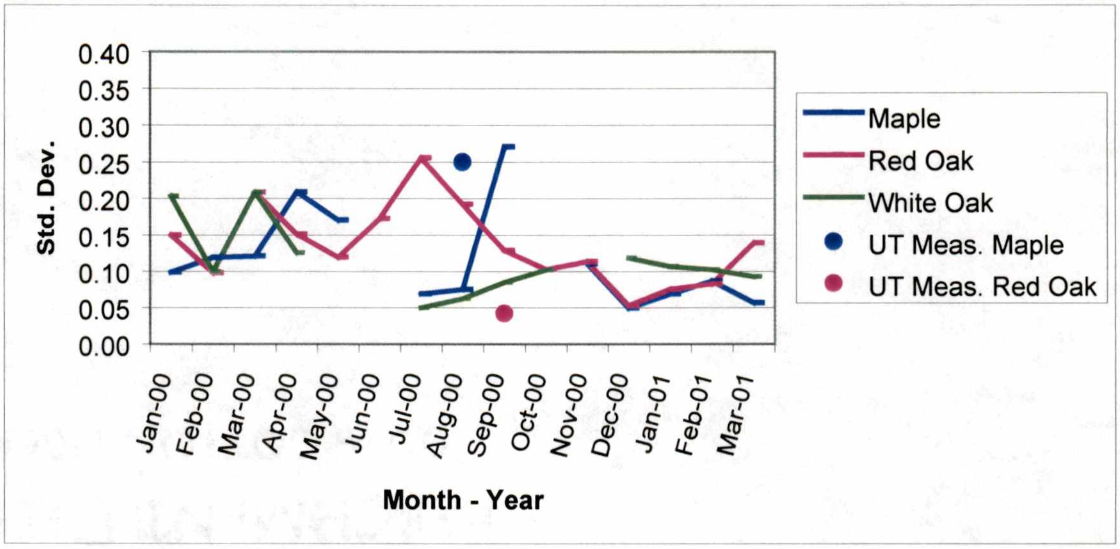
Graph 3a. Standard deviations (mm) for “finished blank” thickness for target length 270 mm.



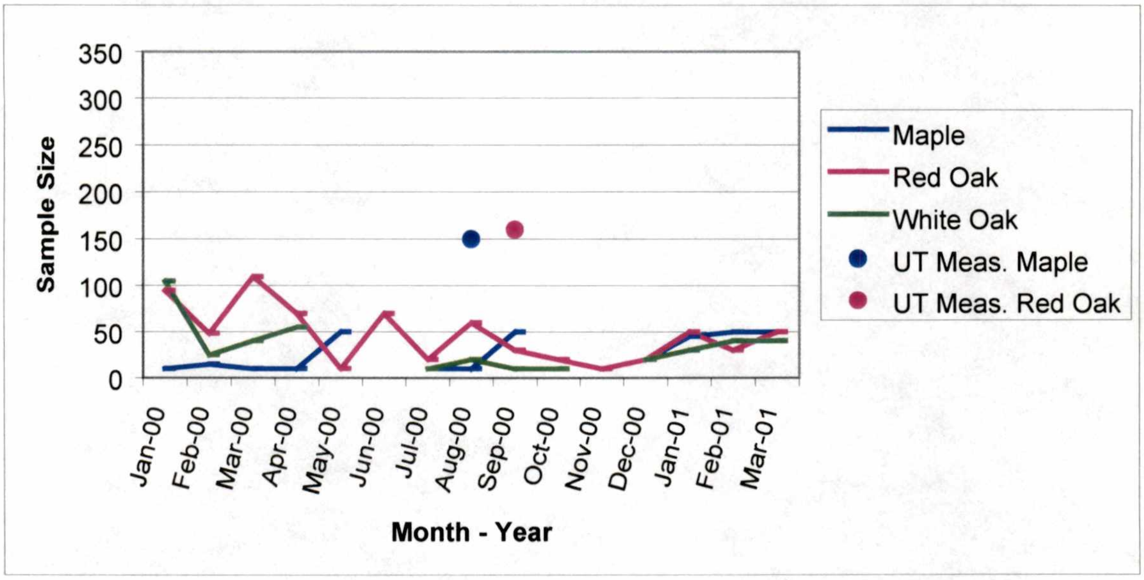
Graph 4a. Sample size for “finished blank” thickness for target length 270 mm.



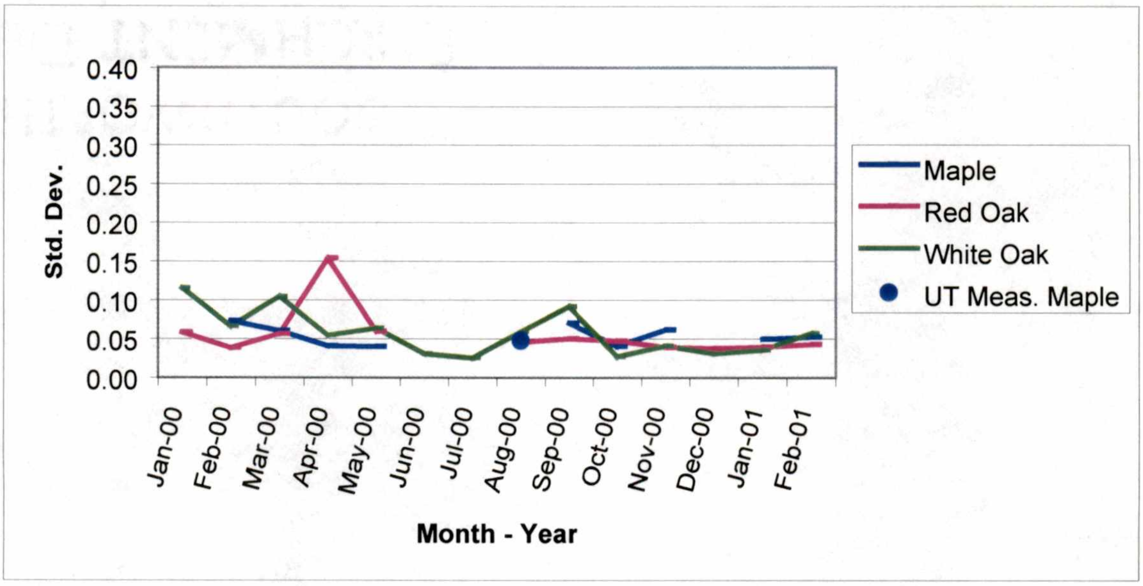
Graph 5a. Standard deviations (mm) for "finished blank" thickness for target length 325 mm.



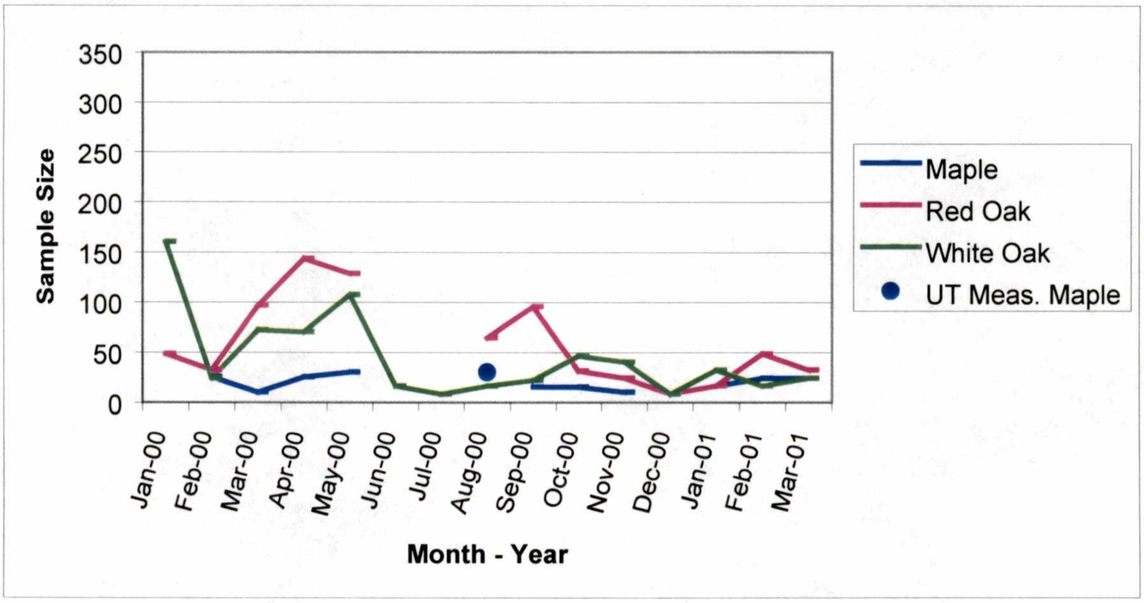
Graph 6a. Sample size for "finished blank" thickness for target length 325 mm.



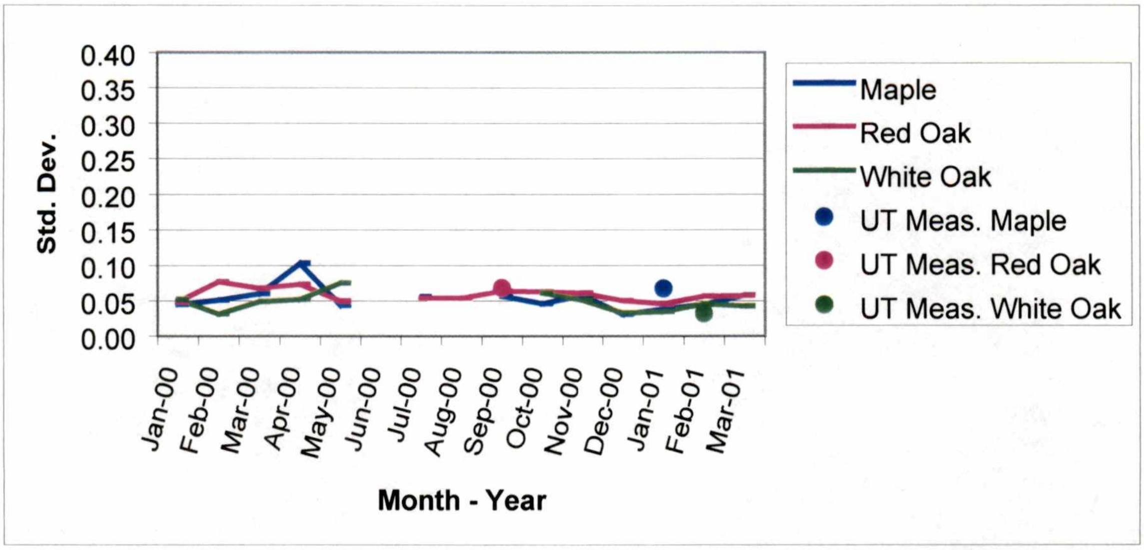
Graph 7a. Standard deviations (mm) for "finished blank" length for target length 215 mm.



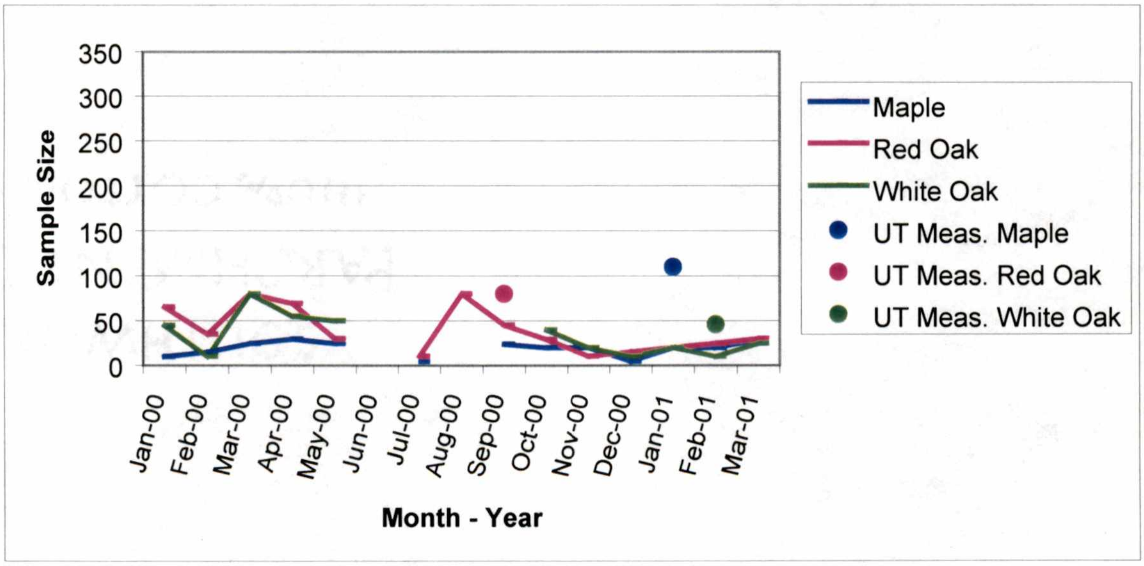
Graph 8a. Sample size for "finished blank" length for target length 215 mm.



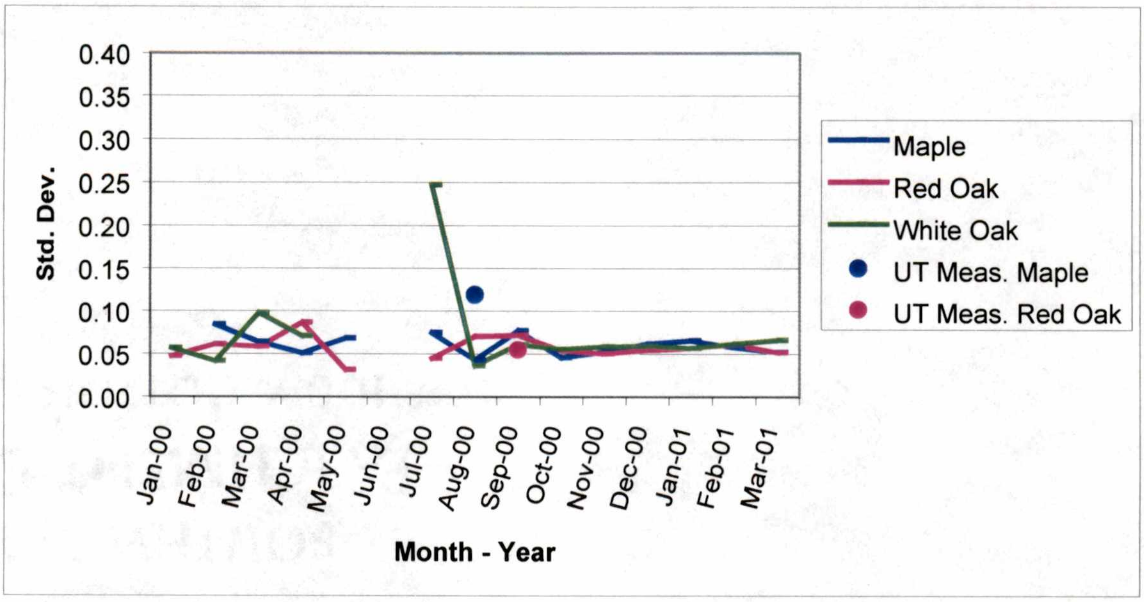
Graph 9a. Standard deviations (mm) for "finished blank" length for target length 270 mm.



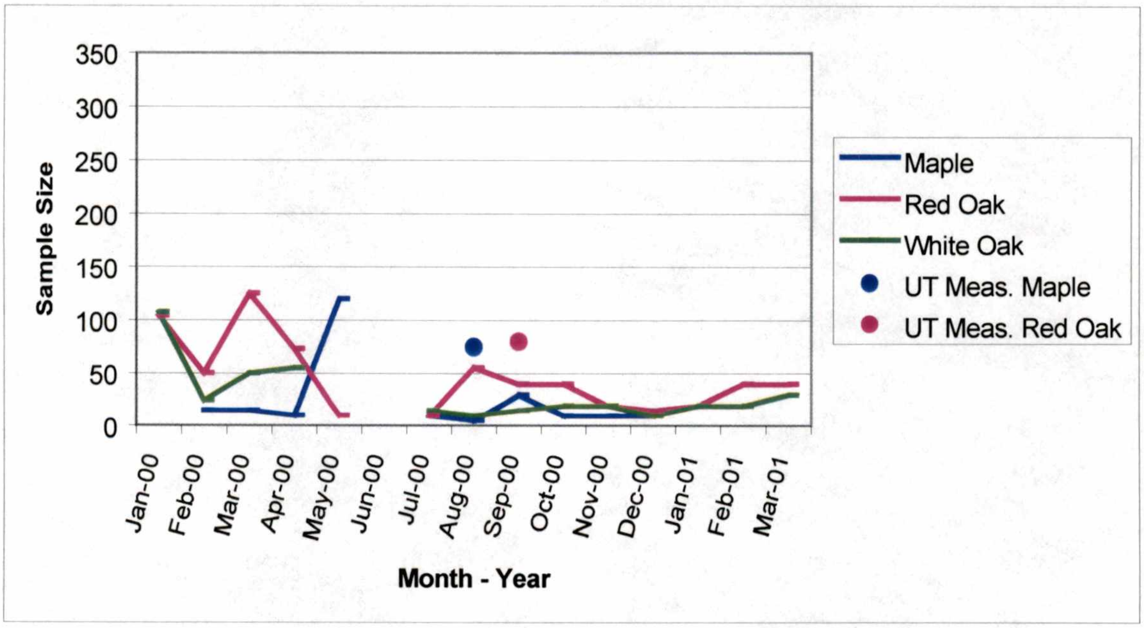
Graph 10a. Sample size for "finished blank" length for target length 270 mm.



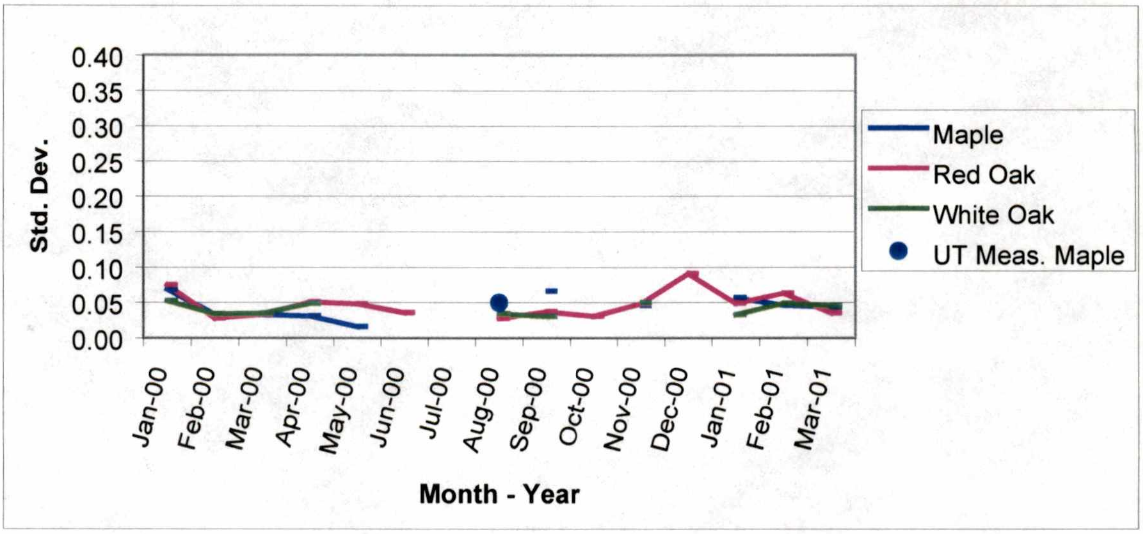
Graph 11a. Standard deviations (mm) for "finished blank" length for target length 325 mm.



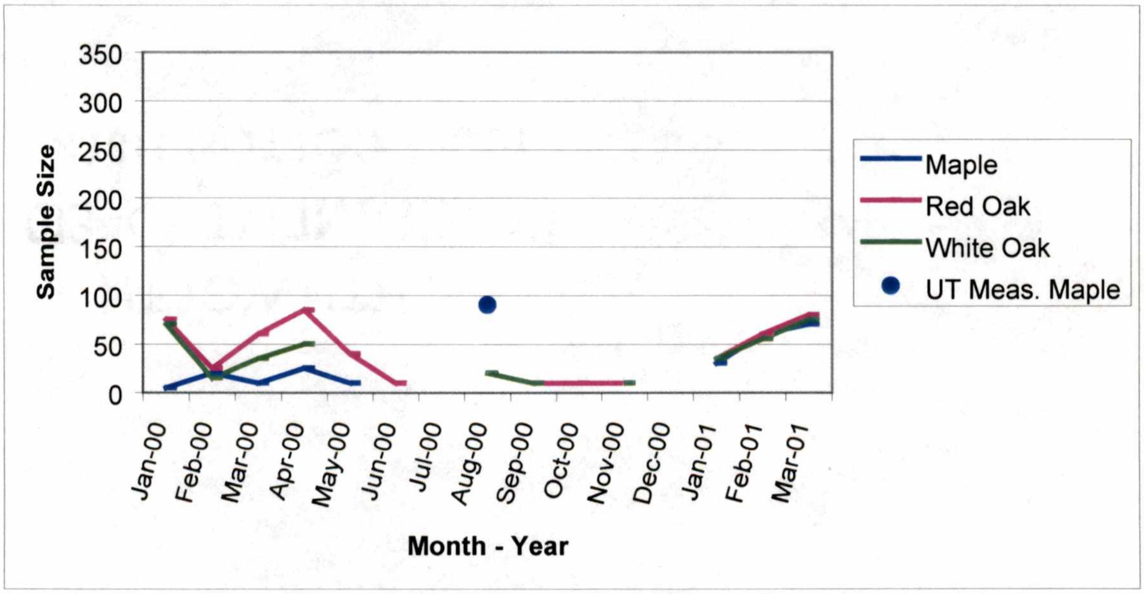
Graph 12a. Sample size for "finished blank" length for target length 325 mm.



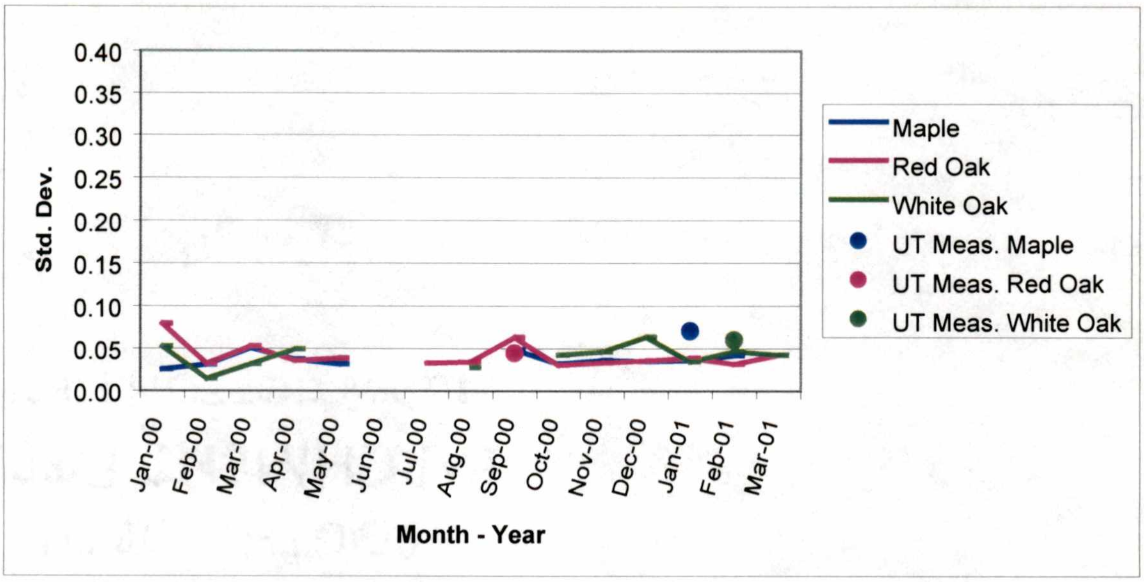
Graph 13a. Standard deviations (mm) for "finished blank" width for target length 215 mm.



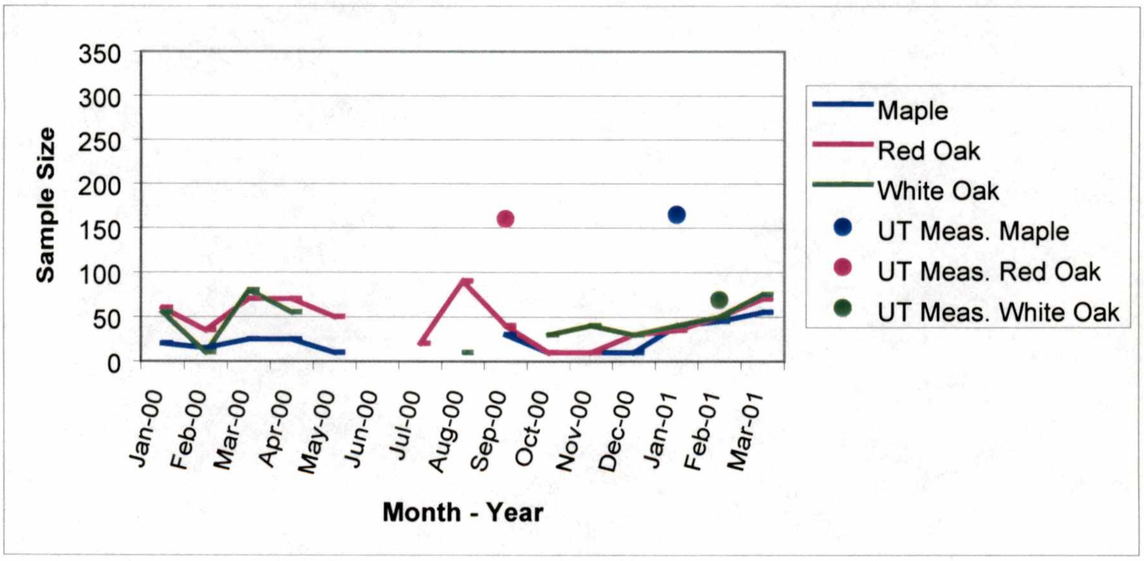
Graph 14a. Sample size for "finished blank" width for target length 215 mm.



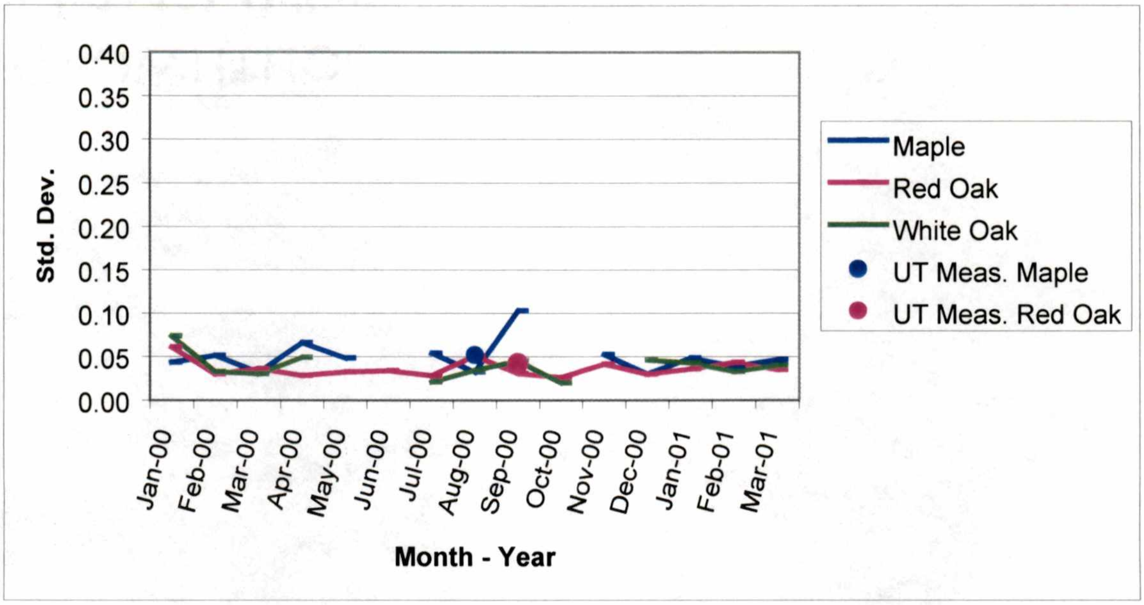
Graph 15a. Standard deviations (mm) for "finished blank" width for target length 270 mm.



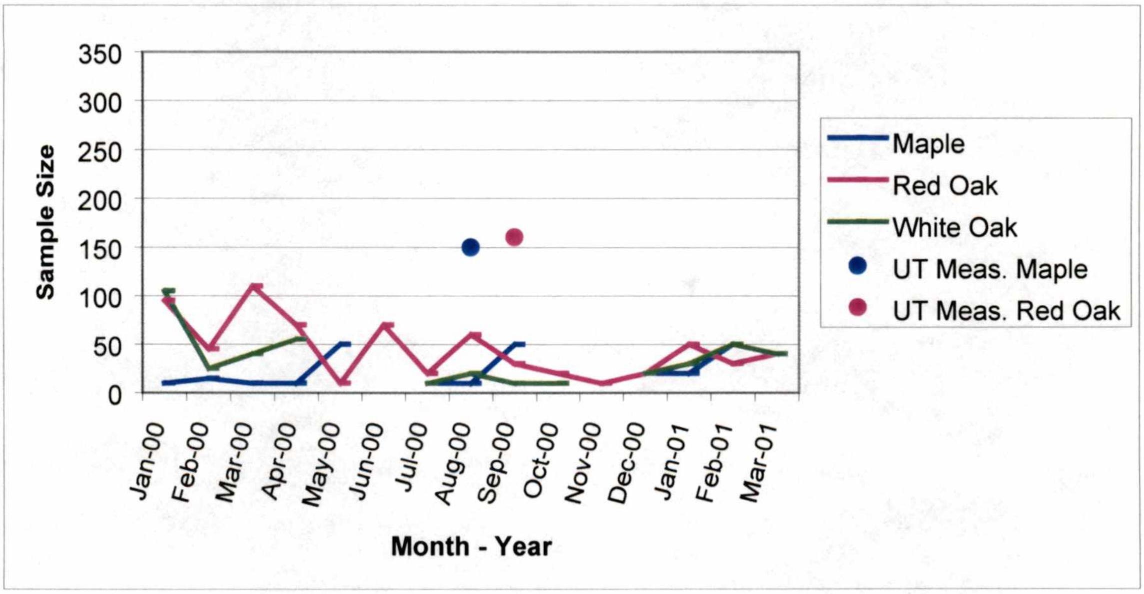
Graph 16a. Sample size for "finished blank" width for target length 270 mm.



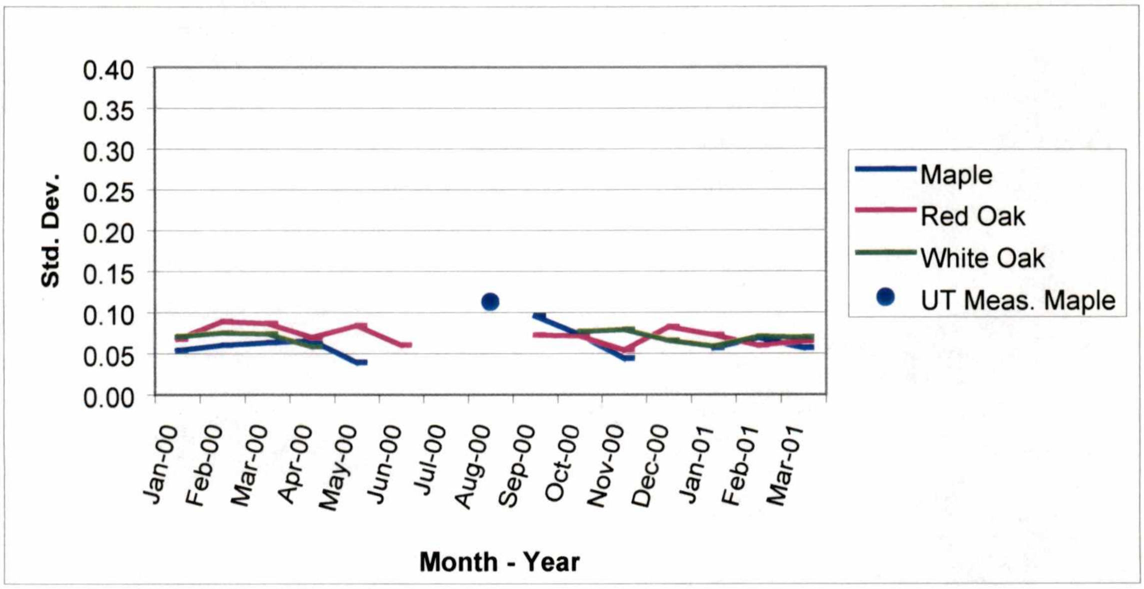
Graph 17a. Standard deviations (mm) for "finished blank" width for target length 325 mm.



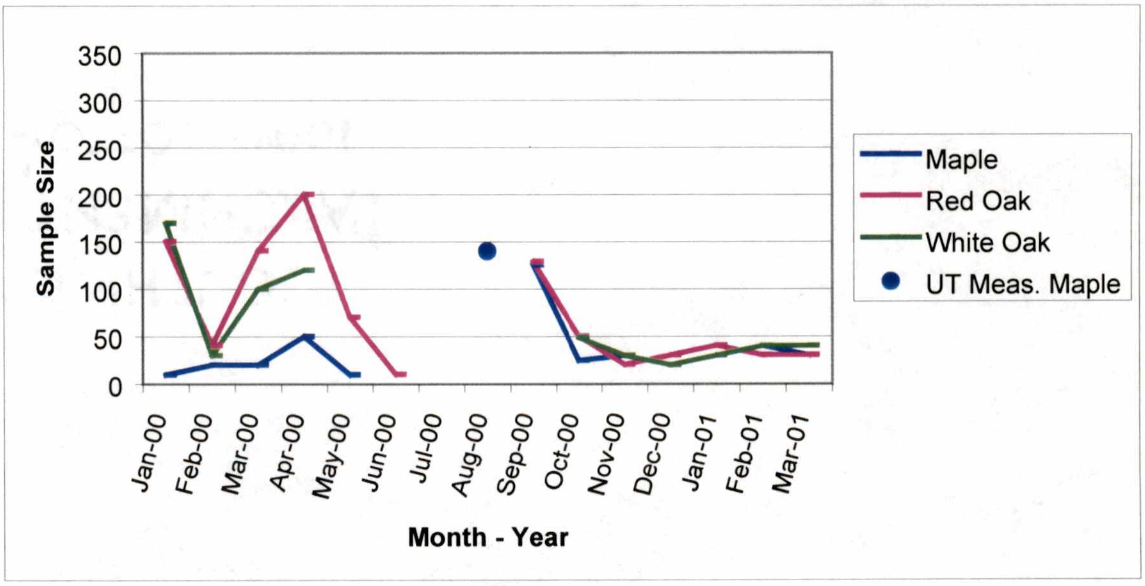
Graph 18a. Sample size for "finished blank" width for target length 325 mm.



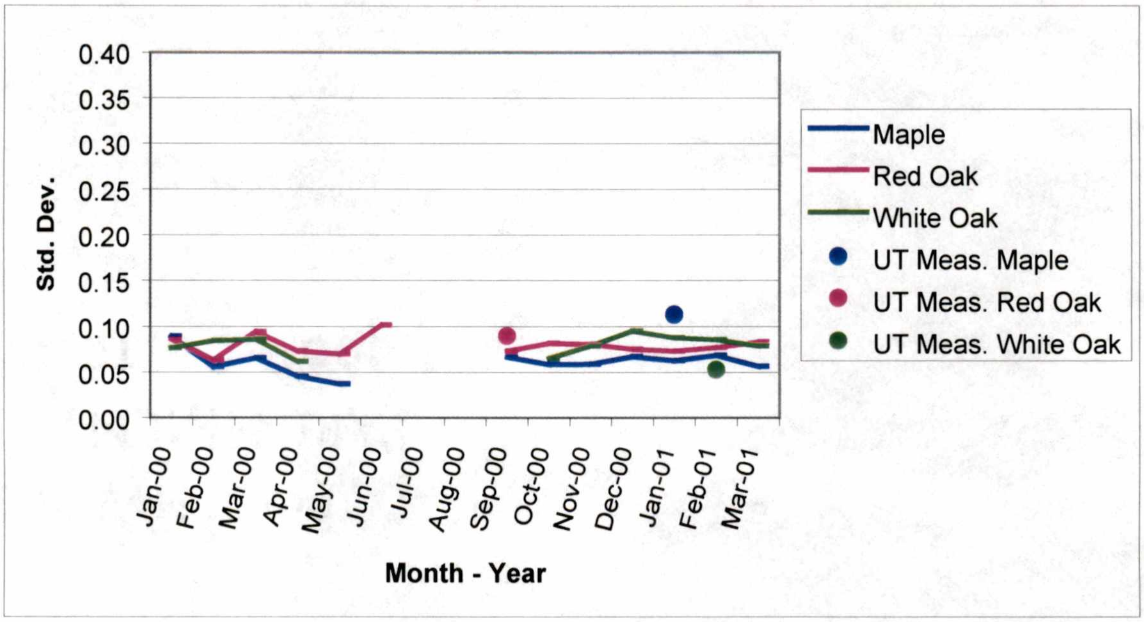
Graph 19a. Standard deviations (mm) for "veneer-slat" thickness for target length 215 mm.



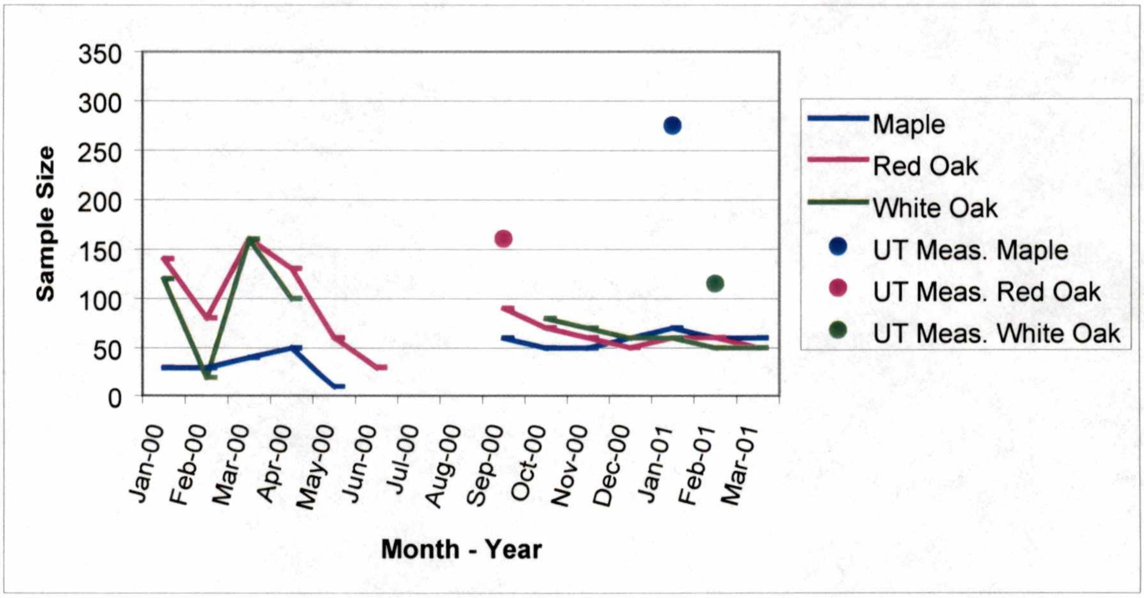
Graph 20a. Sample size for "veneer-slat" thickness for target length 215 mm.



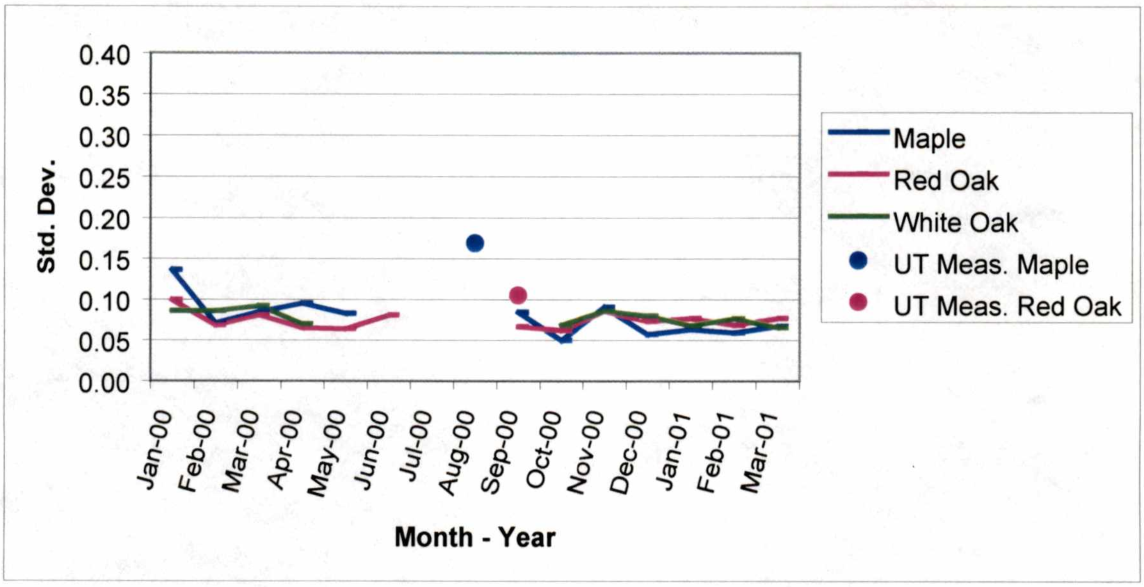
Graph 21a. Standard deviations (mm) for "veneer-slat" thickness for target length 270 mm.



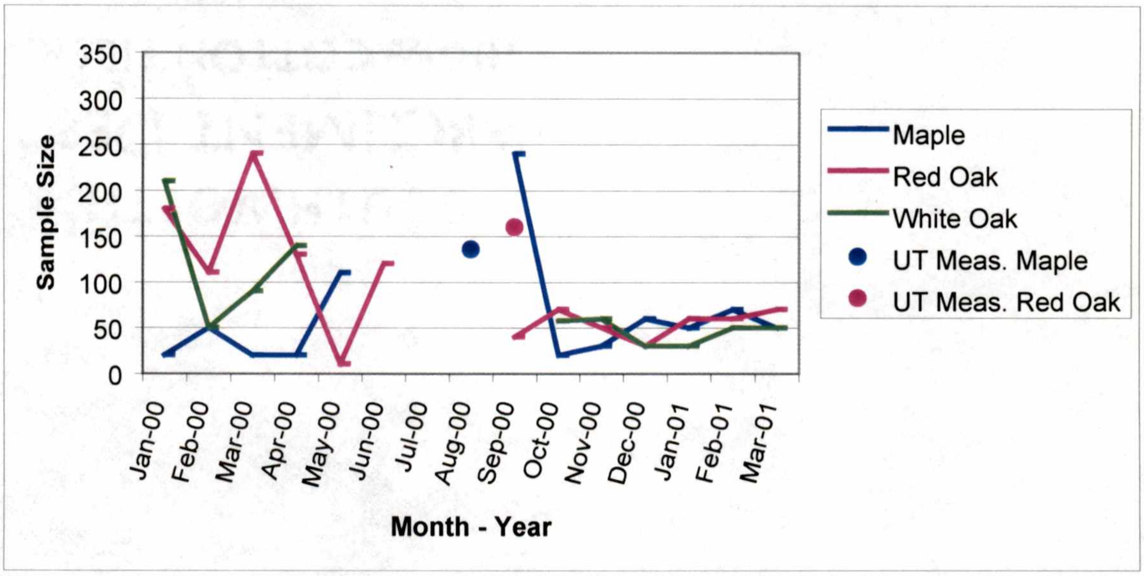
Graph 22a. Sample size for "veneer-slat" thickness for target length 270 mm.



Graph 23a. Standard deviations (mm) for "veneer-slat" thickness for target length 325 mm.



Graph 24a. Sample size for "veneer-slat" thickness for target length 325 mm.



Appendix B

(Tables 1b to 72b)

Table 1b. Averages and medians by month for hard maple (*Acer saccharum*) "finished blank" thickness for target length 215 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Medians	Non-parametric Wilcoxon Comparisons Test
January-2000	5	24.02	24.04	a
February-2000	20	24.16	24.15	b
March-2000	10	24.42	24.43	bc
April-2000	25	23.90	23.90	ab d
May-2000	10	23.87	23.90	b de
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--* (90)**	--* (24.16)**	--* (24.23)**	--*
September-2000	10	24.39	24.39	bc fghi
October-2000	20	24.20	24.23	j
November-2000	10	24.08	24.10	a gh jk
December-2000	--*	--*	--*	--*
January-2001	30	24.17	24.25	a gh jklm
February-2001	60	24.18	24.24	a gh jklmn
March-2001	70	24.15	24.16	a gh jklmno

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is compared with each month thereafter.*

Table 2b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for hard maple (*Acer saccharum*) "finished blank" thickness for target length 215 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	5	0.0799
February-2000	20	0.1154
March-2000	10	0.1718
April-2000	25	0.1240
May-2000	10	0.1315
June-2000	--*	--*
July-2000	--*	--*
August-2000	--* (90)**	--* (0.3613)**
September-2000	10	0.0861
October-2000	20	0.2636
November-2000	10	0.1293
December-2000	--*	--*
January-2001	30	0.2075
February-2001	60	0.2221
March-2001	70	0.1671

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 3b. Averages and medians by month for hard maple (*Acer saccharum*) "finished blank" thickness for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	20	24.06	24.06	a
February-2000	15	24.32	24.35	b
March-2000	25	24.20	24.18	c
April-2000	38	23.98	23.94	d
May-2000	12	24.03	23.92	de
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--*	--*	--*	--*
September-2000	10	24.46	24.39	fghi
October-2000	20	24.43	24.38	b fghij
November-2000	10	24.33	24.33	bc fgh k
December-2000	--*	--*	--*	--*
January-2001	20 (330)**	24.17 (24.20)**	24.16 (24.29)**	a c fgh k lm
February-2001	20	24.15	24.19	a c efgh k lmn
March-2001	23	24.20	24.25	bc fgh k mno

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 4b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for hard maple (*Acer saccharum*) "finished blank" thickness for target length 270 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	20	0.1095
February-2000	15	0.1370
March-2000	25	0.2009
April-2000	38	0.1820
May-2000	12	0.2530
June-2000	--*	--*
July-2000	--*	--*
August-2000	--*	--*
September-2000	10	0.1945
October-2000	20	0.1885
November-2000	10	0.1162
December-2000	--*	--*
January-2001	20 (330)**	0.1155 (0.2497)**
February-2001	20	0.2547
March-2001	23	0.1901

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 5b. Averages and medians by month for hard maple (*Acer saccharum*) "finished blank" thickness for target length 325 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	10	24.04	24.01	a
February-2000	15	24.06	24.07	ab
March-2000	10	24.05	24.06	abc
April-2000	38	24.15	24.17	a d
May-2000	12	24.16	24.15	e
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--* (150)**	--* (24.54)**	--* (24.63)**	--*
September-2000	10	24.08	24.07	g i
October-2000	20	24.05	24.08	j
November-2000	10	24.08	24.10	abc efgh jk
December-2000	--*	--*	--*	--*
January-2001	20	24.50	24.55	e g ij m
February-2001	20	24.41	24.41	g ij mn
March-2001	30	24.09	24.09	g ij no

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is* compared with each month thereafter.

Table 6b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for hard maple (*Acer saccharum*) "finished blank" thickness for target length 325 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	10	0.0989
February-2000	15	0.1196
March-2000	10	0.1214
April-2000	38	0.2492
May-2000	12	0.0686
June-2000	--*	--*
July-2000	--*	--*
August-2000	--* (150)**	--* (0.2499)**
September-2000	10	0.0557
October-2000	20	0.1231
November-2000	10	0.0899
December-2000	--*	--*
January-2001	20	0.2796
February-2001	20	0.1507
March-2001	30	0.1413

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 7b. Averages and medians by month for hard maple (*Acer saccharum*) "finished blank" width for target length 215 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	5	65.14	65.12	a
February-2000	20	65.15	65.16	ab
March-2000	10	65.19	65.19	a c
April-2000	35	65.16	65.16	ab d
May-2000	10	65.20	65.20	c e
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--* (90)**	--* (65.21)**	--* (65.21)**	--*
September-2000	10	65.13	65.13	ab d fghi
October-2000	20	65.15	65.16	j
November-2000	10	65.14	65.15	ab d fghijk
December-2000	--*	--*	--*	--*
January-2001	20	65.17	65.18	abcdefghijklm
February-2001	20	65.20	65.20	a c efgh lmn
March-2001	30	65.20	65.21	a c efgh lmn

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 8b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for hard maple (*Acer saccharum*) "finished blank" width for target length 215 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	5	0.0684
February-2000	20	0.0327
March-2000	10	0.0325
April-2000	35	0.0357
May-2000	10	0.0155
June-2000	--*	--*
July-2000	--*	--*
August-2000	--* (90)**	--* (0.0494)**
September-2000	10	0.0656
October-2000	20	0.0667
November-2000	10	0.0450
December-2000	--*	--*
January-2001	20	0.0709
February-2001	20	0.0483
March-2001	30	0.0529

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 9b. Averages and medians by month for hard maple (*Acer saccharum*) "finished blank" width for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	20	65.14	65.14	a
February-2000	15	65.19	65.19	b
March-2000	25	65.17	65.18	bc
April-2000	38	65.17	65.18	cd
May-2000	12	65.19	65.20	bcde
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--*	--*	--*	--*
September-2000	10	65.17	65.17	bcdefghi
October-2000	20	65.15	65.17	bcdefghij
November-2000	10	65.17	65.19	a cd fghijk
December-2000	--*	--*	--*	--*
January-2001	20 (165)**	65.16 (65.20)**	65.18 (65.19)**	bcdefghijklm
February-2001	20	65.20	65.20	bcdefghijklmn
March-2001	23	65.19	65.16	bcdefghijklmno

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 10b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for hard maple (*Acer saccharum*) "finished blank" width for target length 270 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	20	0.0254
February-2000	15	0.0310
March-2000	25	0.0510
April-2000	38	0.0360
May-2000	12	0.0287
June-2000	--*	--*
July-2000	--*	--*
August-2000	--*	--*
September-2000	10	0.0477
October-2000	20	0.0484
November-2000	10	0.0370
December-2000	--*	--*
January-2001	20 (165)**	0.0350 (0.0707)**
February-2001	20	0.0504
March-2001	23	0.0941

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 11b. Averages and medians by month for hard maple (*Acer saccharum*) "finished blank" width for target length 325 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	10	65.18	65.19	a
February-2000	15	65.14	65.14	b
March-2000	10	65.17	65.17	abc
April-2000	38	65.17	65.19	b d
May-2000	12	65.19	65.20	c e
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--* (150)**	--* (65.17)**	--* (65.17)**	--*
September-2000	10	65.17	65.17	a c efghi
October-2000	20	65.14	65.13	j
November-2000	10	65.15	65.15	abcd fghijk
December-2000	--*	--*	--*	--*
January-2001	20	65.18	65.17	a f ij m
February-2001	20	65.22	65.19	a f ij mn
March-2001	30	65.17	65.17	abc ef ijk mno

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 12b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for hard maple (*Acer saccharum*) "finished blank" width for target length 325 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	10	0.0433
February-2000	15	0.0510
March-2000	10	0.0320
April-2000	38	0.0679
May-2000	12	0.0366
June-2000	--*	--*
July-2000	--*	--*
August-2000	--* (150)**	--* (0.0520)**
September-2000	10	0.0601
October-2000	20	0.0555
November-2000	10	0.0344
December-2000	--*	--*
January-2001	20	0.0942
February-2001	20	0.1176
March-2001	30	0.0723

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 13b. Averages and medians by month for hard maple (*Acer saccharum*) "finished blank" length for target length 215 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	--*	--*	--*	--*
February-2000	25	215.11	215.10	ab
March-2000	10	215.13	215.13	abc
April-2000	55	215.08	215.08	abcd
May-2000	30	215.06	215.06	a e
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--* (30)**	--* (214.97)**	--* (215.08)**	--*
September-2000	15	215.07	215.04	ab defghi
October-2000	15	215.12	215.12	abcd fghj
November-2000	10	215.17	215.16	a c fgh k
December-2000	--*	--*	--*	--*
January-2001	10	215.13	215.14	abc fgh jklm
February-2001	10	270.04	270.04	a fgh l n
March-2001	10	215.08	215.08	abcdefghij lmo

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 14b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for hard maple (*Acer saccharum*) "finished blank" length for target length 215 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	--*	--*
February-2000	25	0.0729
March-2000	10	0.0600
April-2000	55	0.0426
May-2000	30	0.0394
June-2000	--*	--*
July-2000	--*	--*
August-2000	--* (30)**	--* (0.0470)**
September-2000	15	0.0698
October-2000	15	0.0400
November-2000	10	0.0612
December-2000	--*	--*
January-2001	10	0.0267
February-2001	10	0.0335
March-2001	10	0.0503

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 15b. Averages and medians by month for hard maple (*Acer saccharum*) "finished blank" length for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	10	270.11	270.11	a
February-2000	15	270.16	270.17	b
March-2000	25	270.14	270.15	abc
April-2000	55	270.13	270.13	abcd
May-2000	25	270.10	270.10	a e
June-2000	--*	--*	--*	--*
July-2000	5	270.12	270.12	abcdefg
August-2000	--*	--*	--*	--*
September-2000	24	270.10	270.10	a efghi
October-2000	20	270.10	270.10	a efghij
November-2000	20	270.11	270.10	a c efghijk
December-2000	5	270.07	270.06	a efghijkl
January-2001	10 (110)**	270.10 (270.32)**	270.10 (270.18)**	a c efghijklm
February-2001	15	270.11	270.10	a c efghijklmn
March-2001	30	270.08	270.08	a efghijklmno

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 16b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for hard maple (*Acer saccharum*) "finished blank" length for target length 270 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	10	0.0452
February-2000	15	0.0510
March-2000	25	0.0601
April-2000	55	0.0868
May-2000	25	0.0439
June-2000	--*	--*
July-2000	5	0.0559
August-2000	--*	--*
September-2000	24	0.0568
October-2000	20	0.0460
November-2000	20	0.0575
December-2000	5	0.0311
January-2001	10 (110)**	0.0387 (0.4786)**
February-2001	15	0.0469
March-2001	30	0.0341

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 17b. Averages and medians by month for hard maple (*Acer saccharum*) "finished blank" length for target length 325 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	--*	--*	--*	--*
February-2000	15	325.09	325.13	ab
March-2000	15	325.08	325.08	abc
April-2000	130	325.18	325.16	abcd
May-2000	71	325.19	325.17	a e
June-2000	--*	--*	--*	--*
July-2000	10	325.10	325.13	Abcd fg
August-2000	5	325.03	325.00	abc f h
September-2000	35 (75)**	325.06 (325.17)**	325.07 (325.13)**	abcd fghi
October-2000	10	325.15	325.15	ab defg j
November-2000	10	325.14	325.15	ab defg jk
December-2000	10	325.10	325.12	abcd fg ijkl
January-2001	5	325.08	325.08	abcd fghi lm
February-2001	5	270.11	270.10	a f n
March-2001	20	325.12	325.13	ab d f j l o

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 18b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for hard maple (*Acer saccharum*) "finished blank" length for target length 325 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	--*	--*
February-2000	15	0.0840
March-2000	15	0.0641
April-2000	130	0.0707
May-2000	71	0.0658
June-2000	--*	--*
July-2000	10	0.0745
August-2000	5	0.0428
September-2000	35 (75)**	0.0726 (0.1189)**
October-2000	10	0.0453
November-2000	10	0.0520
December-2000	10	0.0617
January-2001	5	0.0286
February-2001	5	0.0313
March-2001	20	0.0289

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 19b. Averages and medians by month for hard maple (*Acer saccharum*) "veneer-slat" thickness for target length 215 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	10	3.53	3.53	a
February-2000	20	3.56	3.56	ab
March-2000	20	3.62	3.60	c
April-2000	60	3.56	3.55	ab d
May-2000	10	3.54	3.55	ab de
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--* (140)**	--* (3.57)**	--* (3.61)**	--*
September-2000	126	3.53	3.55	ab defghi
October-2000	25	3.54	3.55	ab defghij
November-2000	20	3.59	3.59	bc fgh k
December-2000	--*	--*	--*	--*
January-2001	16	3.57	3.58	ab defgh jklm
February-2001	26	3.54	3.55	ab defghij l n
March-2001	26	3.53	3.53	ab defghij l no

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 20b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for hard maple (*Acer saccharum*) "veneer-slat" thickness for target length 215 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	10	0.0541
February-2000	20	0.0603
March-2000	20	0.0636
April-2000	60	0.0622
May-2000	10	0.0395
June-2000	--*	--*
July-2000	--*	--*
August-2000	--* (140)**	--* (0.1131)**
September-2000	126	0.0955
October-2000	25	0.0732
November-2000	20	0.0440
December-2000	--*	--*
January-2001	16	0.0443
February-2001	26	0.0470
March-2001	26	0.0554

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 21b. Averages and medians by month for hard maple (*Acer saccharum*) "veneer-slat" thickness for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	29	3.54	3.56	a
February-2000	30	3.62	3.61	b
March-2000	40	3.62	3.63	bc
April-2000	60	3.55	3.54	a d
May-2000	10	3.54	3.54	a de
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--*	--*	--*	--*
September-2000	60	3.56	3.57	a defghi
October-2000	50	3.56	3.57	a defghij
November-2000	40	3.57	3.58	a efghijk
December-2000	10	3.52	3.52	a defgh l
January-2001	18 (328)**	3.57 (3.60)**	3.58 (3.60)**	a defghijk m
February-2001	18	3.57	3.57	a defghijk mn
March-2001	24	3.53	3.53	a defgh l o

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 22b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for hard maple (*Acer saccharum*) "veneer-slat" thickness for target length 270 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	29	0.0666
February-2000	30	0.0560
March-2000	40	0.0655
April-2000	60	0.0439
May-2000	10	0.0371
June-2000	--*	--*
July-2000	--*	--*
August-2000	--*	--*
September-2000	60	0.0666
October-2000	50	0.0584
November-2000	40	0.0590
December-2000	10	0.0670
January-2001	18 (328)**	0.0457 (0.1130)**
February-2001	18	0.0554
March-2001	24	0.0538

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 23b. Averages and medians by month for hard maple (*Acer saccharum*) "veneer-slat" thickness for target length 325 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	19	3.54	3.58	a
February-2000	50	3.56	3.57	ab
March-2000	20	3.60	3.62	a c
April-2000	130	3.50	3.50	ab d
May-2000	80	3.48	3.49	e
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--* (136)**	--* (3.55)**	--* (3.53)**	--*
September-2000	240	3.53	3.55	a d fghi
October-2000	20	3.54	3.55	ab d fghij
November-2000	20	3.55	3.55	abcd fghijk
December-2000	30	3.56	3.56	ab d fghijkl
January-2001	74	3.57	3.57	ab d fgh jklm
February-2001	52	3.55	3.56	ab d fghijkl n
March-2001	78	3.54	3.55	a d fghijkl no

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 24b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for hard maple (*Acer saccharum*) "veneer-slat" thickness for target length 325 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	19	0.1387
February-2000	50	0.0709
March-2000	20	0.0845
April-2000	130	0.0864
May-2000	80	0.0860
June-2000	--*	--*
July-2000	--*	--*
August-2000	--* (136)**	--* (0.1688)**
September-2000	240	0.0843
October-2000	20	0.0495
November-2000	20	0.0905
December-2000	30	0.0571
January-2001	74	0.0416
February-2001	52	0.0477
March-2001	78	0.0506

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 25b. Averages and medians by month for red oak (*Quercus rubra*) "finished blank" thickness for target length 215 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Medians	Non-parametric Wilcoxon Comparisons Test**
January-2000	75	24.07	24.04	a
February-2000	25	24.11	24.09	b
March-2000	60	24.08	24.06	c
April-2000	124	24.23	24.20	d
May-2000	40	24.52	24.53	abcde
June-2000	10	24.09	24.10	ef
July-2000	--*	--*	--*	--*
August-2000	30	24.47	24.48	abcd fh
September-2000	20	24.51	24.52	abcd f i
October-2000	10	24.63	24.64	abcd fg ij
November-2000	10	24.25	24.28	bcdef hijk
December-2000	10	23.94	23.93	bcdef hijkl
January-2001	10	24.14	24.17	e hijklm
February-2001	10	24.12	24.16	e hijkl n
March-2001	79	24.23	24.21	abcdef hij l no

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is compared* with each month thereafter.

Table 26b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for red oak (*Quercus rubra*) "finished blank" thickness for target length 215 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	75	0.2455
February-2000	25	0.1265
March-2000	60	0.1294
April-2000	124	0.2789
May-2000	40	0.2073
June-2000	10	0.0832
July-2000	--*	--*
August-2000	30	0.1314
September-2000	20	0.1191
October-2000	10	0.0744
November-2000	10	0.0893
December-2000	10	0.0437
January-2001	10	0.1286
February-2001	10	0.1382
March-2001	79	0.1091

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 27b. Averages and medians by month for red oak (*Quercus rubra*) "finished blank" thickness for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	60	24.03	23.99	a
February-2000	35	24.13	24.14	ab
March-2000	70	24.05	24.02	c
April-2000	120	24.13	24.12	d
May-2000	50	24.22	24.16	abcde
June-2000	--*	--*	--*	--*
July-2000	20	24.11	24.04	ab efg
August-2000	90	24.48	24.56	abcdefgh
September-2000	40 (160)**	24.41 (24.42)**	24.42 (24.43)**	abcdefghi
October-2000	10	24.18	24.17	a cd f hij
November-2000	10	24.31	24.34	abcd fghijk
December-2000	30	24.42	24.36	abcdefg j l
January-2001	20	24.19	24.21	a cd fhi klm
February-2001	30	24.16	24.16	cd fhi k mn
March-2001	140	24.25	24.24	abcd lmno

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 28b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for red oak (*Quercus rubra*) "finished blank" thickness for target length 270 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	60	0.1637
February-2000	35	0.2151
March-2000	70	0.2282
April-2000	120	0.2121
May-2000	50	0.1899
June-2000	--*	--*
July-2000	20	0.1431
August-2000	90	0.1919
September-2000	40 (160)**	0.1544 (0.0865)**
October-2000	10	0.0937
November-2000	10	0.1031
December-2000	30	0.2746
January-2001	20	0.0784
February-2001	30	0.0601
March-2001	140	0.1335

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 29b. Averages and medians by month for red oak (*Quercus rubra*) "finished blank" thickness for target length 325 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	95	23.98	23.97	a
February-2000	43	24.10	24.11	ab
March-2000	115	24.22	24.18	abc
April-2000	80	24.08	24.09	a cd
May-2000	10	24.33	24.31	a cde
June-2000	70	24.11	24.13	a cdef
July-2000	20	24.07	24.00	c e g
August-2000	60	24.43	24.44	abcd fgh
September-2000	30 (160)**	24.46 (24.41)**	24.45 (24.42)**	abcdefg i
October-2000	20	24.53	24.57	abcdefg ij
November-2000	10	24.18	24.20	ab de ijk
December-2000	20	24.20	24.20	ab def hij l
January-2001	10	24.12	24.15	a e hij lm
February-2001	20	24.19	24.21	ab def hij mn
March-2001	130	24.22	24.25	ab defghij lmno

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 30b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for red oak (*Quercus rubra*) "finished blank" thickness for target length 325 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	95	0.1500
February-2000	43	0.0959
March-2000	115	0.2101
April-2000	80	0.1741
May-2000	10	0.1196
June-2000	70	0.1726
July-2000	20	0.2558
August-2000	60	0.1920
September-2000	30 (160)**	0.1286 (0.0775)**
October-2000	20	0.1030
November-2000	10	0.1137
December-2000	20	0.0529
January-2001	10	0.0469
February-2001	20	0.0645
March-2001	130	0.1389

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 31b. Averages and medians by month for red oak (*Quercus rubra*) "finished blank" width for target length 215 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	75	65.19	65.18	a
February-2000	25	65.17	65.17	b
March-2000	60	65.18	65.18	c
April-2000	125	65.16	65.16	a cd
May-2000	40	65.15	65.16	a c e
June-2000	10	65.20	65.20	b def
July-2000	--*	--*	--*	--*
August-2000	30	65.15	65.15	abc f h
September-2000	20	65.15	65.15	abc f i
October-2000	10	65.18	65.20	e hij
November-2000	10	65.15	65.16	c f k
December-2000	10	65.17	65.20	c h l
January-2001	10	65.21	65.21	bcde hi k m
February-2001	10	65.21	65.20	bcde hi k n
March-2001	76	65.16	65.16	a c f ij mno

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 32b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for red oak (*Quercus rubra*) "finished blank" width for target length 215 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	75	0.0746
February-2000	25	0.0280
March-2000	60	0.0331
April-2000	125	0.0499
May-2000	40	0.0477
June-2000	10	0.0355
July-2000	--*	--*
August-2000	30	0.0272
September-2000	20	0.0368
October-2000	10	0.0306
November-2000	10	0.0479
December-2000	10	0.0906
January-2001	10	0.0649
February-2001	10	0.0479
March-2001	76	0.0348

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 33b. Averages and medians by month for red oak (*Quercus rubra*) "finished blank" width for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	60	65.19	65.18	a
February-2000	35	65.16	65.16	ab
March-2000	70	65.15	65.16	bc
April-2000	120	65.17	65.17	bcd
May-2000	50	65.18	65.19	a e
June-2000	--*	--*	--*	--*
July-2000	20	65.13	65.13	b g
August-2000	90	65.15	65.15	a d h
September-2000	40 (160)**	65.20 (65.20)**	65.19 (65.20)**	a e i
October-2000	10	65.15	65.17	abcd g j
November-2000	10	65.16	65.17	abcde k
December-2000	30	65.16	65.17	abcde hi kl
January-2001	20	65.19	65.18	a e j m
February-2001	30	65.20	65.20	a e j mn
March-2001	140	65.15	65.16	bcd kl o

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 34b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for red oak (*Quercus rubra*) "finished blank" width for target length 270 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	60	0.0791
February-2000	35	0.0322
March-2000	70	0.0530
April-2000	120	0.0391
May-2000	50	0.0387
June-2000	--*	--*
July-2000	20	0.0327
August-2000	90	0.0343
September-2000	40 (160)**	0.0630 (0.0444)**
October-2000	10	0.0302
November-2000	10	0.0329
December-2000	30	0.0358
January-2001	20	0.0474
February-2001	30	0.0461
March-2001	140	0.0423

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 35b. Averages and medians by month for red oak (*Quercus rubra*) "finished blank" width for target length 325 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	95	65.19	65.18	a
February-2000	40	65.15	65.16	b
March-2000	115	65.17	65.18	c
April-2000	80	65.17	65.17	cd
May-2000	10	65.19	65.19	a e
June-2000	70	65.18	65.19	a ef
July-2000	20	65.17	65.17	bcde g
August-2000	60	65.15	65.15	b gh
September-2000	30 (160)**	65.17 (65.19)**	65.16 (65.19)**	bcde ghi
October-2000	20	65.16	65.16	b d ghij
November-2000	10	65.23	65.24	k
December-2000	20	65.16	65.16	bcd ghij l
January-2001	10	65.16	65.17	bcd ghijklm
February-2001	20	65.14	65.16	b ghijklmn
March-2001	130	65.15	65.16	b ghijklmno

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 36b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for red oak (*Quercus rubra*) "finished blank" width for target length 325 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	95	0.0607
February-2000	40	0.0314
March-2000	115	0.0354
April-2000	80	0.0295
May-2000	10	0.0323
June-2000	70	0.0336
July-2000	20	0.0284
August-2000	60	0.0510
September-2000	30 (160)**	0.0305 (0.0422)**
October-2000	20	0.0259
November-2000	10	0.0413
December-2000	20	0.0297
January-2001	10	0.0228
February-2001	20	0.0417
March-2001	130	0.0349

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 37b. Averages and medians by month for red oak (*Quercus rubra*) "finished blank" length for target length 215 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	30	215.10	215.11	a
February-2000	20	215.02	215.03	b
March-2000	60	215.07	215.06	c
April-2000	160	215.08	215.08	a d
May-2000	70	215.07	215.07	c e
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	40	215.10	215.09	a d h
September-2000	59	215.10	215.10	a d hi
October-2000	20	215.12	215.11	a d hij
November-2000	14	215.12	215.12	a d hijk
December-2000	5	215.02	215.02	bc l
January-2001	10	215.13	215.13	a d hijk m
February-2001	20	215.11	215.11	a d hijk mn
March-2001	104	216.70	215.11	a hijk mno

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 38b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for red oak (*Quercus rubra*) "finished blank" length for target length 215 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	30	0.0579
February-2000	20	0.0378
March-2000	60	0.0558
April-2000	160	0.1210
May-2000	70	0.0590
June-2000	--*	--*
July-2000	--*	--*
August-2000	40	0.0454
September-2000	59	0.0496
October-2000	20	0.0466
November-2000	14	0.0389
December-2000	5	0.0370
January-2001	10	0.0389
February-2001	20	0.0412
March-2001	104	0.0615

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 39b. Averages and medians by month for red oak (*Quercus rubra*) "finished blank" length for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	65	270.12	270.12	a
February-2000	35	270.06	270.06	b
March-2000	80	270.09	270.10	c
April-2000	99	270.10	270.10	ce
May-2000	30	270.11	270.10	a cde
June-2000	--*	--*	--*	--*
July-2000	10	270.10	270.10	abcde g
August-2000	80	270.12	270.13	a d fgh
September-2000	45 (80)**	270.12 (270.13)**	270.15 (270.13)**	a efghi
October-2000	29	270.12	270.12	a c efghij
November-2000	10	270.10	270.11	abcdefghijk
December-2000	15	270.08	270.06	bcdefg i kl
January-2001	10	270.16	270.16	hij m
February-2001	5	270.12	270.13	abcde ghijkl n
March-2001	105	270.11	270.11	a c e g jk no

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 40b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for red oak (*Quercus rubra*) "finished blank" length for target length 270 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	65	0.0483
February-2000	35	0.0768
March-2000	80	0.0677
April-2000	99	0.0667
May-2000	30	0.0494
June-2000	--*	--*
July-2000	10	0.0537
August-2000	80	0.0535
September-2000	45 (80)**	0.0633 (0.0682)**
October-2000	29	0.0627
November-2000	10	0.0609
December-2000	15	0.0497
January-2001	10	0.0162
February-2001	5	0.0164
March-2001	105	0.0377

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 41b. Averages and medians by month for red oak (*Quercus rubra*) "finished blank" length for target length 325 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	104	325.10	325.09	a
February-2000	50	325.08	325.08	ab
March-2000	125	325.10	325.10	a c
April-2000	83	325.10	325.10	a cd
May-2000	10	325.17	325.17	e
June-2000	--*	--*	--*	--*
July-2000	10	325.10	325.10	abcd g
August-2000	55	325.11	325.14	e gh
September-2000	40 (80)**	325.13 (325.03)**	325.13 (325.02)**	ghi
October-2000	40	325.11	325.12	c ghij
November-2000	20	325.09	325.09	abcd gh jk
December-2000	15	325.09	325.07	abcd gh jkl
January-2001	10	325.10	325.10	abcd ghi klm
February-2001	35	325.09	325.09	abcd gh jklmn
March-2001	105	325.11	325.11	c ghijklm o

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 42b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for red oak (*Quercus rubra*) "finished blank" length for target length 325 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	104	0.0469
February-2000	50	0.0610
March-2000	125	0.0580
April-2000	83	0.0850
May-2000	10	0.0310
June-2000	--*	--*
July-2000	10	0.0442
August-2000	55	0.0703
September-2000	40 (80)**	0.0716 (0.0542)**
October-2000	40	0.0541
November-2000	20	0.0500
December-2000	15	0.0538
January-2001	10	0.0354
February-2001	35	0.0326
March-2001	105	0.0388

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 43b. Averages and medians by month for red oak (*Quercus rubra*) "veneer-slat" thickness for target length 215 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	150	3.59	3.59	a
February-2000	40	3.61	3.63	b
March-2000	130	3.57	3.58	a c
April-2000	270	3.53	3.54	d
May-2000	71	3.52	3.52	e
June-2000	139	3.56	3.56	c f
July-2000	--*	--*	--*	--*
August-2000	--*	--*	--*	--*
September-2000	--*	--*	--*	--*
October-2000	50	3.53	3.54	de j
November-2000	30	3.55	3.56	cd f jk
December-2000	20	3.60	3.61	abc l
January-2001	70	3.59	3.59	abc lm
February-2001	46	3.54	3.54	d f jk mn
March-2001	130	3.54	3.54	d jk no

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 44b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for red oak (*Quercus rubra*) "veneer-slat" thickness for target length 215 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	150	0.0675
February-2000	40	0.0886
March-2000	130	0.0866
April-2000	270	0.0736
May-2000	71	0.0830
June-2000	139	0.0717
July-2000	--*	--*
August-2000	--*	--*
September-2000	--*	--*
October-2000	50	0.0711
November-2000	30	0.0539
December-2000	20	0.0819
January-2001	70	0.0804
February-2001	46	0.0616
March-2001	130	0.0530

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 45b. Averages and medians by month for red oak (*Quercus rubra*) "veneer-slat" thickness for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	139	3.59	3.59	a
February-2000	80	3.58	3.59	ab
March-2000	160	3.56	3.57	bc
April-2000	180	3.55	3.56	cd
May-2000	50	3.54	3.56	cde
June-2000	30	3.54	3.53	cdef
July-2000	--*	--*	--*	--*
August-2000	--*	--*	--*	--*
September-2000	90 (160)**	3.56 (3.58)**	3.58 (3.59)**	abcd f i
October-2000	69	3.55	3.54	cdef j
November-2000	20	3.52	3.55	bcdef jk
December-2000	40	3.51	3.51	f kl
January-2001	60	3.60	3.59	ab i m
February-2001	20	3.57	3.57	abcdef i k mn
March-2001	80	3.55	3.55	def jk o

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 46b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for red oak (*Quercus rubra*) "veneer-slat" thickness for target length 270 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	139	0.0860
February-2000	80	0.0629
March-2000	160	0.0939
April-2000	180	0.0721
May-2000	50	0.0695
June-2000	30	0.1012
July-2000	--*	--*
August-2000	--*	--*
September-2000	90 (160)**	0.0726 (0.0894)**
October-2000	69	0.0809
November-2000	20	0.0800
December-2000	40	0.0747
January-2001	60	0.1028
February-2001	20	0.0524
March-2001	80	0.0425

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 47b. Averages and medians by month for red oak (*Quercus rubra*) "veneer-slat" thickness for target length 325 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	200	3.58	3.59	a
February-2000	90	3.57	3.58	ab
March-2000	240	3.56	3.56	c
April-2000	140	3.56	3.56	bcd
May-2000	10	3.55	3.57	abcde
June-2000	120	3.54	3.54	a ef
July-2000	--*	--*	--*	--*
August-2000	--*	--*	--*	--*
September-2000	40 (160)**	3.57 (3.62)**	3.58 (3.62)**	abcde i
October-2000	70	3.56	3.56	bcdef j
November-2000	50	3.52	3.51	ef k
December-2000	30	3.57	3.59	abcde ij l
January-2001	90	3.59	3.60	a e i lm
February-2001	70	3.54	3.54	ef ik n
March-2001	90	3.53	3.54	e k no

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 48b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for red oak (*Quercus rubra*) "veneer-slat" thickness for target length 325 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	200	0.0960
February-2000	90	0.0700
March-2000	240	0.0802
April-2000	140	0.0641
May-2000	10	0.0633
June-2000	120	0.0801
July-2000	--*	--*
August-2000	--*	--*
September-2000	40 (160)**	0.0660 (0.1046)**
October-2000	70	0.0617
November-2000	50	0.0855
December-2000	30	0.0729
January-2001	90	0.0679
February-2001	70	0.0513
March-2001	90	0.0513

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 49b. Averages and medians by month for white oak (*Quercus alba*) "finished blank" thickness for target length 215 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Medians	Non-parametric Wilcoxon Comparisons Test**
January-2000	70	24.07	24.11	a
February-2000	15	24.15	24.15	ab
March-2000	35	24.07	24.02	a c
April-2000	49	24.11	24.11	ab d
May-2000	--*	--*	--*	--*
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	20	24.06	24.08	ab de h
September-2000	10	24.19	24.16	abc i
October-2000	--*	--*	--*	--*
November-2000	10	24.73	24.74	k
December-2000	--*	--*	--*	--*
January-2001	60	24.20	24.20	b i m
February-2001	50	24.19	24.21	b i mn
March-2001	60	24.17	24.17	b i m o

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 50b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for white oak (*Quercus alba*) "finished blank" thickness for target length 215 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	70	0.2022
February-2000	15	0.1003
March-2000	35	0.1688
April-2000	49	0.1026
May-2000	--*	--*
June-2000	--*	--*
July-2000	--*	--*
August-2000	20	0.1338
September-2000	10	0.1031
October-2000	--*	--*
November-2000	10	0.0725
December-2000	--*	--*
January-2001	60	0.0893
February-2001	50	0.0821
March-2001	60	0.0973

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 51b. Averages and medians by month for white oak (*Quercus alba*) "finished blank" thickness for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	55	24.14	24.12	a
February-2000	10	24.08	24.06	ab
March-2000	80	24.02	24.02	bc
April-2000	55	23.97	23.91	d
May-2000	--*	--*	--*	--*
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	10	24.27	24.28	h
September-2000	--*	--*	--*	--*
October-2000	30	24.40	24.43	j
November-2000	40	24.18	24.20	b h k
December-2000	30	24.09	24.08	b l
January-2001	30	24.05	24.13	abc lm
February-2001	80 (138)**	24.27 (24.18)**	24.29 (24.19)**	hj n
March-2001	30	24.23	24.21	h k o

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 52b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for white oak (*Quercus alba*) "finished blank" thickness for target length 270 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	55	0.1280
February-2000	10	0.1699
March-2000	80	0.1992
April-2000	55	0.1610
May-2000	--*	--*
June-2000	--*	--*
July-2000	--*	--*
August-2000	10	0.0389
September-2000	--*	--*
October-2000	30	0.2060
November-2000	40	0.1736
December-2000	30	0.1357
January-2001	30	0.2173
February-2001	80 (138)**	0.1546 (0.0828)**
March-2001	30	0.0973

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 53b. Averages and medians by month for white oak (*Quercus alba*) "finished blank" thickness for target length 325 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	105	24.02	24.04	a
February-2000	25	24.12	24.10	ab
March-2000	40	24.05	24.04	abc
April-2000	56	24.12	24.11	b d
May-2000	--*	--*	--*	--*
June-2000	--*	--*	--*	--*
July-2000	9	24.82	24.82	g
August-2000	20	24.41	24.41	h
September-2000	10	24.11	24.10	abcd i
October-2000	10	24.76	24.72	g j
November-2000	--*	--*	--*	--*
December-2000	20	24.13	24.13	bcd i l
January-2001	50	24.27	24.26	m
February-2001	40	24.23	24.28	mn
March-2001	40	24.21	24.22	no

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 54b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for white oak (*Quercus alba*) "finished blank" thickness for target length 325 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	105	0.2034
February-2000	25	0.1001
March-2000	40	0.2090
April-2000	56	0.1580
May-2000	--*	--*
June-2000	--*	--*
July-2000	9	0.0527
August-2000	20	0.0624
September-2000	10	0.0850
October-2000	10	0.1021
November-2000	--*	--*
December-2000	20	0.1187
January-2001	50	0.0868
February-2001	40	0.1348
March-2001	40	0.0818

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 55b. Averages and medians by month for white oak (*Quercus alba*) "finished blank" width for target length 215 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	70	65.20	65.19	a
February-2000	15	65.14	65.14	b
March-2000	35	65.17	65.17	c
April-2000	50	65.18	65.18	cd
May-2000	--*	--*	--*	--*
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	20	65.13	65.12	b h
September-2000	10	65.17	65.18	a cd i
October-2000	--*	--*	--*	--*
November-2000	10	65.20	65.22	a d h k
December-2000	--*	--*	--*	--*
January-2001	60	65.17	65.16	cd h m
February-2001	50	65.16	65.17	cd h k mn
March-2001	60	65.18	65.18	cd h k mno

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 56b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for white oak (*Quercus alba*) "finished blank" width for target length 215 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	70	0.0517
February-2000	15	0.0337
March-2000	35	0.0345
April-2000	50	0.0483
May-2000	--*	--*
June-2000	--*	--*
July-2000	--*	--*
August-2000	20	0.0339
September-2000	10	0.0300
October-2000	--*	--*
November-2000	10	0.0492
December-2000	--*	--*
January-2001	60	0.0536
February-2001	50	0.0319
March-2001	60	0.0359

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 57b. Averages and medians by month for white oak (*Quercus alba*) "finished blank" width for target length 270 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	55	65.17	65.17	a
February-2000	10	65.19	65.19	ab
March-2000	80	65.17	65.17	abc
April-2000	55	65.14	65.15	d
May-2000	--*	--*	--*	--*
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	10	65.17	65.18	abcd h
September-2000	--*	--*	--*	--*
October-2000	30	65.18	65.19	abcd hj
November-2000	40	65.16	65.16	a cd hjk
December-2000	30	65.16	65.17	ab d hj l
January-2001	30	65.19	65.19	bc hj lm
February-2001	78 (69)**	65.18 (65.20)**	65.18 (65.19)**	abc hjklmn
March-2001	30	65.17	65.18	abc hjklmno

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 58b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for white oak (*Quercus alba*) "finished blank" width for target length 270 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	55	0.0523
February-2000	10	0.0145
March-2000	80	0.0316
April-2000	55	0.0492
May-2000	--*	--*
June-2000	--*	--*
July-2000	--*	--*
August-2000	10	0.0275
September-2000	--*	--*
October-2000	30	0.0424
November-2000	40	0.0463
December-2000	30	0.0636
January-2001	30	0.0195
February-2001	78 (69)	0.0493 (0.0478)
March-2001	30	0.0395

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 59b. Averages and medians by month for white oak (*Quercus alba*) "finished blank" width for target length 325 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	105	65.19	65.18	a
February-2000	25	65.16	65.17	ab
March-2000	40	65.15	65.15	bc
April-2000	56	65.16	65.16	bcd
May-2000	--*	--*	--*	--*
June-2000	--*	--*	--*	--*
July-2000	9	65.16	65.16	abcd g
August-2000	20	65.15	65.15	bcd gh
September-2000	10	65.19	65.20	abc g i
October-2000	10	65.16	65.16	ab d ghij
November-2000	--*	--*	--*	--*
December-2000	20	65.12	65.12	l
January-2001	50	65.17	65.17	ab d g ij m
February-2001	40	65.16	65.17	abcd ghij mn
March-2001	40	65.16	65.18	ab d g ij mno

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 60b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for white oak (*Quercus alba*) "finished blank" width for target length 325 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	105	0.0739
February-2000	25	0.0326
March-2000	40	0.0301
April-2000	56	0.0485
May-2000	--*	--*
June-2000	--*	--*
July-2000	9	0.0199
August-2000	20	0.0340
September-2000	10	0.0447
October-2000	10	0.0196
November-2000	--*	--*
December-2000	20	0.0459
January-2001	50	0.0407
February-2001	40	0.0383
March-2001	40	0.0406

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 61b. Averages and medians by month for white oak (*Quercus alba*) "finished blank" length for target length 215 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	100	215.10	215.11	a
February-2000	15	215.03	215.02	b
March-2000	45	215.06	215.06	bc
April-2000	126	215.10	215.11	a d
May-2000	80	215.09	215.08	c e
June-2000	--*	--*	--*	--*
July-2000	4	215.09	215.08	abc e g
August-2000	9	215.07	215.05	bc e gh
September-2000	15	215.12	215.12	a d ghi
October-2000	25	215.12	215.12	a d ij
November-2000	23	215.11	215.11	a de ijk
December-2000	5	215.12	215.11	a cde hijkl
January-2001	35	215.12	215.12	a d ijklm
February-2001	15	215.09	215.07	a c e ghi kl n
March-2001	70	215.11	215.12	a d ijklm o

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is co*mpared with each month thereafter.

Table 62b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for white oak (*Quercus alba*) "finished blank" length for target length 215 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	100	0.1155
February-2000	15	0.0658
March-2000	45	0.1043
April-2000	126	0.0656
May-2000	80	0.0669
June-2000	--*	--*
July-2000	4	0.0173
August-2000	9	0.0587
September-2000	15	0.0913
October-2000	25	0.0266
November-2000	23	0.0403
December-2000	5	0.0305
January-2001	35	0.0330
February-2001	15	0.0336
March-2001	70	0.0417

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 63b. Averages and medians by month for white oak (*Quercus alba*) "finished blank" length for target length 270 mm.

Month-Year	**Number of Samples**	**Average (x-bar) in mm**	**Median**	**Non-parametric Wilcoxon Comparisons Test**
January-2000	45	270.12	270.12	a
February-2000	10	270.18	270.18	b
March-2000	80	270.11	270.11	a c
April-2000	105	270.09	270.08	cd
May-2000	50	270.08	270.07	de
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--*	--*	--*	--*
September-2000	--*	--*	--*	--*
October-2000	40	270.11	270.13	a cd j
November-2000	20	270.08	270.09	cde jk
December-2000	10	270.06	270.06	e kl
January-2001	25	270.10	270.09	a cd jk m
February-2001	15 (46)**	270.13 (270.10)**	270.13 (270.10)**	a c j n
March-2001	45	270.12	270.13	a j no

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 64b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for white oak (*Quercus alba*) "finished blank" length for target length 270 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	45	0.0523
February-2000	10	0.0316
March-2000	80	0.0489
April-2000	105	0.0642
May-2000	50	0.0755
June-2000	--*	--*
July-2000	--*	--*
August-2000	--*	--*
September-2000	--*	--*
October-2000	40	0.0610
November-2000	20	0.0506
December-2000	10	0.0327
January-2001	25	0.0298
February-2001	15 (46)**	0.0284 (0.0475)**
March-2001	45	0.0440

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 65b. Averages and medians by month for white oak (*Quercus alba*) "finished blank" length for target length 325 mm.

Month-Year	**Number of Samples**	**Average (x-bar) in mm**	**Median**	**Non-parametric Wilcoxon Comparisons Test**
January-2000	107	325.10	325.10	a
February-2000	25	325.07	325.09	b
March-2000	50	325.08	325.06	bc
April-2000	56	325.09	325.10	abcd
May-2000	--*	--*	--*	--*
June-2000	--*	--*	--*	--*
July-2000	14	325.17	325.10	a d g
August-2000	10	325.06	325.05	bcd h
September-2000	15	325.09	325.09	abcd ghi
October-2000	20	325.10	325.10	ab d g ij
November-2000	20	325.13	325.14	g jk
December-2000	10	325.08	325.08	abcd ghijkl
January-2001	35	325.12	325.12	g jk m
February-2001	20	325.12	325.13	a g ijklmn
March-2001	60	325.10	325.11	a d g ijklmno

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 66b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for white oak (*Quercus alba*) "finished blank" length for target length 325 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	107	0.0565
February-2000	25	0.0411
March-2000	50	0.0976
April-2000	56	0.0709
May-2000	--*	--*
June-2000	--*	--*
July-2000	14	0.2564
August-2000	10	0.0356
September-2000	15	0.0608
October-2000	20	0.0554
November-2000	20	0.0586
December-2000	10	0.0593
January-2001	35	0.0270
February-2001	20	0.0365
March-2001	60	0.0425

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 67b. Averages and medians by month for white oak (*Quercus alba*) "veneer-slat" thickness for target length 215 mm.

Month-Year	**Number of Samples**	**Average (x-bar) in mm**	**Median**	**Non-parametric Wilcoxon Comparisons Test**
January-2000	170	3.57	3.58	a
February-2000	30	3.58	3.60	ab
March-2000	100	3.57	3.56	abc
April-2000	120	3.56	3.57	cd
May-2000	--*	--*	--*	--*
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--*	--*	--*	--*
September-2000	--*	--*	--*	--*
October-2000	49	3.53	3.54	j
November-2000	39	3.60	3.59	ab k
December-2000	10	3.59	3.58	abcd kl
January-2001	20	3.54	3.53	cd j m
February-2001	24	3.57	3.57	abcd kl n
March-2001	43	3.56	3.56	abcd j lmno

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 68b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for white oak (*Quercus alba*) "veneer-slat" thickness for target length 215 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	170	0.0709
February-2000	30	0.0754
March-2000	100	0.0739
April-2000	120	0.0581
May-2000	--*	--*
June-2000	--*	--*
July-2000	--*	--*
August-2000	--*	--*
September-2000	--*	--*
October-2000	49	0.0767
November-2000	39	0.0792
December-2000	10	0.0658
January-2001	20	0.0505
February-2001	24	0.0632
March-2001	43	0.0665

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 69b. Averages and medians by month for white oak (*Quercus alba*) "veneer-slat" thickness for target length 270 mm.

Month-Year	**Number of Samples**	**Average (x-bar) in mm**	**Median**	**Non-parametric Wilcoxon Comparisons Test**
January-2000	120	3.54	3.55	a
February-2000	20	3.61	3.61	b
March-2000	160	3.58	3.58	bc
April-2000	100	3.54	3.54	a d
May-2000	--*	--*	--*	--*
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--*	--*	--*	--*
September-2000	--*	--*	--*	--*
October-2000	79	3.54	3.54	a d j
November-2000	39	3.50	3.51	k
December-2000	50	3.53	3.54	a d jkl
January-2001	80	3.57	3.57	bc m
February-2001	60 (138)**	3.54 (3.53)**	3.54 (3.54)**	a d j l n
March-2001	110	3.53	3.54	a d j l no

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*
**** Rows with dissimilar letters have significantly different medians at an α=0.05, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 70b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for white oak (*Quercus alba*) "veneer-slat" thickness for target length 270 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	120	0.0766
February-2000	20	0.0846
March-2000	160	0.0859
April-2000	100	0.0617
May-2000	--*	--*
June-2000	--*	--*
July-2000	--*	--*
August-2000	--*	--*
September-2000	--*	--*
October-2000	79	0.0656
November-2000	39	0.0793
December-2000	50	0.0953
January-2001	80	0.0684
February-2001	60 (138)**	0.0555 (0.0695)**
March-2001	110	0.0488

**Blank cell indicates no data was available.*
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

Table 71b. Averages and medians by month for white oak (*Quercus alba*) "veneer-slat" thickness for target length 325 mm.

Month-Year	Number of Samples	Average (x-bar) in mm	Median	Non-parametric Wilcoxon Comparisons Test
January-2000	210	3.57	3.58	a
February-2000	50	3.59	3.59	ab
March-2000	90	3.58	3.57	abc
April-2000	140	3.56	3.57	a cd
May-2000	--*	--*	--*	--*
June-2000	--*	--*	--*	--*
July-2000	--*	--*	--*	--*
August-2000	--*	--*	--*	--*
September-2000	--*	--*	--*	--*
October-2000	58	3.56	3.56	a cd j
November-2000	39	3.60	3.61	bc k
December-2000	20	3.50	3.50	l
January-2001	80	3.57	3.57	abcd j m
February-2001	60	3.54	3.54	j l n
March-2001	110	3.53	3.54	l no

**Blank cell indicates no data was available.*

*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

**** Rows with dissimilar letters have significantly different medians at an $\alpha=0.05$, i.e., "a" is for January-2000 and is compared with each month thereafter, "b" is for February-2000 and is com*pared with each month thereafter.

Table 72b. Standard deviations (mm), *s*, and sample sizes, *n*, by month for white oak (*Quercus alba*) "veneer-slat" thickness for target length 325 mm.

Month-Year	Number of Samples	Standard Deviation
January-2000	210	0.0859
February-2000	50	0.0856
March-2000	90	0.0922
April-2000	140	0.0694
May-2000	--*	--*
June-2000	--*	--*
July-2000	--*	--*
August-2000	--*	--*
September-2000	--*	--*
October-2000	58	0.0685
November-2000	39	0.0857
December-2000	20	0.0798
January-2001	80	0.0684
February-2001	60	0.0555
March-2001	110	0.0488

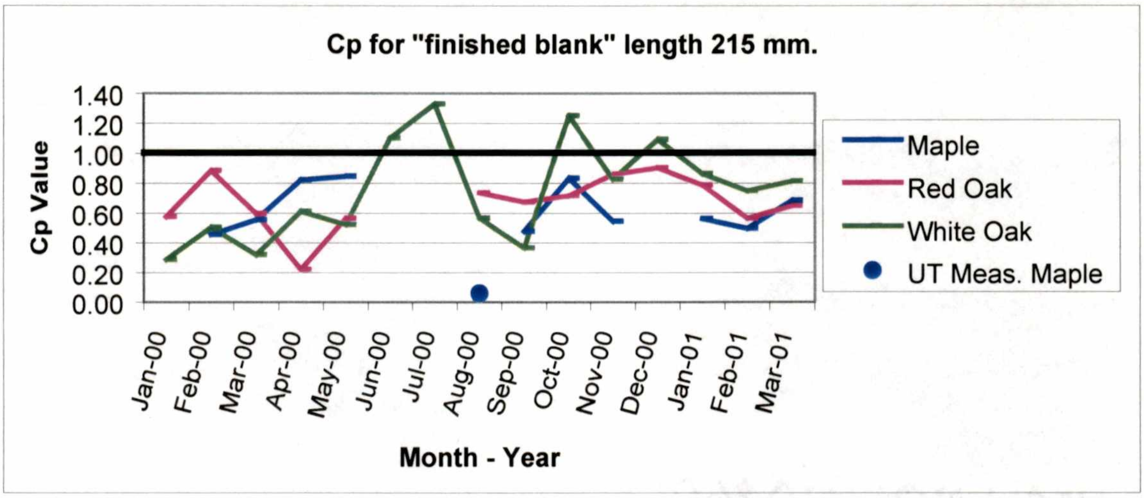
**Blank cell indicates no data was available.*

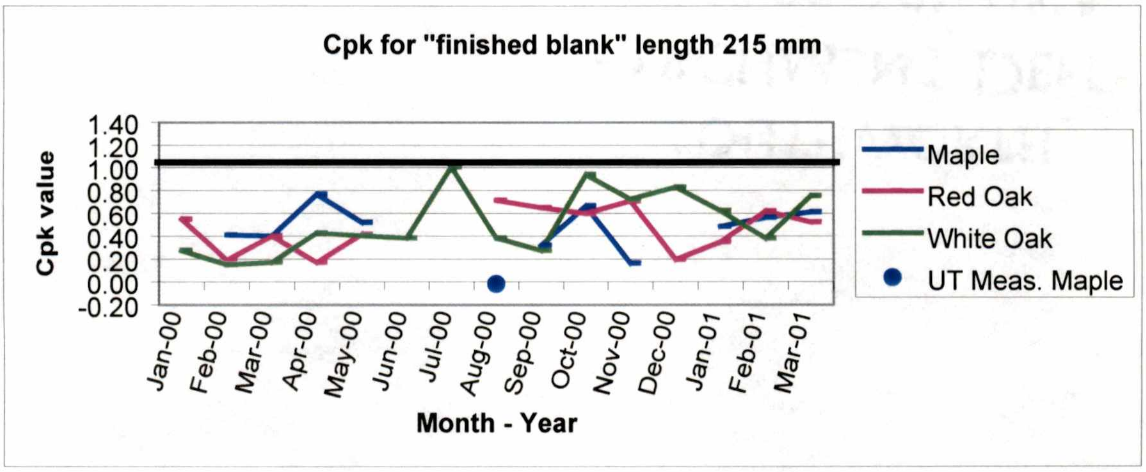
*** Statistics in parenthesis were estimates that were taken as part of a sampling study.*

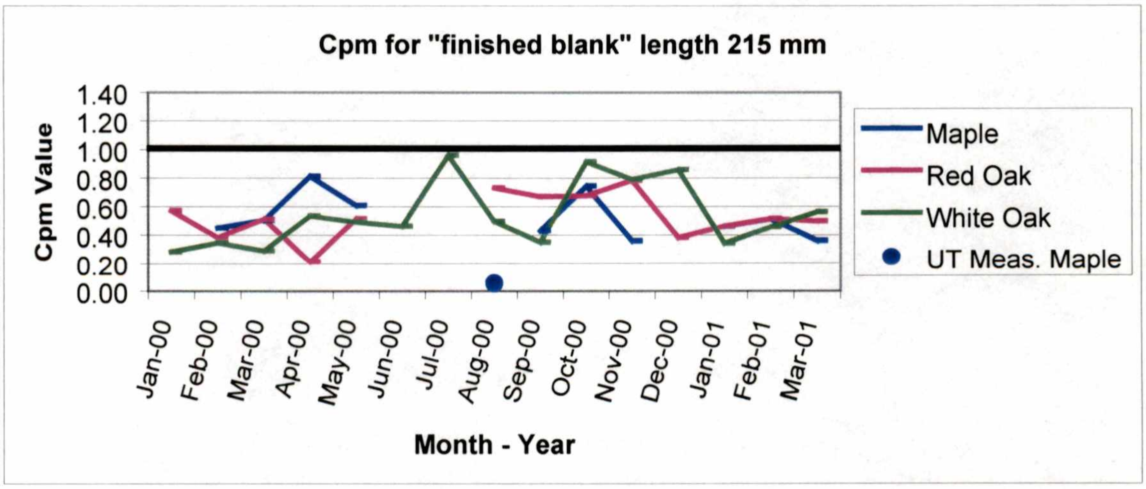
Appendix C

(Graphs 1c to 9c)

Graph 1c. Capability indices for "finished blank" length for target length 215 mm.

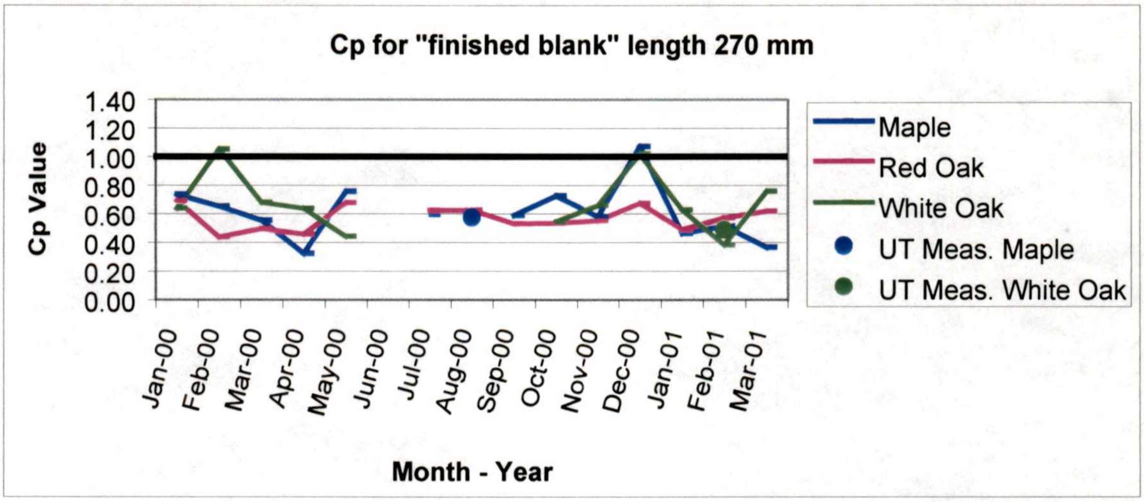


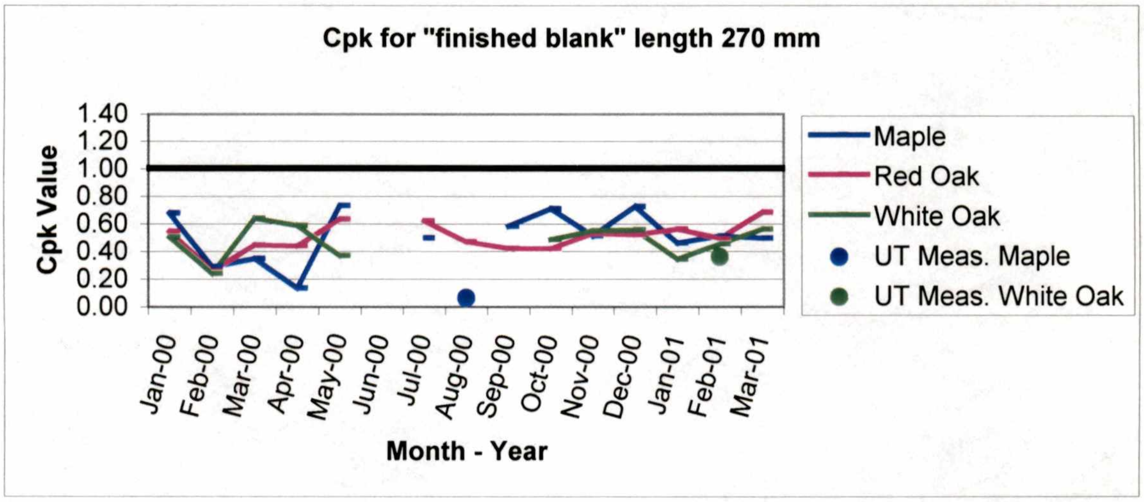


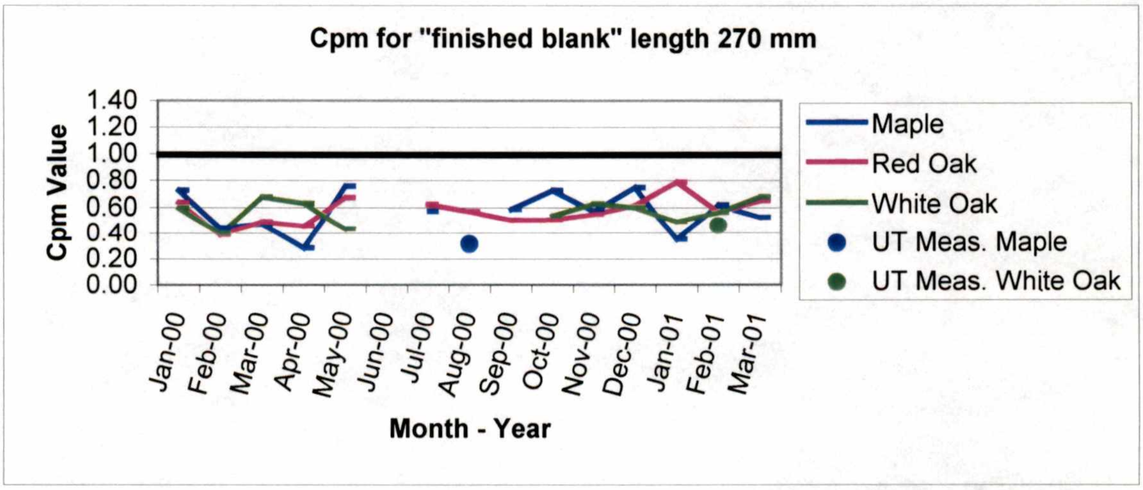


Note: C_p, C_{pk}, or C_{pm} value equal to 1 indicates process is capable.

Graph 2c. Capability indices for "finished blank" length for target length 270 mm.

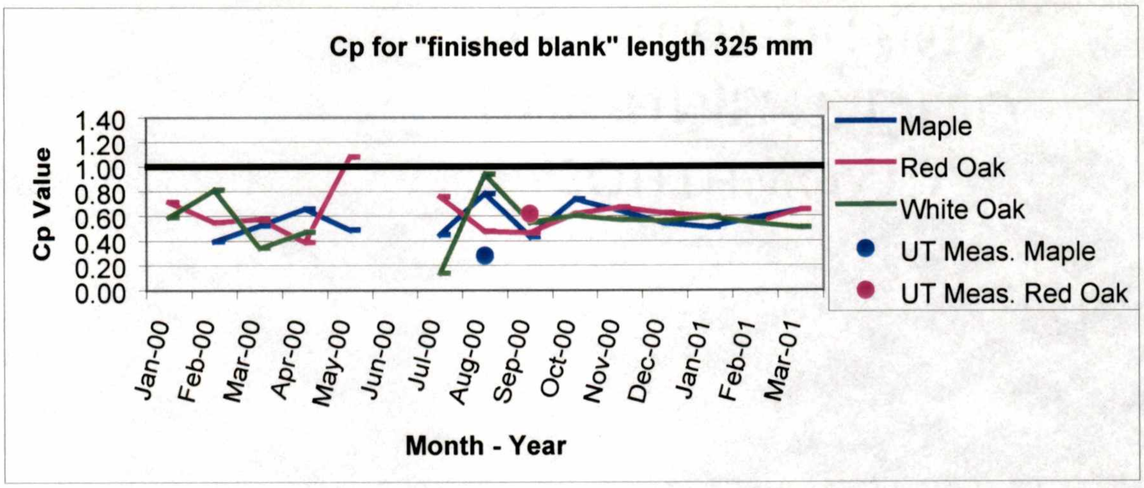


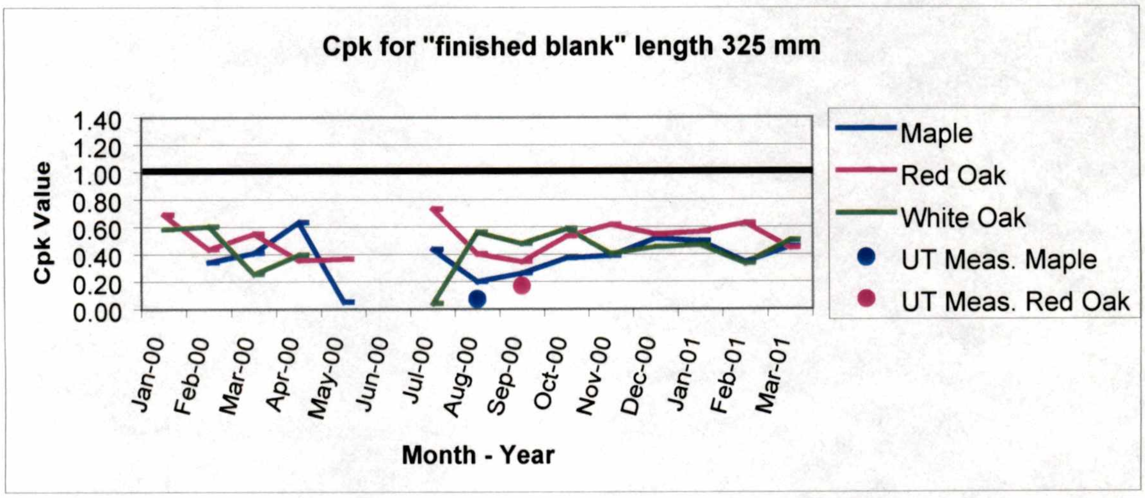


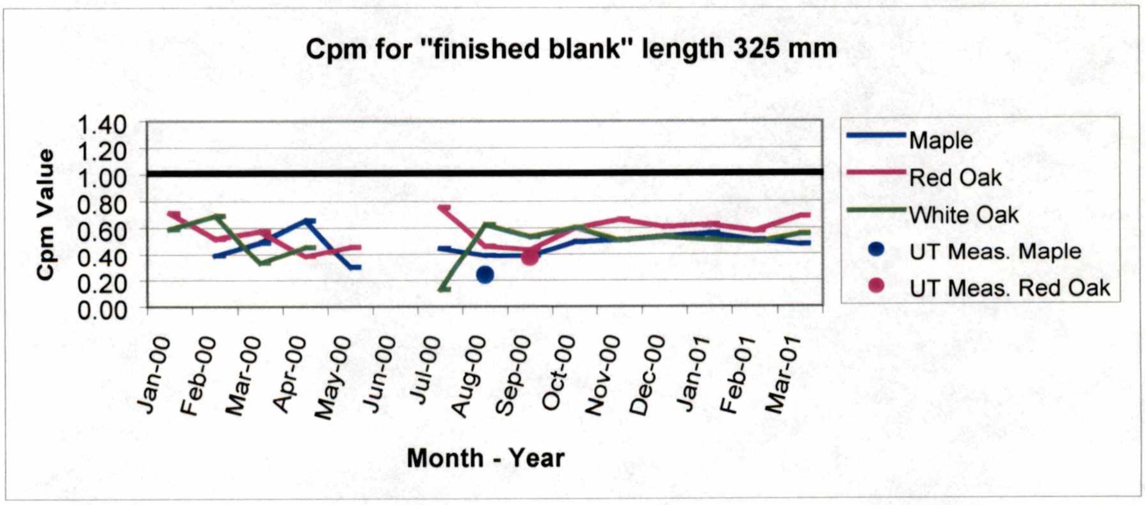


Note: C_p, C_{pk}, or C_{pm} value equal to 1 indicates process is capable.

Graph 3c. Capability indices for "finished blank" length for target length 325 mm.

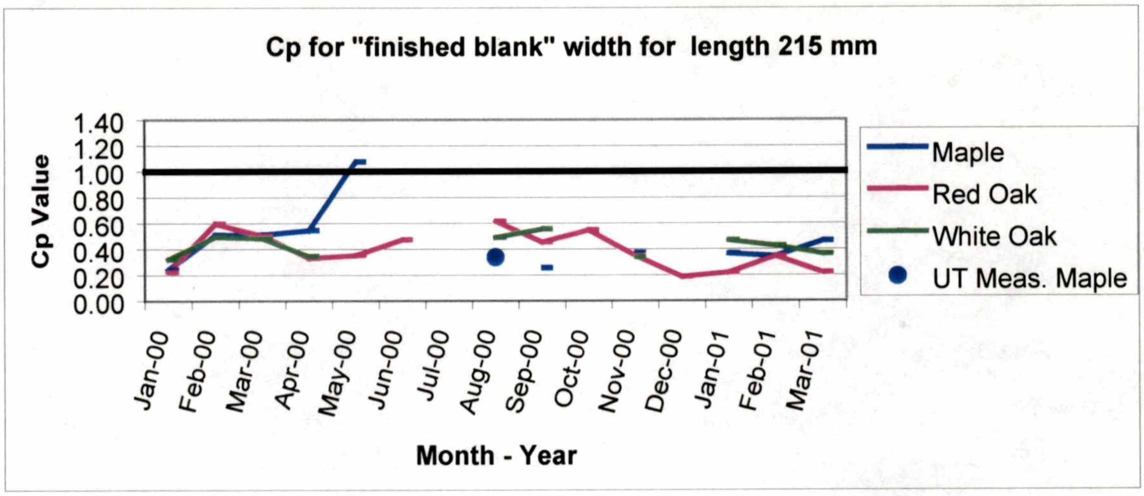


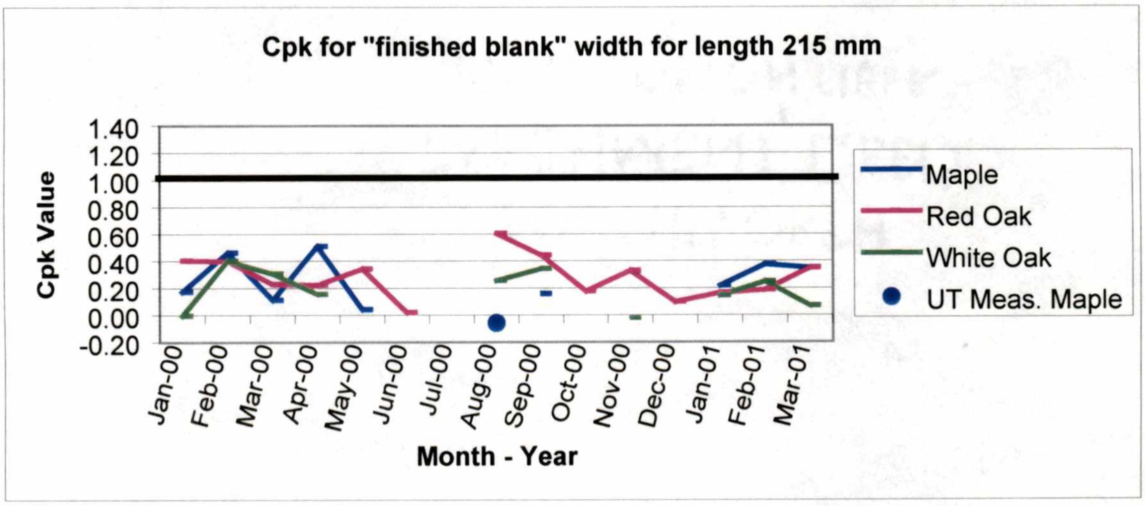


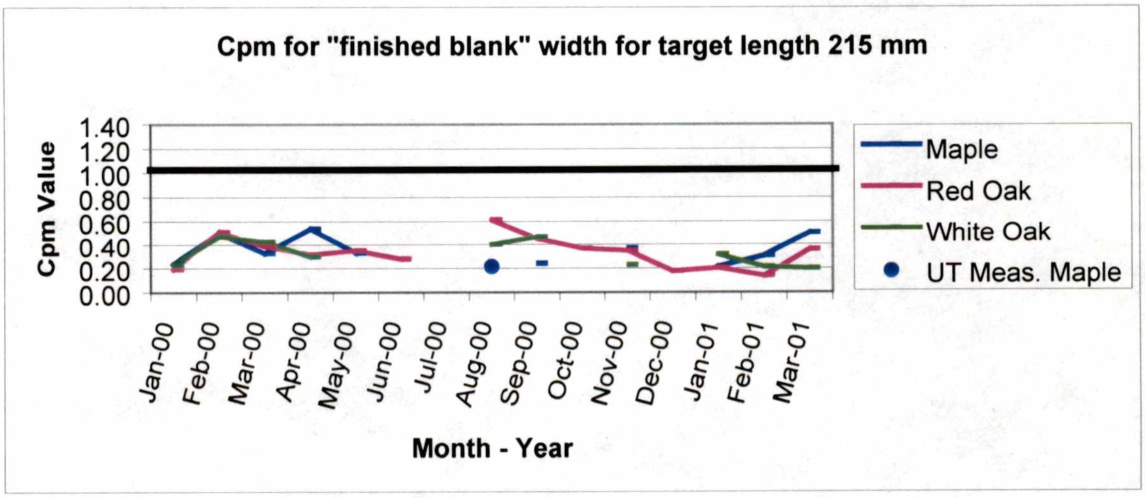


Note: C_p, C_{pk}, or C_{pm} value equal to 1 indicates process is capable.

Graph 4c. Capability indices for "finished blank" width for target length 215 mm.

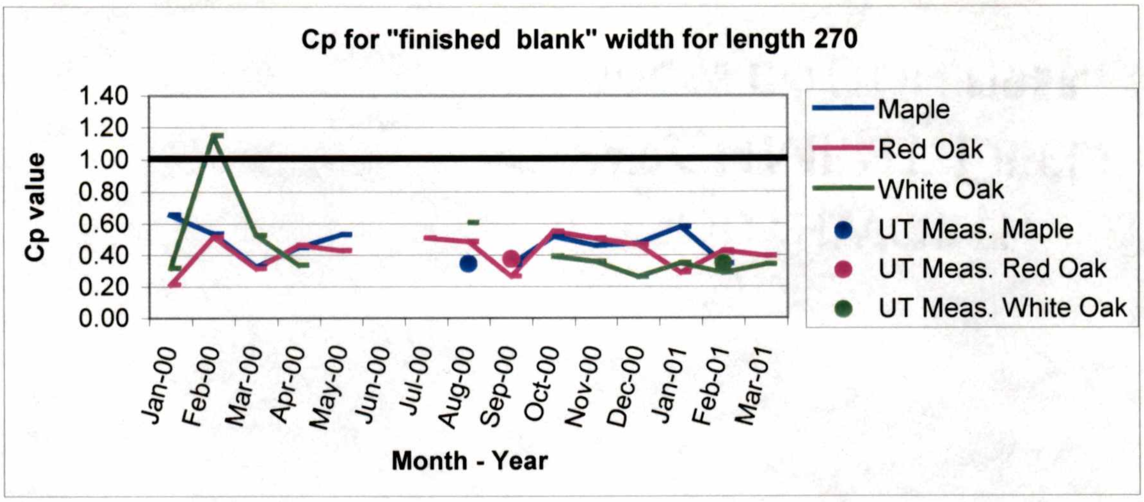


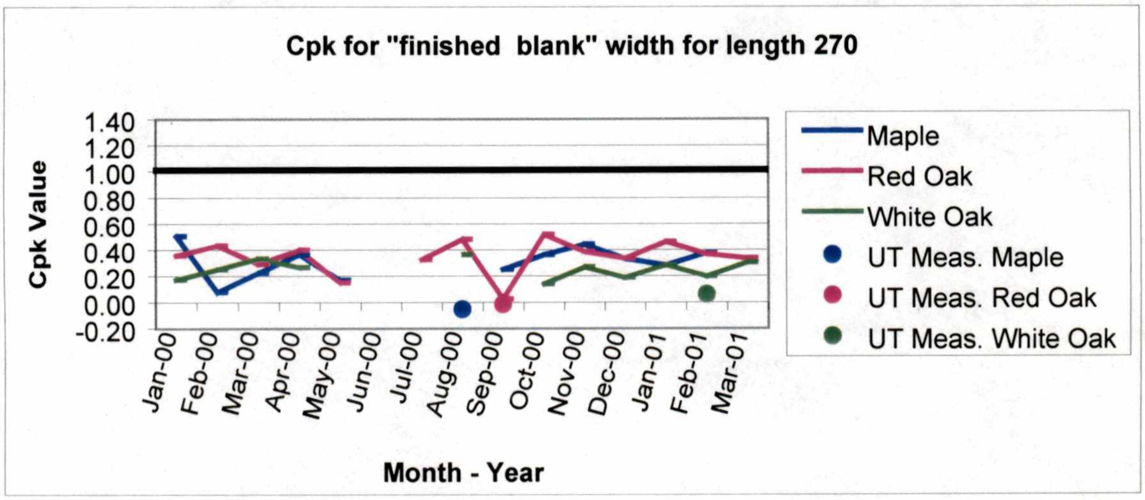


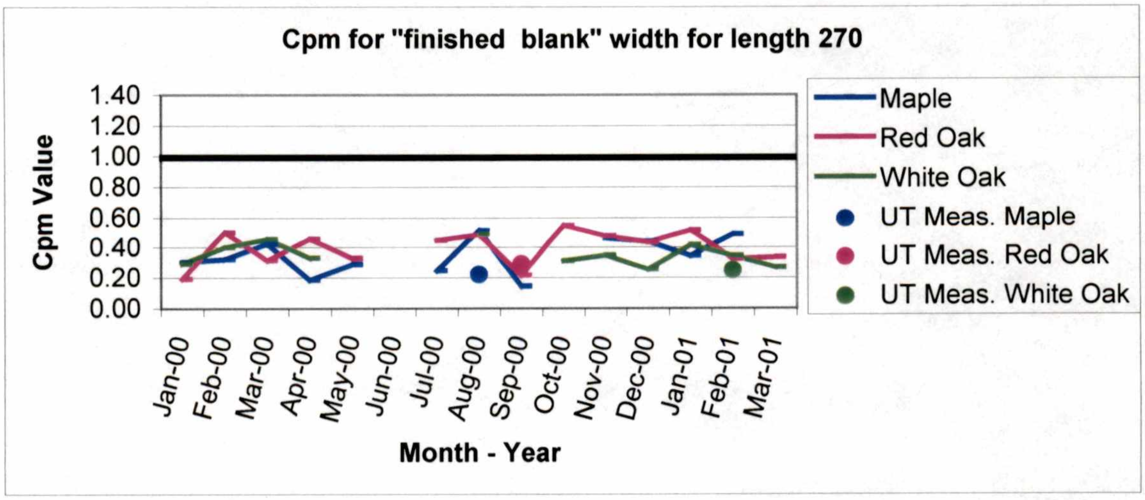


Note: C_p, C_{pk}, or C_{pm} value equal to 1 indicates process is capable.

Graph 5c. Capability indices for "finished blank" width for target length 270 mm.

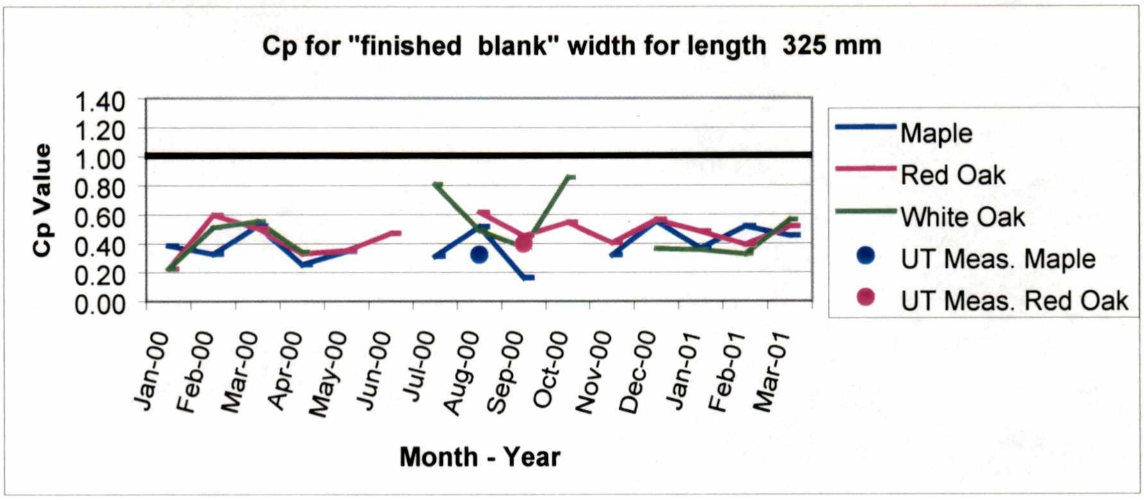


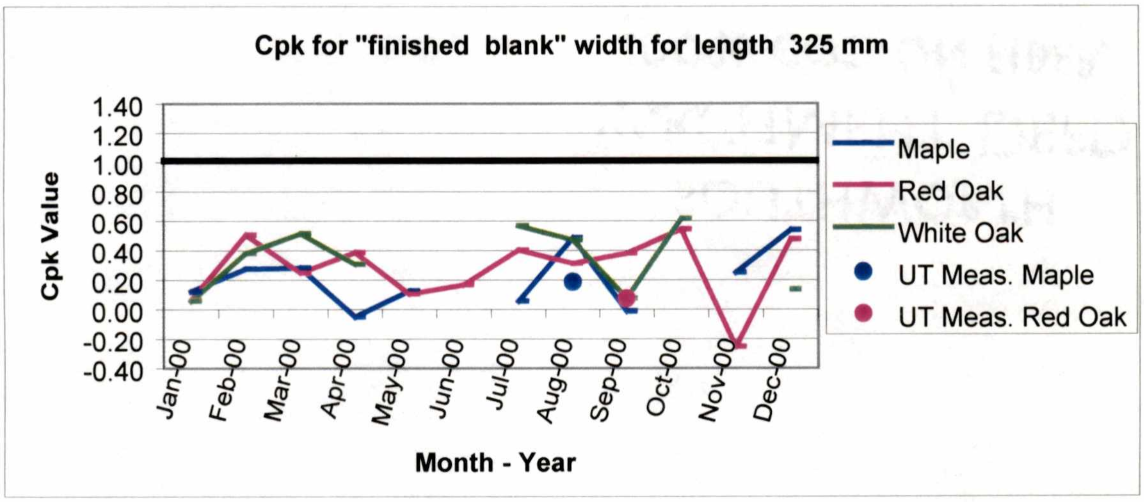


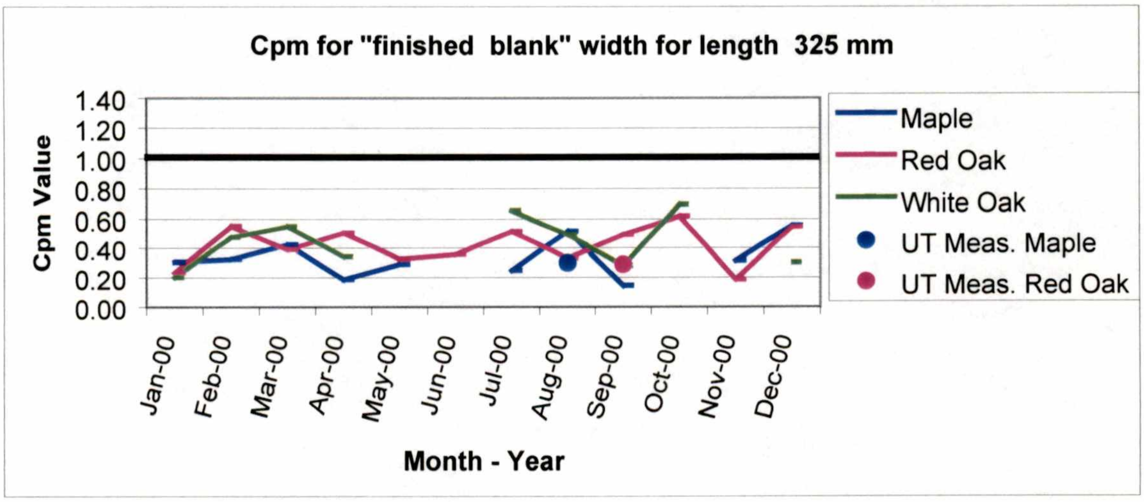


Note: C_p, C_{pk}, or C_{pm} value equal to 1 indicates process is capable.

Graph 6c. Capability indices for "finished blank" width for target length 325 mm.

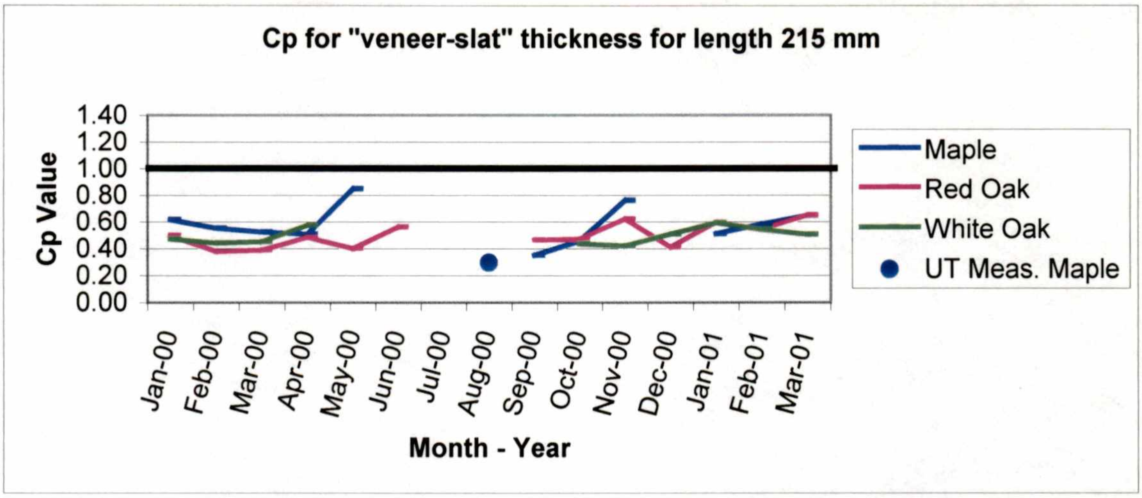


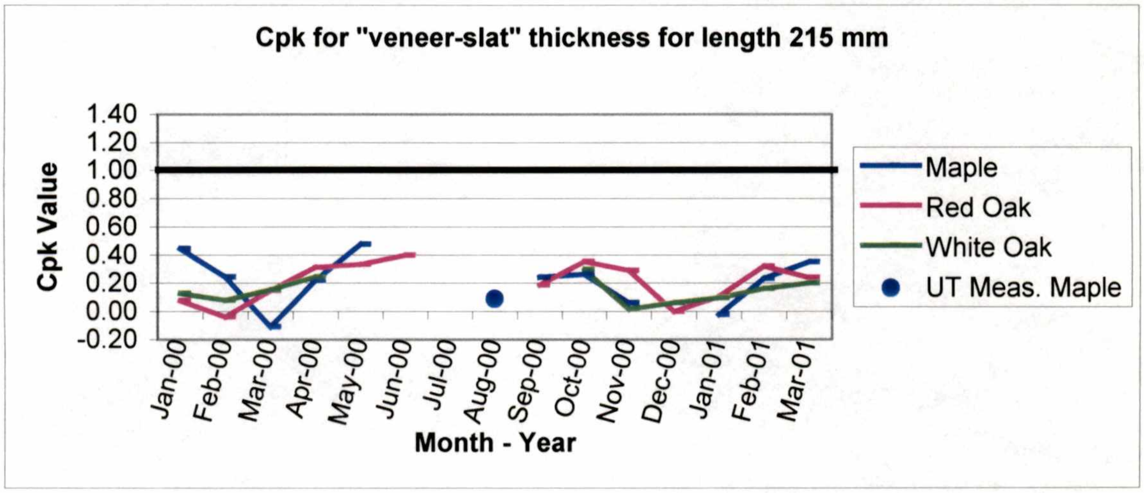


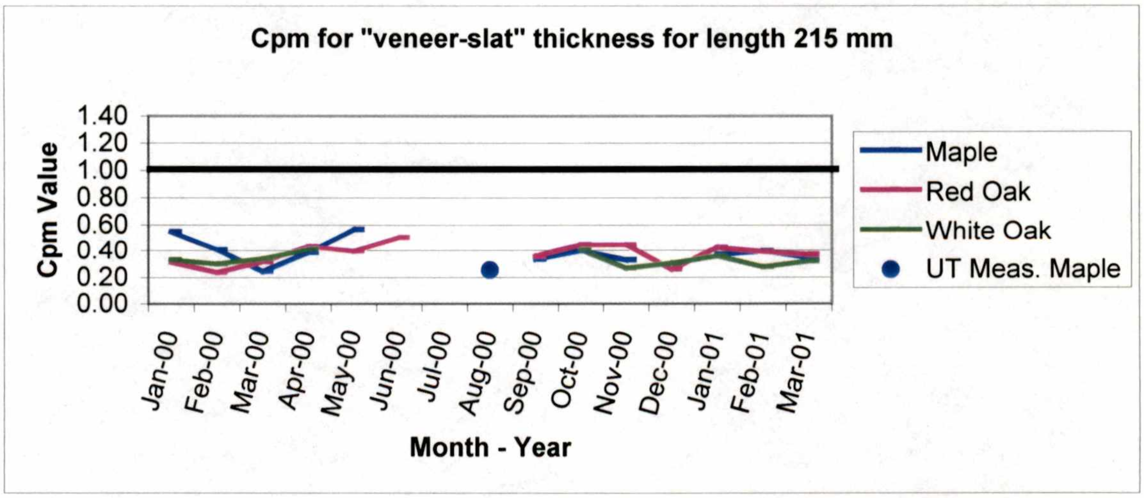


Note: C_p, C_{pk}, or C_{pm} value equal to 1 indicates process is capable.

Graph 7c. Capability indices for "veneer-slat" thickness for target length 215 mm.

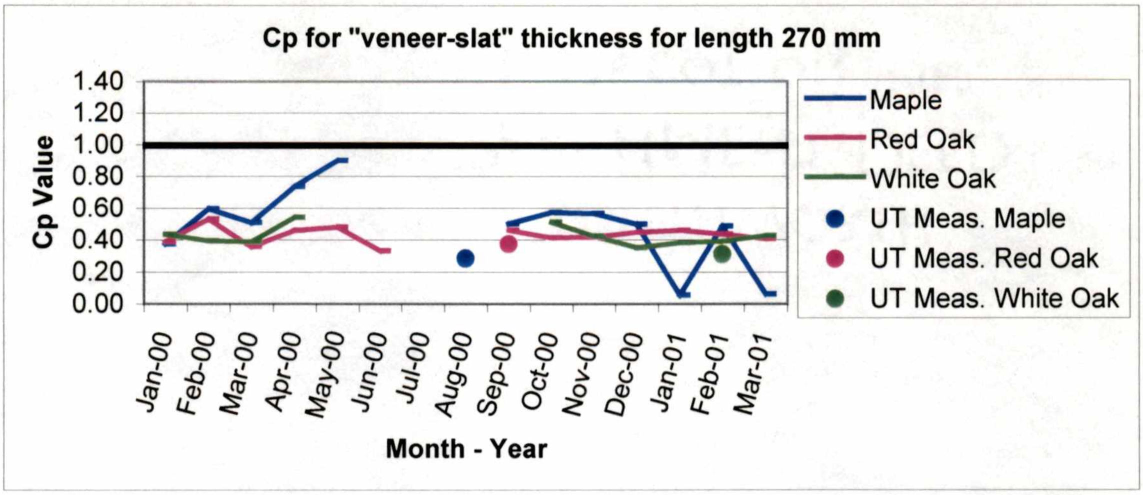


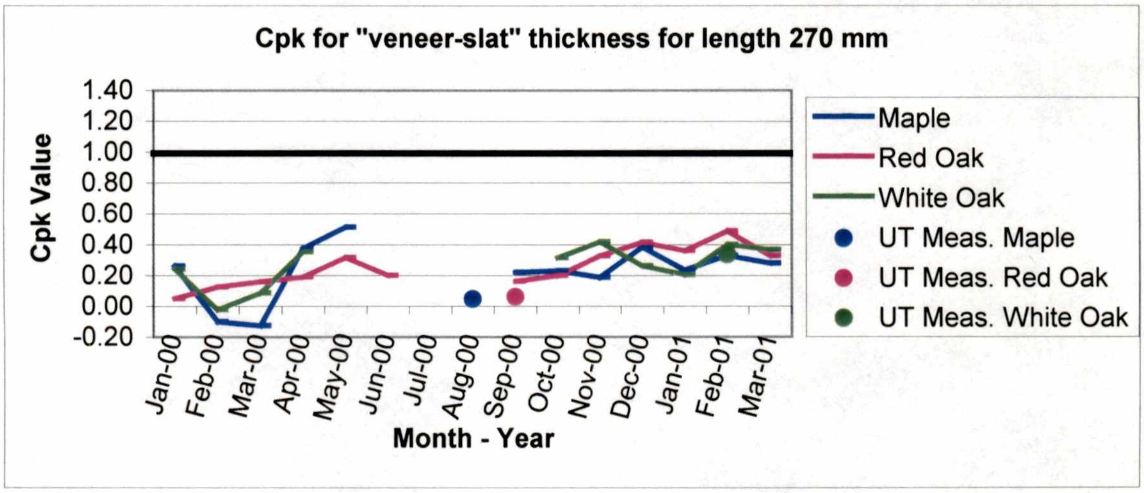


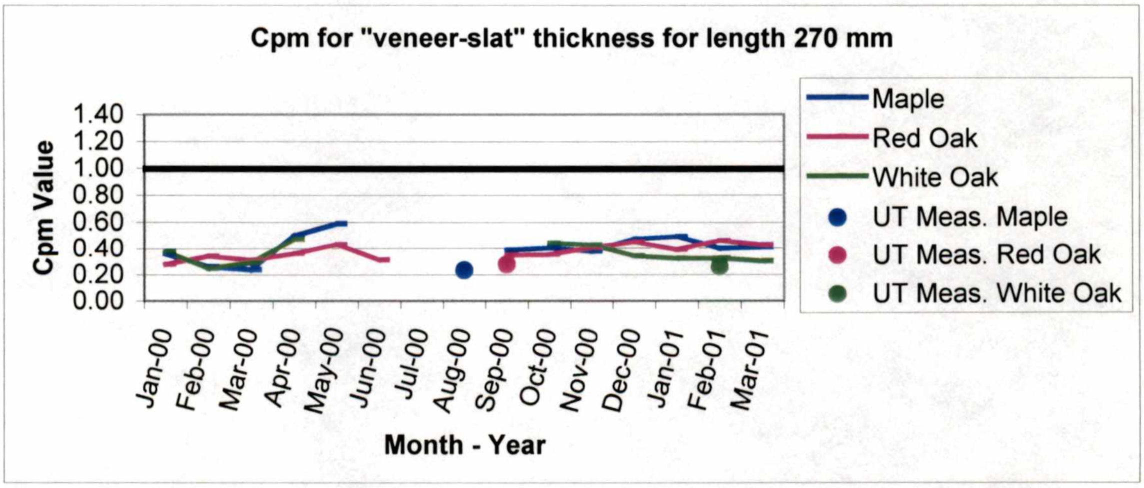


Note: C_p, C_{pk}, or C_{pm} value equal to 1 indicates process is capable.

Graph 8c. Capability indices for "veneer-slat" thickness for target length 270 mm.

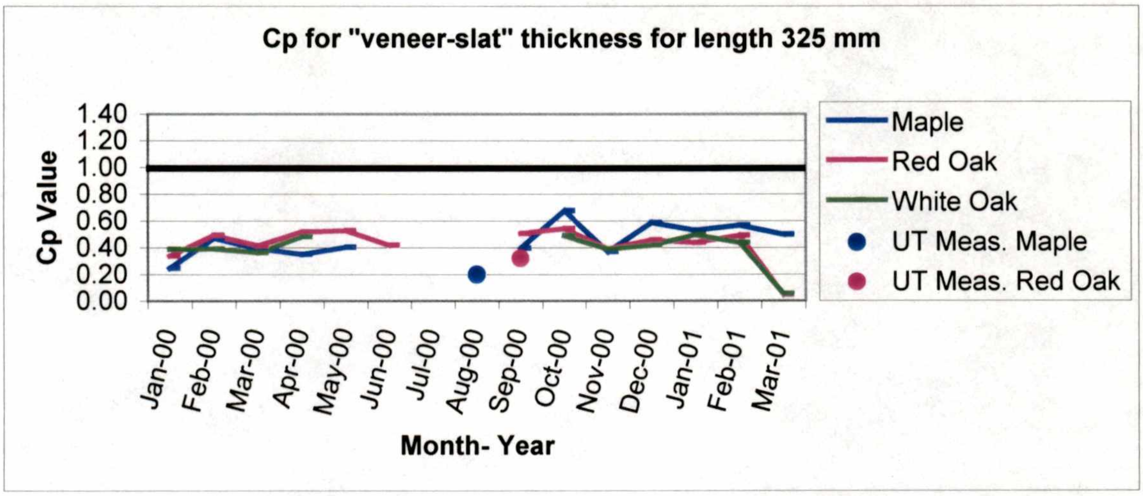


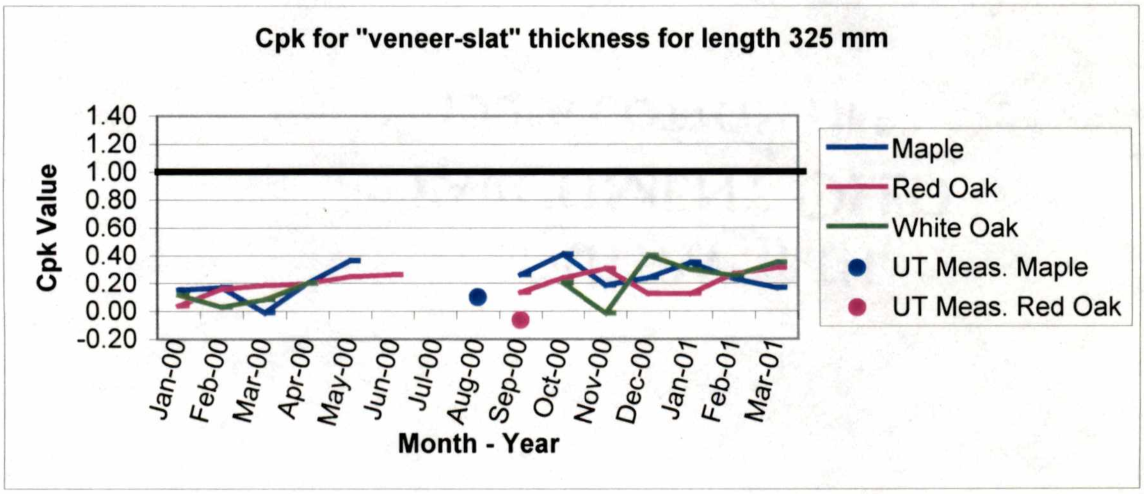


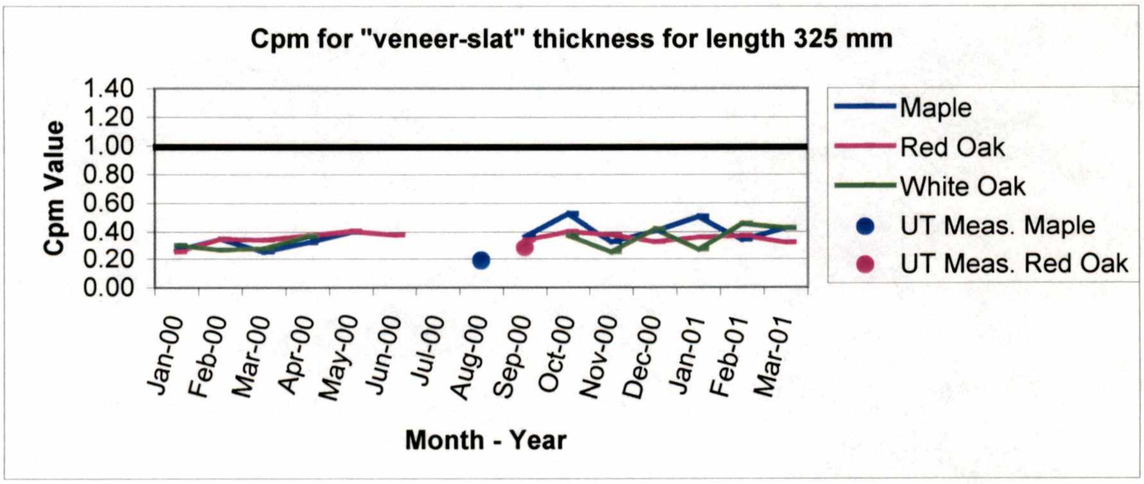


Note: C_p, C_{pk}, or C_{pm} value equal to 1 indicates process is capable.

Graph 9c. Capability indices for “veneer-slat” thickness for target length 325 mm.







Note: C_p, C_{pk}, or C_{pm} value equal to 1 indicates process is capable.

VITA

Thomas N. Williams was born in Corning, New York on February 10, 1975. He attended a boarding school in Mercersburg, PA, graduating from The Mercersburg Academy High School in June 1994. He entered the University of Tennessee in June, earning a Bachelor of Science in Forestry with a concentration in Wood Utilization. In August of 1999, he entered the masters program in Tennessee Forest Products Center at the University of Tennessee. He graduated with a Masters of Science in Forestry with a minor in Statistics and a concentration in wood utilization and management. Upon graduation he started working with Georgia-Pacific Corporation working as a Quality Control Manager in Oxford, Mississippi.