Impact of Ellipticality on Lumber Grade and Volume Recovery

For Red Oak Logs

By

Roncs Ese-Etame

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Approved:

Brian H. Bond, Chair

Janice K.Wiedenbeck　　　　Robert L. Smith

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Abstract

Hardwood sawmills must become more efficient to remain competitive. One way to increase efficiency and competitiveness is to increase the value or lumber volume produced from logs. While methods to maximize value and volume recovery exist for round logs, little information exists on how to maximize these outcomes for logs with ellipticality.

The goal of this research was to determine the impact of low and high degrees of ellipticality on green lumber grade and volume recovery for red oak logs under current sawing methods. Logs of low and high ellipticality were selected and processed at four Appalachian area sawmills. Processing variables and lumber output were tracked for all logs.

It was determined that there was no significant difference in overrun, lumber volume, lumber value, and lumber grade between low and high ellipticality logs when comparing the log output at all four sawmills. It was determined that how an individual sawmill processes logs affects the outcome between logs with high and low ellipticality. None of the sawmills produced more value for high elliptical logs than for low elliptical logs and it was possible to produce more lumber volume and value with low elliptical logs.

Highly elliptical logs required more processing time than low ellipticality logs in terms of log turns, total elapsed time at the headrig, and number of sawlines at the headrig. The increased processing time results in increased processing costs which were estimated to be $1.28 to $11.33 per log. These costs were not offset by an increase in lumber volume nor lumber value; therefore, highly elliptical sawlogs are less desirable to process than low elliptical logs using current sawing methods.

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CHAPTER 1 - INTRODUCTION

1.1 - Problem statement

Research has shown that stumpage prices continue to increase faster than lumber prices in the U.S. hardwood sawmill industry. Because of this, profit margins in sawmilling have decreased, forcing lumber producers to be more efficient or go out of business (Luppold et al., 1998). Loss of traditional markets and pressure from foreign competition is also forcing sawmills to become more efficient and competitive. Among the many ways to improve efficiency in lumber production is to maximize volume and grade recovery from logs. Much research has been done to determine optimal grade and volume recovery for round logs. Wagner and Taylor (1993) reported that despite the importance of log shape to the sawmill industry, no definitive research has been conducted to determine the relative roundness, straightness, or taper of sawlogs in different regions of the United States. Recent research has demonstrated that the average sawlog in West Virginia and Ohio contains moderate ellipticality and that 43% were categorized as being highly elliptical (Bond et al., 2006). Research carried out by Zheng et al. (1989) demonstrated that over 70% of the logs examined in China were actually elliptical or oval in shape. Despite this knowledge, most current sawing practices are based upon the assumption that logs are circular in cross section.

It is believed that sawyers currently process elliptical logs using the same methods as those used on round logs. In hardwood sawmills a sawyer typically tries to maximize the lumber value by rotating the log to move visible external defects in area that will maximize the volume of high value lumber. The affect on lumber grade and volume yield for processing non-round hardwood logs is not well documented and there is a need for better understanding of how different sawing patterns could optimize lumber volume and grade yield.

Known factors affecting the yield of lumber from “round” logs for current sawing practices are: log diameter, log taper, log sweep and crook, log breakdown decisions, saw kerf, sawing method, saw operator, and sawing variation. With this large number of variables, it is hypothesized that ellipticality will likely affect lumber volume recovery and lumber value yield.

Common sawing practices assume that logs are round, and do not take into account the level of ellipticality occurring naturally in various hardwood log species. The lack of knowledge regarding the impact of elliptical log shape likely impacts lumber grade and volume yield. By quantifying the impact of ellipticality in hardwood saw logs on lumber grade and volume recovery, it may be possible to develop methods to yield significant higher grade lumber and optimize lumber recovery.

1.2 - Hypothesis

It is hypothesized that there is a significant difference between lumber volume, grade and value recovery for low and high elliptical red oak hardwood logs. It is also hypothesized that differences in processing, such as time required to process, will be greater for high elliptical logs. These potential differences will likely reduce the efficiency and productivity of a hardwood sawmill processing elliptical logs using current sawing methodology.

1.3 - Objectives

The purpose of this research was to determine if current sawing methods are sufficient for processing both round and elliptical red oak sawlogs. The specific objectives of this research were to:

1. Determine if green lumber volume, grade and value recovery differences exist between round and highly elliptical red oak logs.
2. Determine differences in the processing variables: number of turns, sawing time and number of sawlines for round and highly elliptical red oak logs.

1.4 - Significance

By examining how highly elliptical logs are processed using current sawing methods it can be determined if an optimal sawing practice for elliptical logs should be developed. An improvement in lumber grade and volume recovery for non-round hardwood sawlogs should lead to improved profitability for hardwood sawmills and increased utilization of the forest resource.

CHAPTER 2 - LITERATURE REVIEW

2.1 - Introduction

Market changes, foreign competition and increased raw material costs are pressuring hardwood sawmills to become more efficient. Part of being an efficient sawmill operation is being able to maximize the volume and value of lumber produced by sawing logs. Each log contains variability such as species, size, length, quality and shape that must be considered when determining how it should be processed.

2.2 - Hardwood log scaling and grading

The volume and quality of lumber produced will vary based on the form, shape, size, and grade of the log. Most hardwood sawlogs are evaluated by log scale and grade, where the scale estimates the lumber volume yield and the grade indicates the quality of lumber that could be produced. Log scaling and grading methods are important in determining the value of a log and are used in methods to determine sawmill efficiency.

2.2.1 - Log scaling

Log scaling is a method that estimates the volume of a log or group of logs and stick scaling is the direct measurement of log volume. Stick scaling is what is typically used to determine the amount of lumber that can be expected from a hardwood log given its diameter and length. In the United States and Canada, there are over 95 log scaling rules bearing about 185 names that have been developed and used (Cassens, 2001). Log scale estimates are usually derived using one of three rules. These rules estimate lumber volume based on: drawings of the log and right angled parallelopiped to represent lumber in the log (diagram rules); theoretical relationships using closed form mathematical models (formula rules); and combinations of both rules (combination rules). In the Eastern United States, three main log rules are currently used: the Doyle log rule, the Scribner rule, and the International ¼ inch rule (Cassens, 2001).

The International ¼ inch log rule is a combination rule, the Doyle rule is a formula rule and the Scribner log rule is a diagram rule. Cassens (2001) indicated that for the Scribner rule the original numbers were derived by fitting boards into perfect circles that represent the ends of the logs.

The Doyle rule was developed by Edward Doyle and published in 1837. The rule suggests subtracting 4 inches from the diameter for slabs and edgings, squaring the result, and adjusting for log length. Log taper is ignored. Equation 1 indicates how to calculate the amount of board feet of a log using the Doyle log rule.

$$\text{Board feet Doyle} = (D-4)^2 \times (L/16) \qquad \textbf{Equation 1}$$

Where: D = the average of the major and minor diameter inside bark at the small end of the log in inches

L = the length of the log in feet.

Cassens (2001) reported that the Doyle log rule is accurate with large-diameter logs and greatly underestimates the volume of lumber that can be obtained from small-diameter logs. This is due to the edgings and slabs allowance being too large for small logs, and too small for large logs according to Cassens (2001). It is the most widely used rule on private timber.

J. M. Scribner developed the Scribner log rule in 1846 and it is based on the diameter of the small end of a perfectly round log (Cassens, 2001). This rule tends to overscale large logs and underscale small logs. In this rule there is no uniform slab allowance for log diameter and log taper is ignored. Another version of the Scribner rule is the Scribner decimal C rule. Equation 2 indicates how to calculate log volume in board feet using the Scribner log rule.

Board Feet Scribner = $(0.79D^2 - 2D - 4) \times L/16$ **Equation 2**

Where: D = the average of the major and minor diameter inside bark at the small end of the log in inches

L = the log length of the log in feet.

Judson C. Clark developed the International 1/8-inch log rule around 1906. In 1917, he increased the saw kerf allowance to ¼-inch in the formula. The International ¼ inch rule in use today is based on an analysis of the losses occurring during conversion of saw logs to lumber. It provides the most accurate lumber volume estimation and is the only rule that includes taper and sawkerf (Denig, 1993). Equation 3 indicates how to calculate log volume in board feet using the International ¼ inch log rule.

Board feet International 1/4 = $0.04976191LD^2 + 0.006220239L^2D - 0.1854762LD - 0.000259176L^3 - 0.1159226L^2 + 0.04222222L$ **Equation 3**

Where: D = the average of the major and minor diameter inside bark at the small end of the log in inches

L = the length of the log in feet.

Bond (2000) reported that the critical factor in the use of any log rule is the consistency with which it is applied. However, the International ¼-inch rule is the most accurate of the three rules. Since the International ¼-inch rule is the most accurate method to estimate lumber volume production from small end diameter and log length measurements, it is the ideal log rule to use for experimental comparisons.

2. 2. 2 - Log grading

Log grading is a method of determining the quality of lumber produced from a log based on log shape and external defect indicators. Most hardwood sawmills purchase logs based on a log grade and log scale. Grades are assigned to a log based on the number of visible defects on the surface such as knots and rot. Defects affect the quality and quantity of lumber that can be produced from the log. The higher the log grade, the more high-grade lumber can be expected from a log (Rast et al., 1973). Consequently, a high-grade log is worth more than a low-grade log of the same volume. The U.S. Forest Service developed standard hardwood sawlog grade specifications based on the position of the log in the tree, diameter, straightness, the size and amount of defect free material in the grading face selected (Rast et al., 1973).

There is no organization or government agency that has control over the measurement of logs (Freese, 1973). As a consequence each individual buyer could develop a rule to fit a set of operating conditions in their respective region. Most hardwood sawmills develop and use their own log grading specifications rather than using the U.S. Forest Service log grade rules. Custom log grade specifications are typically based on the number of clear faces, diameter and length. Examples of two custom log grade specifications are given for two different sawmills in Table 1.1.

Table 2.1. Two highest log grade specifications for two sawmills in Virginia and Western Virginia

Grade	Sawmill A	Sawmill B
Prime	4 clear sides	4 clear sides
	12” and up diameter	13” Minimum diameter
	10’ minimum length	10’ minimum length
		Can have one defect within 2’from end not over 3’’ in diameter
Select	2 clear side	3 clear sides
	12” and up	12” Minimum diameter
	8’ minimum length	8’ minimum length

It is important to use uniform log grade specifications because log grade has an impact on lumber grade and volume recovery. High-grade logs will likely produce higher-grade lumber and volume recovery than low grade logs. It is important to keep log grades uniform to avoid variability within a log sample or between sample groups.

2.3 - Hardwood lumber grading

The value of lumber produced from a log is typically more important than the volume produced. The value of the lumber produced is determined by its grade. While hardwood lumber grades are based on many criteria, the number and size of clear cuttings that can be cut from the board and visible features such as knots, checks, pitch pockets, shake, warp, and stain play a major role in the assignment of grade. Hardwood lumber grades are determined using the rules assigned by the National Hardwood Lumber Association (NHLA, 1998). Most lumber is graded based on the worse face of the board. The value of lumber decreases as the number of defects increases. Higher-grade lumber has fewer defects and larger clear cutting areas than lower grade lumber. The standard grades of hardwood lumber from the highest to the lowest are First And Seconds (FAS),

FAS 1 Face (FIF), Selects, No.1 Common, No.2A Common and No.2B Common, No.3A Common, and No.3B Common (NHLA, 1998). While different lumber grading practices do coexist due to the wide variety of wood species, industrial practices, and customer needs (Kent et al. 1999), NHLA rules are the most commonly used by the industry.

Most hardwood lumber is bought and sold based on prices that are reported in two trade publications, the Hardwood Market Report (HMR, 2005) and the Weekly Hardwood Review (WHR, 2005). These publications list lumber prices per grade for different regions (Southern, Appalachian, and Northern) in North America. Comments associated to the trend in lumber market prices for green and dried lumber are also indicated for certain wood species. Since most lumber is purchased and sold using NHLA grading rules and prices published in market reports, these methods will be used to determine lumber value in this study.

2.4 - Log ellipticality

Hardwood log ellipticality describes how much a log's outline deviates from a circle. The ellipticality can be calculated from the dimension of the length of the major axis and the length of the minor axis of an ellipse. An illustration of the major and minor axis in relation to ellipticality is shown in Figure 1. The measure of ellipticality is a unitless measure.

The formula used to measure ellipticality (e) indicated in equation 4 (Steward, 1999):

$$e = \frac{\sqrt{\left[(d/2)^2 - (d'/2)^2\right]}}{(d/2)}$$ **Equation 4**

Where, d is the length of the major axis and d’ is the length of the minor axis of the log.

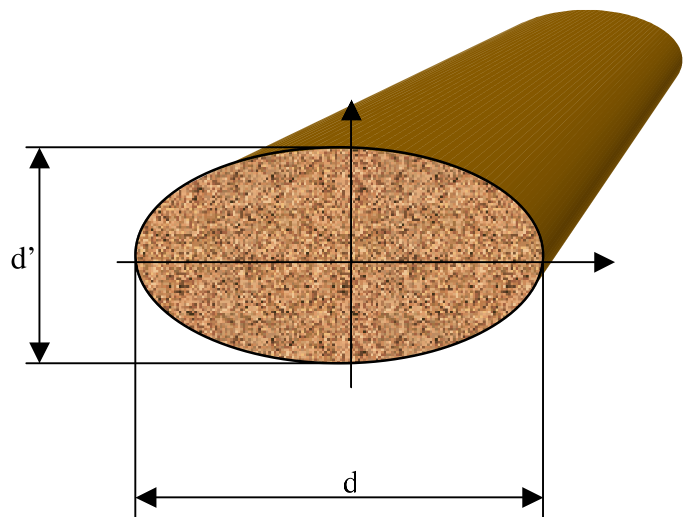

Figure 2.1. Elliptical log

Wagner and Taylor (1993) reported that in the North American hardwood lumber industry, no previous research has been conducted to quantify or classify the cross sectional shape of hardwood log ends. As part of a larger project, that included this work ellipticality in hardwood saw logs was classified into three categories of ellipticality: low (≤ 0.3), moderate (0.3-0.4), and high (≥ 0.4) based on data collected by the USDA Forest Service Northeastern station (Madhok, 2003). Madhok’s work involved using red oak, yellow poplar, and white oak harvested in West Virginia and Southern Virginia. It was also determined that the average sawlog in West Virginia and Ohio contains moderate ellipticality (1-1/14 inch difference between major and minor axis) and that 43% of logs could be categorized as being highly elliptical (Bond et al. 2006). Due to the large occurrence of ellipticality in hardwood sawlogs for the region studied and the large number of sawlogs that were classified as highly elliptical, a study to determine the impact of ellipticality on lumber production is warranted.

2.5 - Current sawing practices

The efficiency of a sawmill is affected by its sawing practice, which greatly impacts lumber volume and grade yield. Sawing method is the sequence of cuts used to break down a log into lumber (Steele, 1984). There are three sawing practices that are generally used when producing lumber from a log: grade sawing, cant sawing and live sawing. Grade sawing is the practice of sawing around the log in an attempt to recover high-grade lumber from the outside of a log. Cant sawing is where lumber is generally produced on a headrig or resaw and the cant is processed in a gang. Cant sawing differs from grade sawing in that the focus is on producing a cant rather than the highest grade of lumber possible. Live sawing involves breaking down with parallel saw lines. Advocates of live sawing claim that it generates fewer sawlines and less sawdust than cant sawing, resulting in a higher potential for lumber recovery (Hallock and Lewis, 1976). Cant sawing advocates argue that when live sawing, all taper in the plane normal to the board faces is lost in edgings, while in cant sawing, some of this material can be saved as short boards.

Generally hardwood sawmills use different sawing patterns compared with softwood sawmills in breaking down their logs. Most hardwood sawmills use the grade sawing method the value difference between low and high grade lumber is significant for most species. Also, grade sawing allows the log grade center of a log to be produced as a cant and sold to the pallet and container industry. Live sawing results in the low grade center of the log being produced into boards, the removal of which requires extra processing. While several studies have indicated that live sawing for hardwoods can produce high value and volumes for some species (Steele, 1984), most sawmill owners believe that the maximum value is obtained from a log in this manner (Richards and Newman, 1979).

2.6.1 - Effect of log shape on sawing methods

Taper is the difference between large and small end diameters of a log. Taper can be handled by sawing parallel to the bark or sawing parallel to the pith Denig (1993). According to Denig (1993) the two methods to handle taper include split taper and full taper. Split taper sawing is when half of the taper is set out on the first face, taper is taken out on opposite face. Full taper sawing is when taper is set out all the way on the first face; then opposite taper is taken out.

Hallock and Lewis (1976) suggested that full-taper promises higher yields, since the possibility of an additional piece of lumber from the log is better if all the taper is thrown to one sawing face rather than divided between two opposite faces. Researchers of split-taper feel it is best because it produces less radically tapered side lumber and cants with a more balanced form. Moreover, Hallock and Lewis (1976) suggested also that the best results are obtained by using a mixture of the eight sawing methods, with the best method determined by individual log geometry. Harpole and Hallock (1977) claimed that the problem of maximizing lumber yields is essentially a problem of fitting a rectangle into a circle.

2.6.2 - Location of pith

The pith is the soft core in the center of a log. To avoid this heart center zone of the log the most common method used in hardwood sawmill is the practice of sawing around the log in attempt to recover high grade lumber from outside of the log. Sawing around the log leads to the production of a cant that contains the pith. A cant is square material, often 3 1/3 x 6 inches that contain the lowest grade material and the heart center of the log. Cants are often produced instead of lumber since the value of a cant can be significantly higher than producing low grade lumber. Cants are typically used for blocking or used to manufacture pallets. Loung (1965) recommended that if the pith is off center, the log should be oriented so that one face is perpendicular to the longest radius.

2.6.3 - Sweep and crook

According to Denig (1993) when dealing with sweep more lumber can be produced with sawline parallel to the sweep to produce more high grade lumber another method is to place the sweep at a 45 degree angle. Denig also reported that in an attempt to deal with crook, sawlines should be perpendicular to the sweep.

2.6.4 - Log roundness

All logs are not identical; therefore, the potential exists to optimize yield using a sawing method for a specific for log shape. Lewis's (1985) suggested that the best way to recover the maximum lumber grade and get the highest yield from elliptical logs is to orient the major axis up for extra pieces and a potential piece in the cant. Another way is to orient the minor axis up to favor increased yields from wider cants or extra side pieces. These suggestions have not been followed up with research to identify their accuracy;

therefore it is important that investigations be carried out in order to find out if the suggested methods could be effective when sawing elliptical logs.

2.7 - The best opening face principle

Harpole and Lewis (1977) developed the Best Opening Face (BOF) principle, which finds the first sawline placement resulting in the maximum yield for a log when sawn by a given set of actual or hypothetical sawing conditions. In other words, by specifying all the sawing conditions, the best breakdown pattern could be known for each situation. Hallock and Lewis (1971) mentioned that knowledgeable people in the sawmilling field have long known that the volume of lumber yielded from a given log is related to the width and position of the opening face. Hallock and Lewis (1971) developed the best opening face principle in an attempt to determine how the first saw line should be placed in relation to the next cuts. Logs theoretically sawn by the BOF model were assumed to be truncated cones with no defects. The literature associated with the modified version of BOF has indicated that it is possible to determine the optimal orientation of the log in an attempt to obtain the highest yield from elliptical logs (Lewis 1985). The BOF application in hardwood sawmills has been limited although the technology has been successful in softwood sawmills Hallock and Lewis (1971).

2.8 - Sawing simulators

Sawing simulators allow comparison of sawing methods without actually having to conduct actual sawing studies, thus allowing for greater sample sizes and flexibility of methods tested. They also reduce the effect of log variability so common in actual mill tests. However, lumber volume and grade yields derived from sawing simulations are often greater than lumber volume and grade yields from a sawmill because the simulator often simplifies the shape of logs. Some of the earliest sawing simulation studies reported in the literature were the theoretical log sawing done by Peter and Bambing (1962), and Hallock (1962). Peter and Bambing (1962) diagrammed logs and included defects to determine the first saw line. Hallock (1962) considered saw lines in terms of kerf width and the relevant lumber recovered.

Leach (2003) developed the Sawmill Simulation Program (SAWSIM). SAWSIM determines the sawing pattern for each log, the effect of changing the raw material supply and products mix, the effect of changing target sizes, and wane specifications. Leach reported that SAWSIM simulates the sawing of logs with crook and sweep. Todoroki (1990) reported that Simulating Wood Quality (SIMQUA) simulates the sawing to produce a visual analysis of wood quality. Singmin developed the Sawing Simulator SIMSAW to evaluate the effect of sawing pattern in lumber recovery from logs. SIMSAW simulates log quality in terms of knotty defect core and the board grades resulting from each log and production scenario (Todoroki 1990). Todoroki (1990) also developed a sawing simulation system comprising three computer programs: AUTOSET (provides selection of sawing pattern), AUTOSAW (provides sawing strategies), and SAWOUT (analyses output data). Vuorilehto (2002) reported that the System to improve the Efficiency of European Sawmill (SEESAW) enables to get information on sawing process and manage the production process, saw machines and sawblades. Unfortunately, SEESAW doesn't incorporate elliptical cross section of logs.

2.9 - Sawmill efficiency

Sawmill efficiency can be evaluated by lumber grade and volume yield. A grade yield study in a hardwood sawmill will produce information that relates log grade to the grade of lumber produced. Similar to a volume yield study this method can be used on a single log or a group of logs of the same grade. Grade and yield studies provide information which compares the price paid for a log and the value of the product derived from the log. While this is useful in determining lumber volume recovery efficiency, it does not indicate the exact cost of processing the log into lumber.

2.9.1 - Volume efficiency measures

The two most common methods of measuring sawing efficiency related to lumber production is the expression of lumber overrun and lumber recovery factor (LRF) Overrun refers to difference in the actual volume of lumber produced by the mill and the lumber volume estimated by the log scale. Equation 5 indicates how to compute overrun.

$$Overrun = \left[\frac{Lumber\ \ tally}{Log\ \ scale} - 1 \right] x\,100$$

Equation 5

Cassens (2001) reported that many factors can affect overrun including log rule used, scaling practices, overall roughness of the logs, log taper, log diameter and length, species, slab thickness, and edging practices. Factors such as board thickness variation, kerf thickness, over sizing, sawyer experience, grade sawing versus volume sawing, laser lights, computer controls, and scanning equipment can also affect overrun (Cassens 2001).

The lumber recovery factor measurement is calculated by dividing the total lumber volume (in board feet) by the log input volume (in cubic feet). The log volume is calculated by squaring both the small end diameter inside bark and the large diameter inside bark, then multiplying the sum of diameters squared by the length of the log and 2727x 10^{-6}.

Lumber recovery factor (LRF) is calculated by the formula in Equation 6:

$$LRF = \frac{Total\ lumber\ Yield}{Total\ \log\ volume}$$

Equation 6

Cubic feet volume of log = 0.002727 x (d^2 + D^2) x L

Where d is the small end diameter inside the bark, D is the large diameter inside the bark, and L is the length of the log.

However, log size and quality have a major impact on lumber volume recovery. Thus, lumber volume recovery alone cannot always measure sawmill performance accurately. Denig (1993) reported that lumber recovery factor (LRF) has advantage over traditional overrun as an indicator of mill’s conversion efficiency because it is not based on a log rule. One difficulty with obtaining accurate LRF values is the computation of the cubic feet volume of a log, which requires the measurement of both the large and small end of the log. Accurate measurements of the large end of butt logs are made difficult due to butt swell and odd shape.

2. 9.2 - Grade yield studies

Grade yield studies have been used within hardwood sawmill industries to evaluate the amount of lumber that is obtained from logs. Grade yield studies in the hardwood industry focus on the quality of lumber that is produced (White 1980). Grade yield studies can be conducted on individual logs or groups of logs. Usually, within the sawmill industry, grade yield is measured for a group of logs by comparing the volume of logs going in the sawmill to the volume of lumber output at the sawmill.

2.9.3 - Time motion studies

Time motion studies are operator-efficiency studies. They are used to determine the relative efficiency of an operator or a specific activity during a workday (White 1980). Time motion studies can provide information on the amount of time allocated for the sawing process. According to White (1980) operations that occur at the headrig such as loading on the carriage, log turning and carriage return constitute the most important time consuming activities at the sawmill operation. An activity such as log turning and log loading at the headrig can be considered as constraints during log breakdown process.

Malcolm (1961) studied the effect of sawing time on lumber grade production for grade 1, 2, and 3 logs. Malcolm reported that the number of sawlines and log turns was made from the board-sawing-sequence diagrams for logs. An analysis of the summary data did not indicate any significant differences either between sawing methods or log grades. The data simply indicated that the larger the log, the greater the number of saw lines and turns.

2.9.4 – Operating costs

Accurate information on sawmill operating cost can also be one of the good indication of sawmill efficiency. Mayer and Wiedenbeck (2005) reported that sawmill study can reflect conditions and profitability under operating conditions. By tracking individual logs and relating the processing costs to lumber grades and lumber volume production, profit/loss level can be determined. Hardwood operating cost evolves around $2.25 per minute to more than $20 per minute for more sophisticated sawmill (Mayer and Wiedenbeck, 2005). As a consequence, the longer the log stays in the mill the more lumber produced from the log cost to produce. Personal communication with some sawmill in West Virginia indicated that the cost per sawline evolve around $0.68 for mill using sophisticated technology in processing log (Peskar, 2002). Since elliptical logs may require more processing time, by determining elliptical logs processing time, and comparing lumber volume and value produced, indication can be obtained on the effect of processing time upon sawing elliptical logs.

CHAPTER 3 - METHODOLOGY

3.1 - Introduction

This chapter will present the experimental design and procedure for satisfying each objective. The first objective was to determine if green lumber volume, grade and value recovery differences exist between round and highly elliptical red oak logs. The second objective was to determine differences in the processing variables: number of log turns on the headsaw carriage, sawing time, and number of sawlines for round and highly elliptical red oak logs.

Since the data for the two objectives were related in terms of number of logs, the degrees of ellipticality, and sawmills involved in the study, the data was collected at the same time, the same experimental design was used to meet both objectives.

A completely randomized block design was used in this study where the four sawmills involved in the research study were the blocking factors. The two degrees of ellipticality were the treatment variables, set at two levels, low and high. Logs with low ellipticality are essentially round ($e \leq 0.3$) compared to logs with high ellipticality ($e \geq 0.4$) that are distinctly non- round. The same number of logs were sampled for each of the two ellipticality groups at each sawmill. The experimental units were red oak logs that met Forest Service log grading rules for grade 1 sawlogs. A balanced design was used in regard to sampling the same number of logs in each block.

3.2 - Log selection criteria

All logs used for this study were required to meet the Forest Service specifications for log grade 1 (Table 3.1). Further limitations were placed on logs to limit variability. These limitations included: no crook; no double pith; sweep was limited to 1.5-in; log diameters were limited to 14- 18 inches; and log length was limited to 10-12 feet. Logs meeting the above criteria were selected at random in the log yard at each sawmill.

Previous sawmill studies have used different sample sizes to predict various outcomes. The determination of sample sizes can be estimated or based on previous experimentations. Malcolm (1961) selected a sample size of twenty hardwood logs. At sawmill’s log yard it was not easy to find logs meeting all of the above selection criteria. For instance, after selecting for grade the degrees of low and high ellipticality were not easy to be meet by all logs at all sawmills. Moreover, the study depended on sawmills schedules in sawing red oak. Therefore, logs selection relied heavily on logs available at individual sawmills and at the time the sawmills were willing to saw red oak logs. In this research project twenty logs of low and twenty logs with a high degree of ellipticality were selected at each of the four participating sawmills.

Four sawmills participated in this project. Three were located in Virgina and one in West Virginia. All sawmills procured logs from the area known as the Allegheny Plato. These sawmills were identified as mills A, B, C, and D. Each mill utilized a different strategy in processing logs and had a different mill layout. Mills A and B utilized band resaws as a secondary breakdown method while mill C processed all lumber on the headrig and mill B utilized a gangsaw as a secondary breakdown method.

Table 3.1. Forest service grade 1 hardwood log specifications. U.S.D.A (1973)

Grade factor		**Log grade 1**		
Position in the tree		Butts only	Butts & uppers	
Minimum diameter (inches)		13-15	16-19	20+
Minimum length (feet)		10+	10+	10+
Clear cuttings on each of the three best faces	Minimum length (feet)	7	5	3
	Maximum number	2	2	2
	Min. yield face length	5/6	5/6	5/6
Max. sweep and crook allowance;% of gross vol.		15		
Max. cull and sweep allowance;% of gross vol.		40		

3. 3 - Ellipticality computation

A tape measure was used to determine the length of each log's major and minor axis on the small end of the log (in inches), and the log length (in feet). The ellipticality value was then computed at the log yard with the formula defined in Section 4 (Equation 4). Overall, 160 elliptical logs were selected encompassing 80 logs of low ellipticality and 80 logs of high ellipticality. The average ellipticality (e) for the four sawmill ranged from e = 0.20 to e = 0.22 for low ellipticality logs, and from e = 0.42 to e = 0.48 for highly elliptical logs

3.4 - Log scaling and lumber grading rule selection

Log volumes were estimated using the International ¼" inch log rule. Since the International ¼-inch rule is the most accurate method for estimating lumber volume production based on small-end diameter and log length measurements, it is the ideal log rule to use for experimental comparisons. The National Hardwood Lumber Association grading rules are the most commonly used by the industry. Lumber grades were determined by the lumber grader employed at each mill.

3.5 - Sawing preparation, quadrant identification and sawmill work

After the degree of ellipticallity was determined, the small end of each log was divided into four quadrants. The quadrants were selected based on the major and the minor axis of the log's small end as illustrated in Figure 3.1. The small end of all logs was colored using different color paint for each quadrant. The colors were oriented the same in each log so that the origin of the lumber could be tracked back to major and minor axis locations.

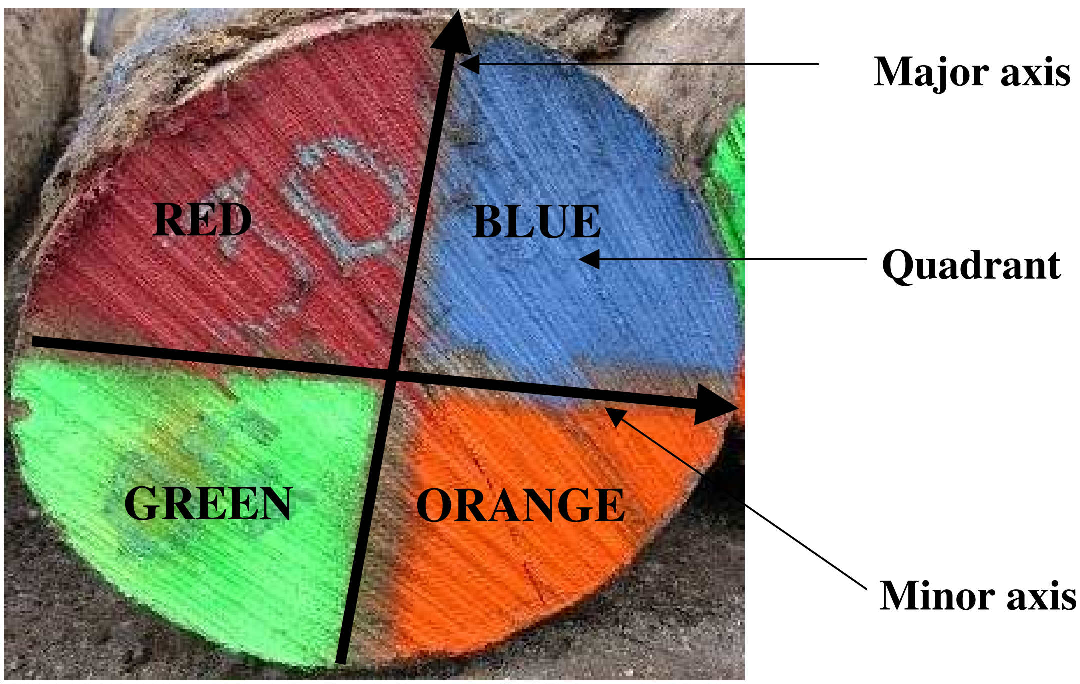

Figure 3. 1. Illustration of log small end depicting four quadrants marked with four different colors.

At sawmills A and B, graduate students assisted in recording lumber grade, and lumber volume produced and the colors of the painted board before the trimmer as assigned by the lumber grader. At sawmill C, the trimmer was stopped from working during the study. The lumber grader recorded both lumber grade and lumber volume. A graduate student recorded the painted colors on board ends at the grading line. At sawmill D, USDA Forest Service Northeastern Research station sawmill specialists assisted in recording lumber volume and lumber grade yields as assigned by the sawmill lumber inspector. A graduate student recorded the painted colored on the board end before the trimmer.

3.6 - Quadrant identification work

Low ellipticality logs and highly elliptical logs were numbered and marked using industrial color paints (orange, green, red, and blue) on the ends to identify lumber and track the boards at various steps of the sawing process, and at the lumber grading line before the trimmer. The color tally was based on the area covered by each color at the end of the board. A 25% coverage was the selection criteria for a color to be taken into account in the tally. When the end of the board was covered by different colors, at least 25% of the area needed to be covered by the industrial paint for any one color to be tallied. Most boards that were derived from slabs and did not meet the coverage criteria were not recorded for the quadrant study. Boards that did not have any color were discarded from the quadrant and orientation study. Some boards did not have a color painted on their ends (i.e., they were derived from jacket boards that tapered at the ends and thus were not full-length. All mills were handled in the same way with regards to boards that were generated but did not have colored ends. The purpose for dividing the log small end into four quadrants and then coloring each quadrant with individual color was to identify the origin of the board and to determine the orientation of the sawline compared to the major and minor axis through the videotape (Table 3.2).

The sawing process for each sample log was videotaped to determine how sawyers choose the first opening face for elliptical logs under current sawing practices. The position of the first sawline compared to the orientation of the log's small end major and minor axes was recorded. Moreover, the videotape captured the number of log turns, sawline orientation on the log, and total elapsed time of the log at the headrig.

Table 3. 2 Mapping sawline orientation to the major and minor axis

Quadrant Color	**Sawline orientation**
Blue/Red **(BR)**	Blue/Red Sawline perpendicular to the major axis
Green/Orange **(GO)**	Green/Orange Sawline perpendicular to the major axis
Green /Red **(GR)**	Green/Red Sawline perpendicular to the minor axis
Orange/Blue **(OB)**	Orange/Blue Sawline perpendicular to the minor axis
Blue/Blue **(BB)**	Blue/Blue Sawline within the major and the minor axis
Green /Green **(GG)**	Green/Green Sawline within the major and the minor axis
Orange/Orange **(OO)**	Orange/Orange Sawline within the major and the minor axis
Red/Red **(RR)**	Red/Red Sawline within the major and the minor axis

Figure 3.2. Lumber paint indicates different quadrants from which a board originated relative to the major and minor axes of each log

Figure 3.2 illustrates how the painted ends of the boards appeared immediately after the edger and before the trimmer. An analysis of the end colors was performed to identify the original location of the board and to relate each board to the log quadrant.

3.7. - Measurement of processing variables

The second objective was to determine differences in the processing variables: number of turns, sawing time and number of sawlines for round and highly elliptical red oak logs. For the two treatment variables (the two degrees of ellipticality) and the blocking factors (sawmills), a videocamera was used to capture the number of log turns, the number of sawlines, and total elapsed time at the headrig. A turn was identified as a rotation of the log at the headrig performed after a cut was taken. Sawing time at the headrig was calculated from the time the saw blade hits the log quadrant during the first cut until the end of the last cut when the square cant is ejected from the headrig and conveyed towards the band resaw or gangsaw. The number of sawlines was the number of cuts from the first cut at the headrig to the last cut at the band resaw or the gangsaw.

3.8. – Analysis procedure

The objective of the project was to determine the effect of the degree of ellipticality of a log on the response variables: overrun, lumber volume, and lumber value for red oak logs under current sawing methods. Data for this project were collected at four sawmills (A, B, C, and D) in Virginia and West Virginia. At each sawmill 20 logs with low degree of ellipticality and 20 logs with high degree of ellipticality were processed. Logs' diameter ranged between 14 to 18 inches and log length range was between 10 feet to 12 feet. Log volumes were estimated (log scaling rule was the International ¼ inch) using measurement from each log's diameter and length.

At each sawmill, logs for each degree of ellipticality category (low and high) were selected at random. However, analysis of the log diameter data for most sawmills seems to indicate that the log group with low ellipticality contained a greater scaling diameter than the high ellipticality log group. Therefore, variability in log diameter and log volume between the two sample groups being compared (low and high ellipticality) could significantly affect the interpretation of the data collected on the response variables (overrun, lumber volume, and lumber value).

To evaluate the data collected for the responses variables of the two distinct ellipticality ranges established in this project, a statistical analysis using the software package Statistical Analysis System (SAS/STAT release 9.1.3) was performed. Analysis of variance (ANOVA) was conducted using SAS proc mixed procedure to determine statistical differences associated with the several response variables: overrun, lumber volume, lumber value, and lumber grade between logs with low and high degrees of ellipticality. Using an alpha level of 0.05 the pairwise comparisons were adjusted using

Tukey adjustment. In an attempt to adjust for effects of log volume variability, log length and scaling diameter variations were used as covariates in the model. The slice option was used to partition the interaction between the sawmill and the degree of ellipticality for individual sawmills and for the individual ellipticality degrees. This option is equivalent to an unadjusted t-test within the sawmills, since the ellipticality degree only has two levels but splits up the overall variability due to the combined sawmill and degree effect into the part for high degree and low degree.

In summary, the analyses of the three dependent variables, lumber volume, lumber value, and overrun were all done the same way as a factorial ANOVA with covariates length, and scaling diameter using SAS proc mixed. This was the full model for all three dependent variables. Reduced models were produced for each dependent variable as appropriate (any covariate that was not significant at 5% was eliminated sequentially).

CHAPTER 4 – RESULTS AND DISCUSSION

4.1 - Introduction

In this chapter results to the response variables: average overrun, average lumber volume, average lumber value and grade, and processing differences between low and high ellipticality logs will be presented. Analysis was carried out on the average response variables for the effect of low and high ellipticality logs at all four sawmills, at each individual sawmill, and for all interactions between each sawmill and the two degrees of ellipticality.

4.2 - Ellipticality and log specification

Data on log size and shape was collected before processing logs. Table 4.1 shows data for the average ellipticality value, the average log scaling diameter, and the average log length results recorded for low and high ellipticality logs at participating sawmills A, B, C, and D.

Table 4.1. Average log characteristics for low and high ellipticality logs for sawmills A, B, C, and D

Log characteristic	SAWMILL							
	A		B		C		D	
	Low	High	Low	High	Low	High	Low	High
Average ellipticality	0.22	0.44	0.22	0.42	0.20	0.45	0.20	0.48
Average scaling diameter (inches)	16	15	17	16	16	15	16	16
Average length (ft)	11	11	11	11	12	12	11	11

The average ellipticality (e) ranged from $e = 0.20$ to $e = 0.22$ for low elliptical logs, and from $e = 0.42$ to $e = 0.48$ for high elliptical logs. The scaling diameter ranged from 16 inches to 17 inches for low elliptical logs and from 15 inches to 16 inches for highly elliptical logs. The average log length for low and high ellipticality logs ranged from 11 feet to 12 feet. The average log scale is presented in Figure 4.1. The distribution of log scaling diameter for both groups is presented in Figure 4.2 and Figure 4.3. The actual log data collected is presented for each mill and ellipticality group in appendix 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, and 4.8.

All hardwood logs contain variability in size, shape, and defects. In this research project, since log grade and log scale could affect lumber volume and value recovery, an attempt to limit this variability was undertaken by limiting the log grade, length, diameters, and form (i.e. sweep/crook) of all logs used in this study. While logs for each ellipticality category (low and high) were selected at random, analysis of the log diameter data clearly shows that for most sawmills, the log group with low ellipticality contained a greater scaling diameter than the high ellipticality log group (Table 4.1). Variability in log diameter and log volume between the two groups being compared (low and high ellipticality) could significantly affect the interpretation of output results.

An ANOVA was used to determine if there was a significant difference in the average log scale for all sawmills. The null hypothesis was that low and high elliptical log volume scale were equal. The alternative hypothesis was that low and high elliptical log volume scale were not equal. ANOVA analysis indicates that log scale was significantly different between the two sample groups (p-value < 0.01). Figure 4.1 illustrates the average log scale distribution for each degree of ellipticality and sawmill.

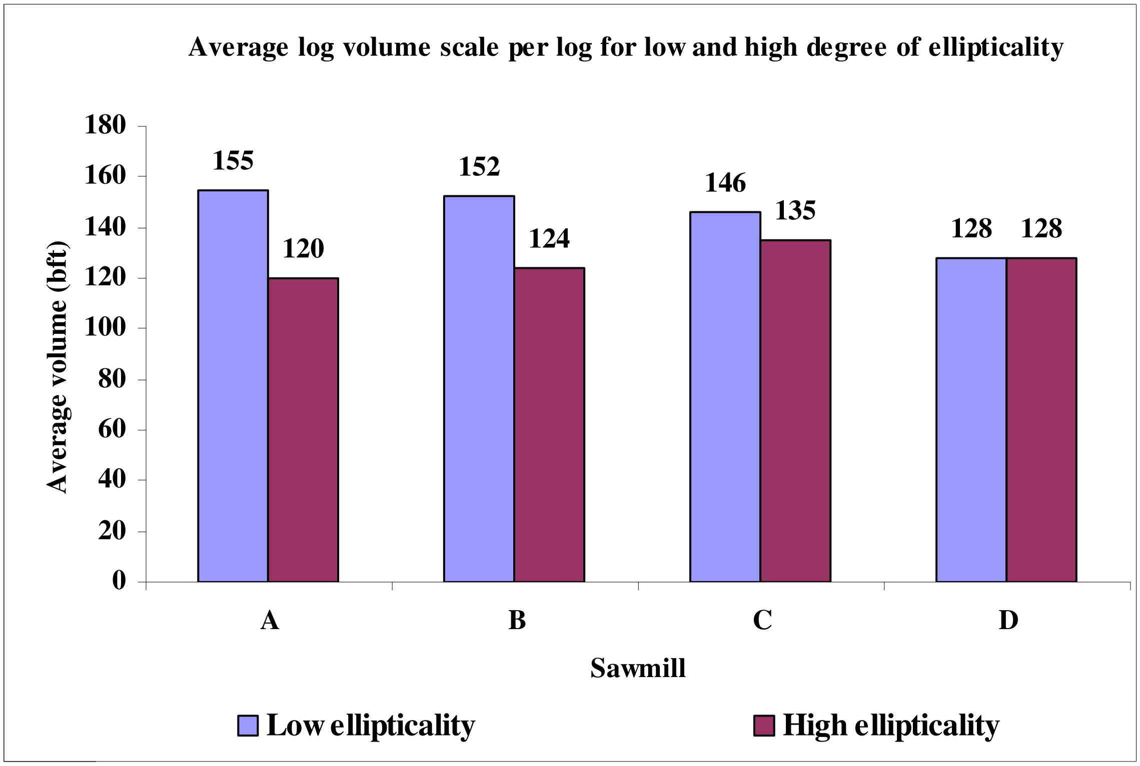

Figure 4.1. Average log volume scale (international ¼ log scaling rule) per log for low and high degrees of ellipticality at sawmills

A statistical model to limit log scale variability was used for all comparisons. In an attempt to adjust for effects of log volume variability, log length and scaling diameter variations were used as covariates in the model. The slice option was used to partition the interaction between the sawmill and the degree of ellipticality for individual sawmills and for the individual ellipticality degrees. This option is equivalent to an unadjusted t-test within the sawmills, since the ellipticality degree only has two levels but splits up the overall variability due to the combined sawmill and degree effect into the part for high degree and low degree. This produce what is known as tests of simple effects (Ott and Longnecker 2001). The slice option produces a table titled "Test of Effect slice" (SAS, 2006). Log diameter and length were found to be not significant for any of the comparisons (overrun, volume, and value recovery); therefore, the difference is log scale between the low and high ellipticality log groups does not affect the statistical comparisons discussed in the remainder of this section.

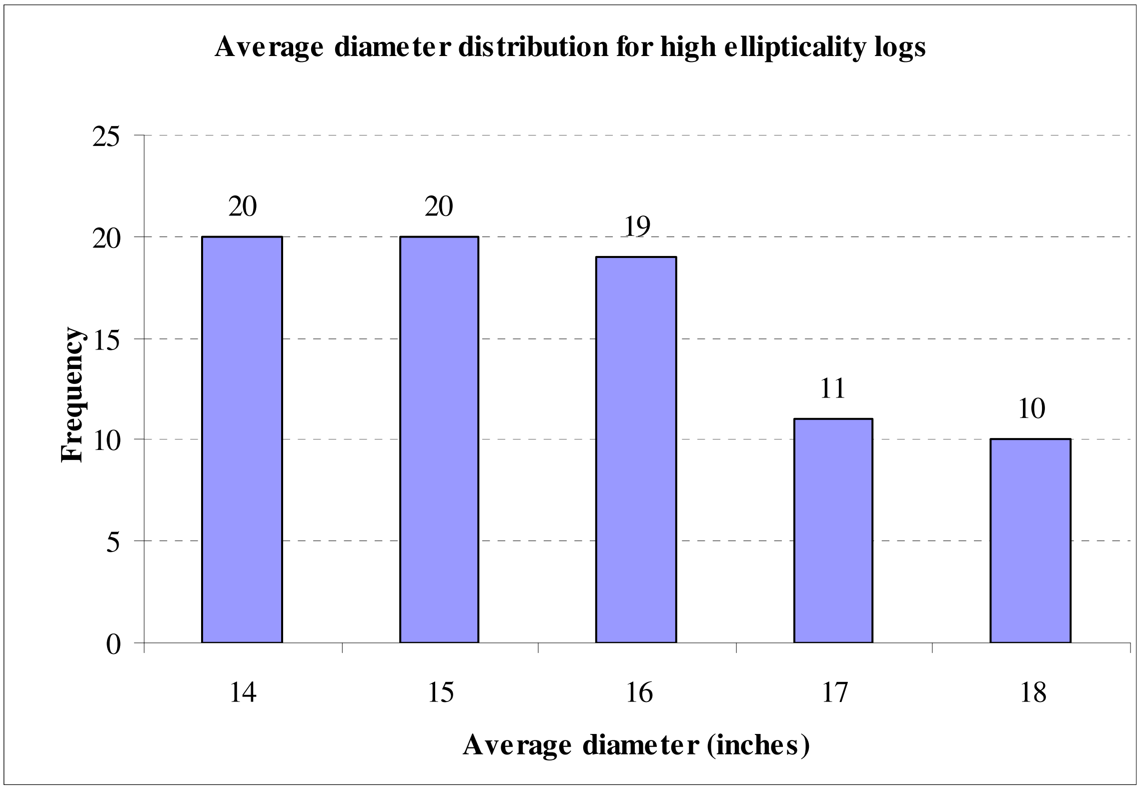

Figure 4.2. Average diameter distribution for high ellipticality logs

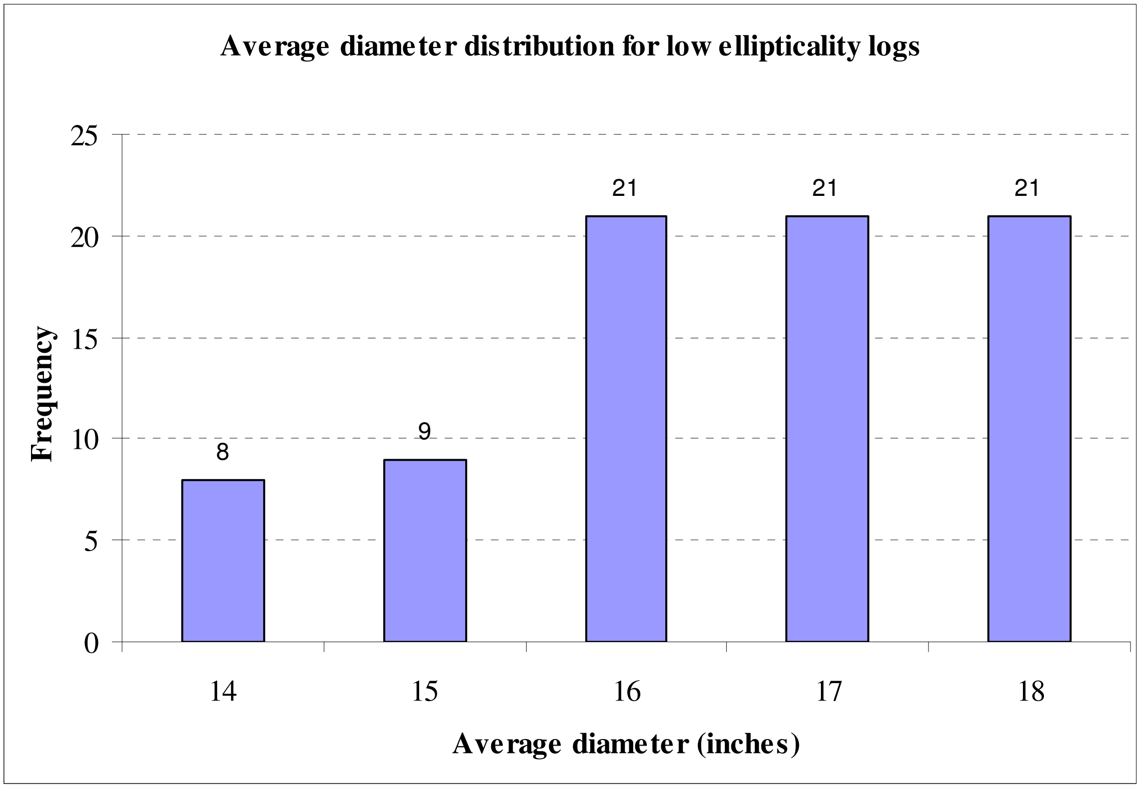

Figure 4.3. Average diameter distribution for low ellipticality logs

4.3 - Overrun

Overrun is an indicator of sawmill efficiency and was used in this study to determine whether there were differences in lumber volume production when sawing logs of low and high ellipticality. The data for the average overrun for low and high elliptical logs recorded at the four sawmills is presented in Table 4.2 and Figure 4.4. The 95% confidence interval of the average overrun per log for low and high ellipticality logs is shown at each sawmill using a bar chart with error bars as illustrated in Figure 4.4. The error bars indicate potential error for the average overrun per log graphically relative to low and high ellipticality logs.

Table 4.2. Average overrun per log for low and high degree of ellipticality at each sawmill

Sawmill	High elliptical log (%)	Low elliptical log (%)
A	6	17
B	4	10
C	20	10
D	6	3
Stdev	7	6
Average (%)	9	10

Table 4.3. ANOVA table for comparison of average overrun per log

Effect	DF	F value	Pr > F
Sawmill	3	6.95	<0.01
Degree of ellipticality	1	0.62	0.43
Sawmill* Degree of ellipticality	3	5.26	<0.01

The average overrun per log was compared for low and high ellipticality logs for all sawmills using ANOVA. The null hypothesis was that the average overrun per log for low and high elliptical logs were equal. The alternative hypothesis was that the average overrun per log for low and high elliptical logs were not equal.

ANOVA results (Table 4.3) indicate that (p-value 0.43) there was no significant difference between the average overrun per log for low and high ellipticality logs for the four sawmills. However, there was a significant difference in overrun between sawmill location and a significant interaction between sawmill and the degree of ellipticality. The significant interaction indicates that differences must exist between low and high ellipticality logs at individual sawmills (Figure 4.4); therefore, analysis of variance on the effect of ellipticality on the average overrun for low and high ellipticality logs was carried out for the individual mills. The null hypothesis was that the average overrun per log for low and high ellipticality logs were equal at each sawmill. The alternative hypothesis was that the average overrun per log for low and high ellipticality logs were not equal at each sawmill.

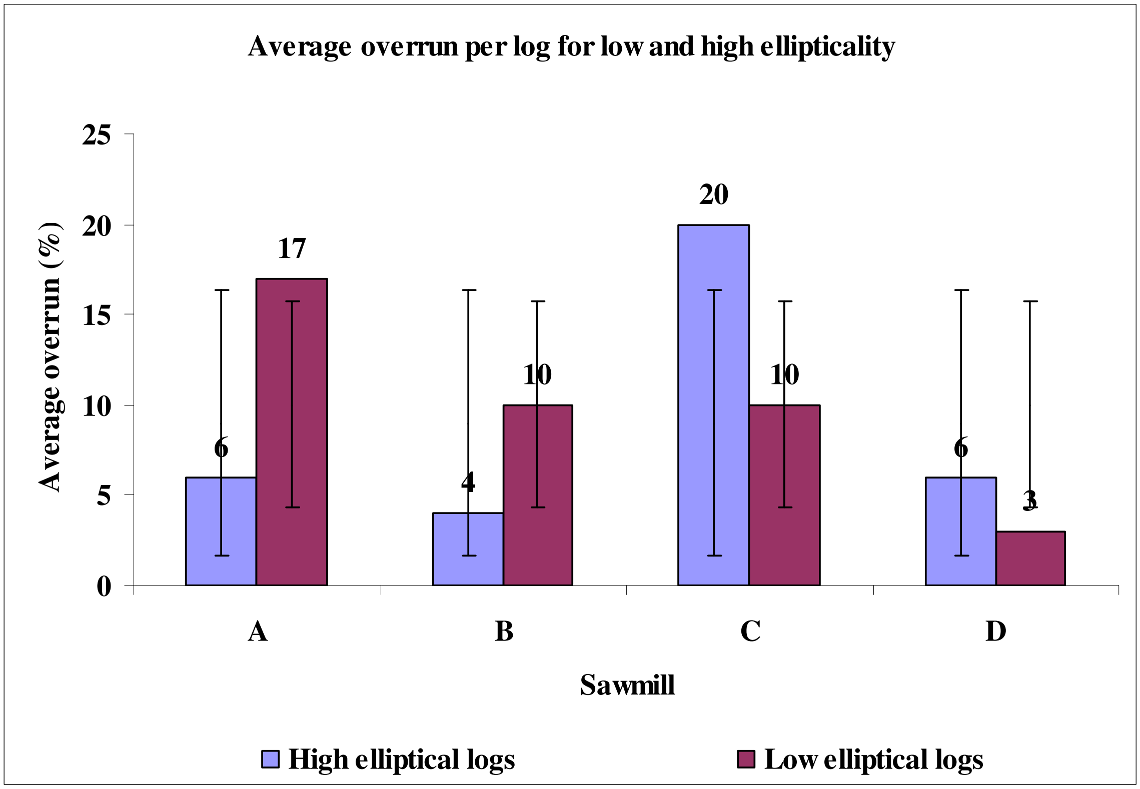

Figure 4.4. Average overrun per log for low and high elliptticallity

Analysis of variance (Table 4.4) indicates significant interaction between the effect for the variable sawmill and the degree of ellipticality, at sawmills A and C. The average overrun values for log ellipticality differ for sawmill A and C. At sawmill A, logs with low ellipticality produced significantly more average overrun (17%) as compared to logs with high ellipticality (6%). At sawmill C, logs with high ellipticality produced significantly greater average overrun (20%) than logs with low ellipticality (10%). At sawmill B and D logs with low and high ellipticality did not produce significantly different average overrun values. These three potential outcomes in the average overrun for logs with different degrees of ellipticality seem to indicate that different processing methods can produce different average overrun values for logs with different degrees of ellipticality.

Table 4.4. Output for ANOVA testing for the interaction at sawmill A, B, C, and D for average overrun per log

Effect	Sawmill	DF	F Value	Pr > F
Sawmill* Degree of ellipticality	D	1	0.24	0.62
Sawmill* Degree of ellipticality	B	1	2.88	0.09
Sawmill* Degree of ellipticality	C	1	5.71	0.02
Sawmill* Degree of ellipticality	A	1	7.60	<0.01

To further validate that different processing methods were used at each sawmill, resulting in different average overrun values, an ANOVA using slice option (specifies how to partition interaction effects) was conducted between the variable sawmills to determine if there was a difference upon sawing logs of each individual group of ellipticality. The null hypothesis was that the average overrun values at the four sawmills were equal for each degree of ellipticality of logs. The alternative hypothesis was that the average overrun amounts at the four sawmills were not equal for each degree of ellipticality.

When the treatment effect (high degree of ellipticality) was fixed, all sawmills produced significantly different average overrun values per log (Figure 4.4) indicating that each mill processed highly elliptical logs differently. When the treatment effect (low degree of ellipticality) was fixed, sawmills A and D produced significantly different average overrun values per log (Appendix 4.9, 4.10, and 4.11) indicating that low ellipticality logs are not always processed differently.

While there was no significant difference in the average overrun per log between low and highly elliptical logs at the four sawmills, a significant interaction of the degree of ellipticality and the individual sawmill exists. Analysis of average overrun values per log at each of the sawmills indicates that logs with different degrees of ellipticality can produce higher, lower and equal amounts of average overrun depending on how they are processed. Differences in the average overrun between sawmills for high ellipticality logs could be explained by process flow or by the sawing practice used at individual mills (number of sawlines, number of turns, and sawing time) when processing elliptical logs. Analysis of these variables will be discussed in section 4.7.

4.4 - Impact of ellipticality on lumber volume

While overrun is one predictor of sawmill efficiency, it can be impacted by differences in log scale; therefore, the next comparison for differences in elliptical logs was carried out for average lumber volume output. The range of data for the average lumber volume recovered from low and high ellipticality logs recorded at the four sawmills is presented in Table 4.5 and Figure 4.5. The 95% confidence interval of the average lumber volume per log for low and high ellipticality logs is shown at each sawmill using a bar chart with error bars as illustrated in Figure 4.5. The error bars indicate potential error for the average lumber volume per log graphically relative to low and high ellipticality logs.

Table 4.5. Average lumber volume per log for low and high degree ellipticallity at sawmills

Sawmills	High elliptical log (bft)	Low elliptical log (bft)
A	120	155
B	124	152
C	135	146
D	128	128
Stdev	6	12
Average (bft)	127	145

Table 4.6. ANOVA table for comparison of average lumber volume per log

Effect	DF	F value	Pr > F
Sawmill	3	6.85	<0.01
Degree of ellipticality	1	3.05	0.08
Sawmill* Degree of ellipticality	3	5.64	<0.01

The average lumber volume per log was compared for low and high ellipticality logs for all sawmills using ANOVA. The null hypothesis was that the average lumber volume per log for low and high ellipticality logs were equal. The alternative hypothesis was that the average lumber volume per log for low and high elliptical logs were not equal. ANOVA results (Table 4.6) indicate that (p-value 0.08) there is no significant difference between the average lumber volume per log for low and high elliptical logs for the four sawmills. However, there was a significant difference in the variable sawmill and a significant interaction between sawmill and the degree of ellipticality. The significant interaction indicates that differences must exist between the treatments effect (ellipticality) at individual blocks (sawmills) (Figure 4.5). These results are the same as those found for overrun.

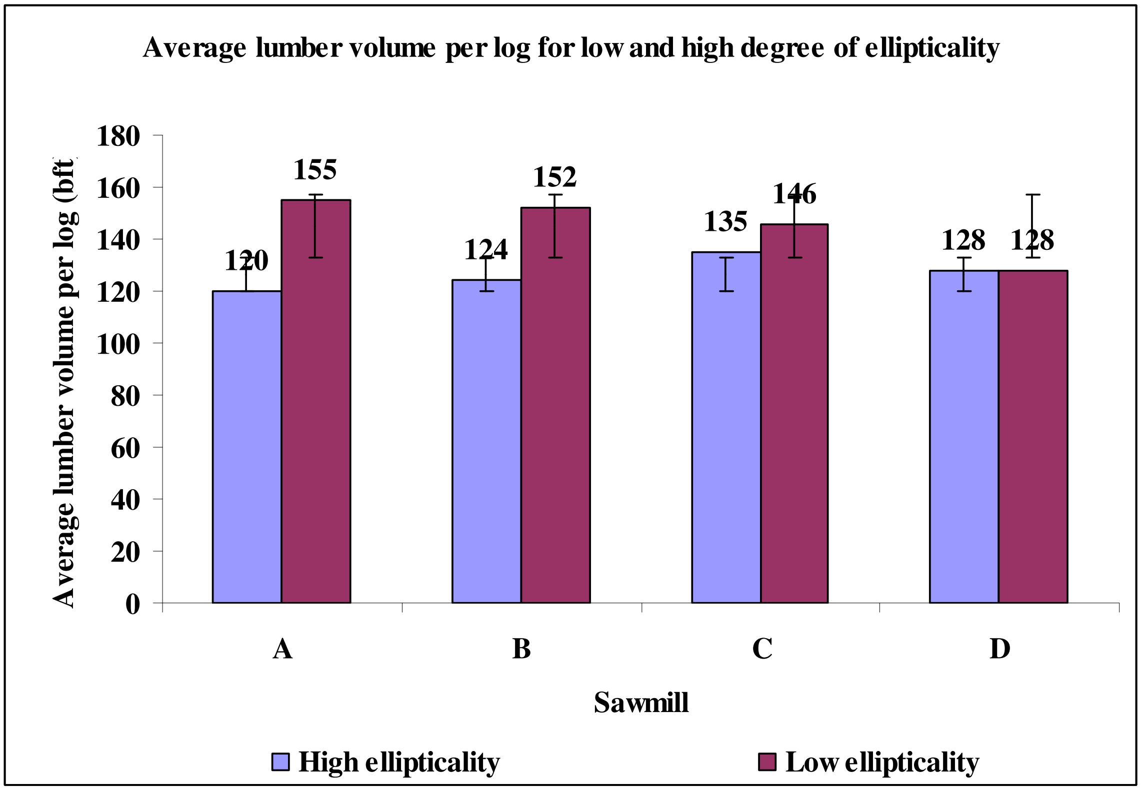

Figure 4.5. Average lumber volume per log for low and high degree of ellipticality

An analysis of variance on the effect of ellipticality on the average lumber volume per log for low and high ellipticality logs was carried out for the individual mills. The null hypothesis was that the average lumber volume per log for low and high ellipticality logs were equal at each sawmill. The alternative hypothesis was that the average lumber volume per log for low and high ellipticality logs were not equal at each sawmill.

Analysis of variance (Table 4.7) indicates a significant interaction between sawmill and the treatment factor (ellipticality) at sawmills A and B. At sawmill A and B logs with low ellipticality produced significantly more (35 bft and 28 bft) average lumber volume per log as compared to logs with high ellipticality. Sawmill C and D produced equal lumber volume per log for both low and high elliptical logs. The two outcomes in the average lumber volume per log indicate that while there is no significant difference in the average lumber volume between low and high ellipticality logs when comparing the average volume per log for all four sawmills, when comparing these variables at individual sawmills differences can occur. The differences between mills suggest that logs with low ellipticality can produce equal or higher average lumber volume output.

Table 4.7. Output for ANOVA testing for the interaction at sawmill A, B, C, and D for average lumber volume per log

Effect	Sawmill	DF	F Value	Pr > F
Sawmill* Degree of ellipticality	D	1	0.20	0.65
Sawmill* Degree of ellipticality	B	1	5.99	0.01
Sawmill* Degree of ellipticality	C	1	2.67	0.10
Sawmill* Degree of ellipticality	A	1	10.70	<0.01

To further validate that different processing methods are used at each sawmill, resulting in different average lumber volume values, an ANOVA using slice option was conducted between sawmills to determine if there is a difference upon sawing logs of each degree of ellipticality. The null hypothesis was that the average lumber volume per log at the four sawmills were equal for each degree of ellipticality of logs. The alternative hypothesis was that the average lumber volume per log at the four sawmills were not equal for each degree of ellipticality. When the treatment effect (high degree of ellipticality) was fixed, all sawmills produced significantly different average lumber volumes per log. When the treatment effect (low degree of ellipticality) was fixed, sawmill A and D produced significantly different average lumber volume per log (Appendix 4.12, 4.13, and 4.14). These findings are identical to those for overrun.

While there is no significant difference in the average lumber volume per log between low and high ellipticality for the four sawmills, a significant interaction of the degree of ellipticality and the sawmills exists. To determine why these differences occur; analysis of processing variables is required and such analysis is discussed in section 4.7.

4.5 - Lumber value

Lumber volume output measures are important when comparing sawing methods but the impact on lumber value can be just as, if not more important. Such differences are more important in hardwoods where differences in lumber grade can have a tremendous impact on the value of the product produced. For hardwood lumber, the production of more volume does not necessarily indicate that more value was obtained; therefore, when comparing differences in lumber output between ellipticality in red oak logs, lumber value differences were analyzed.

The value of red oak lumber produced from the logs selected for this study was computed based on green lumber grade prices indicated in the Hardwood Market Report dated October 1, 2005 for the Appalachian hardwood region (HMR, 2005). The data for the average lumber value for low and high ellipticality logs range recorded at the four sawmills is presented in Table 4.8 and Figure 4.6. The 95% confidence interval of the average lumber value per log for low and high ellipticality logs is shown at each sawmill using a bar chart with error bars as illustrated in Figure 4.6. The error bars indicate potential error for the average lumber value graphically relative to low and high ellipticality logs.

Table 4.8. Average lumber value per log for low and high degree of ellipticality at sawmills

Sawmill	High elliptical log ($)	Low elliptical log ($)
A	128	138
B	102	133
C	128	120
D	62	92
Stdev	31	21
Average ($)	105	121

Table 4.9. ANOVA table for comparison of average lumber value per log

Effect	DF	F value	Pr > F
Sawmill	3	5.49	<0.01
Degree of ellipticality	1	0.01	0.94
Sawmill* Degree of ellipticality	3	3.75	0.01

The average lumber value per log was compared for low and high ellipticality logs for all sawmills using ANOVA. The null hypothesis was that the average lumber value per log for low and high ellipticality logs were equal. The alternative hypothesis was that the average lumber value per log for low and high ellipticality logs were not equal. ANOVA results (Table 4.9) indicate that (p-value 0.94) there was no significant difference between the average lumber values per log for low and high ellipticality logs for the four sawmills. However, there was a significant difference in the variable sawmill and a significant interaction between sawmill and the degree of ellipticality. The significant interaction indicates that differences must exist between the treatment effect (ellipticality) at individual blocks (sawmills) (Figure 4.6).

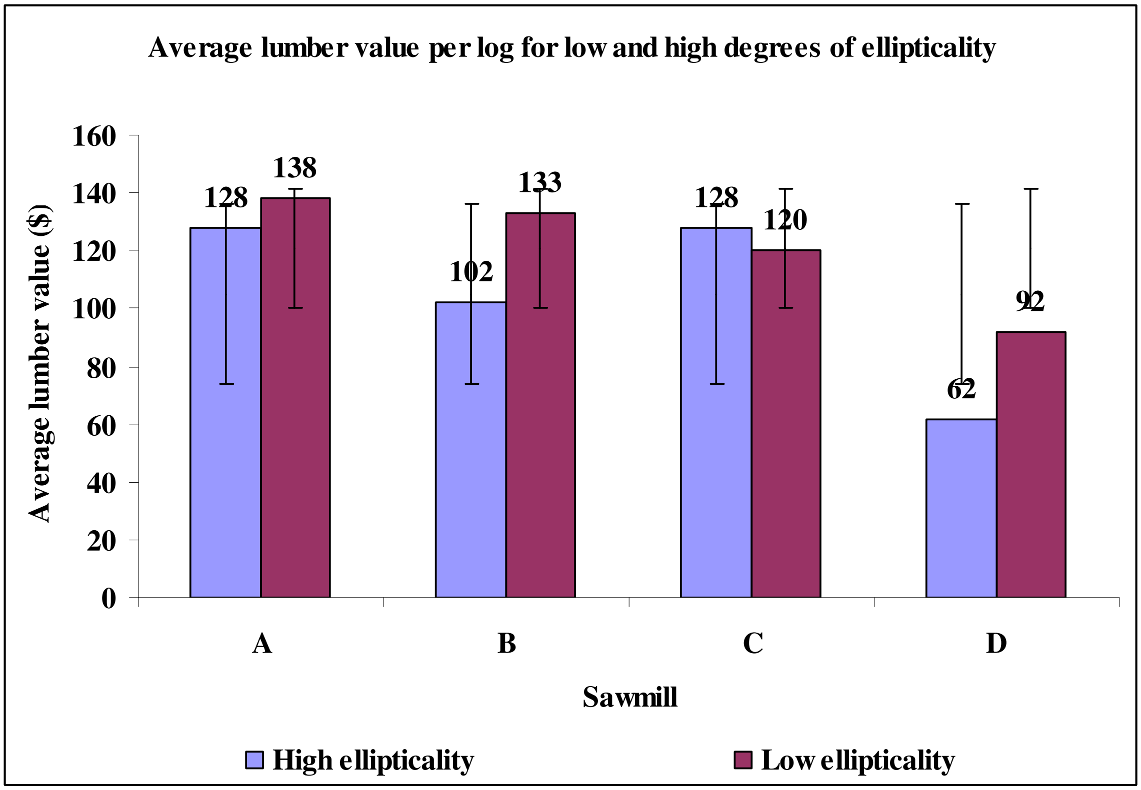

Figure 4.6. Average lumber value per log for low and high degrees of ellipticality

An analysis of variance on the effect of ellipticality on the average lumber value per log for low and high ellipticality logs was carried out for the individual mills. The null hypothesis was that the average lumber values per log for low and high ellipticality logs were equal at each sawmill. The alternative hypothesis was that the average lumber values per log for low and high ellipticality logs were not equal at each sawmill.

Analysis of variance (Table 4.10) indicated a significant interaction between sawmill and the degree of ellipticality at sawmill A, B and D. The average lumber value per log for log ellipticality differs for sawmills A, B, and D. Logs with low ellipticality produced significantly more ($10, $31, and $30) average lumber value compared to logs with high ellipticality. Sawmill C produced equal average lumber value per log for low and high ellipticality logs. These two outcomes in the average lumber value for logs with different degrees of ellipticality clearly indicate that low ellipticality logs either produce the same average value as high or higher average value of lumber than high elliptical logs.

Table 4.10. Output for ANOVA testing for the interaction at sawmill A, B, C, and D for average lumber value per log

Effect	Sawmill	DF	F Value	Pr > F
Sawmill* Degree of ellipticality	D	1	5.67	0.04
Sawmill* Degree of ellipticality	B	1	6.57	<0.01
Sawmill* Degree of ellipticality	C	1	0.80	0.37
Sawmill* Degree of ellipticality	A	1	7.78	<0.01

To further validate that different processing methods were used at each sawmill, resulting in different average lumber values, an ANOVA using slice option was conducted between sawmills to determine if there was a difference upon sawing logs of each degree of ellipticality. The null hypothesis was that the average lumber value per log at the four sawmills were equal for each degree of ellipticality of logs. The alternative hypothesis is that the average lumber value per log at the four sawmills were not equal for each degree of ellipticality. When the treatment effect (high degree of ellipticality) was fixed, none of the sawmills produced significantly different average lumber values (Figure 4.6) indicating that while different average lumber values were produced at each sawmill for highly elliptical logs, the different sawing methods did not result in significant average lumber value differences. When the treatment effect (low degree of ellipticality) was fixed, sawmill A, B, C and D produced significantly different average lumber value (Appendix 4.15, 4.16, and 4.17). The difference in the average lumber value amounts indicates that individual sawmill processing practices have a significant impact on the average lumber value. The difference in the average lumber value between sawmills and the degree of ellipticality is related to lumber grade derived from sawing low and high elliptical logs at individual sawmill.

While there is no significant difference in the average lumber value per log between low and highly ellipticality for the four sawmills, a significant interaction of the degree of ellipticality and the sawmill exists. Analysis of the average lumber value per log at each of the sawmills indicates that logs with a low degree of ellipticality produced either more or equal average lumber value per log.

4.6 - Impact of ellipticality on lumber grade

Since there was a difference in the average lumber value per log at sawmill A , B and D for low and high ellipticality logs, a study to determine the volume of lumber for each lumber grade was carried out. The data for the average lumber volume per log for each individual grade for low and highly elliptical logs recorded at the four sawmills is presented in Table 4.11. The average lumber volume per log for low ellipticality logs appears greater as compared to high ellipticality logs for all lumber grades except for 3A lumber grade; however, one must take into account the log diameter and scale differences between the two groups when looking at the raw output data.

Table 4.11. Average lumber volume per grade and log, for low and high ellipticality logs at sawmills

	FAS/1F (bft)		1C (bft)		2A (bft)		3A (bft)		CANT (bft)	
Sawmills	Low	High	Low	High	Low	High	Low	High	Low	High
A	84	55	27	30	19	16	5	6	22	21
B	42	61	44	24	45	26	0	0	21	16
C	41	25	54	55	32	35	0	0	19	21
D	58	57	25	21	25	28	12	12	17	12
Average (bft)	56	50	37	32	30	26	4	4	20	17
Stdev	20	17	14	15	11	8	6	6	3	4

Figures 4.7 and 4.8 indicate the average lumber grade distribution per log for low and high degrees of ellipticality. High-grade lumber production is the goal of any mill operation that strives to obtain the maximum value from sawing hardwood logs; however, many sawmills focus on lumber volume production and some combine and effort of maximize volume while attempting to achieve some grade recovery. The

effectiveness of any of these three strategies can only be determined when comparing the value of the total output. In this section, each lumber grade output is compared for low and high elliptical logs. It was hypothesized that differences in lumber grade output between the two levels of ellipticality may allow a sawing practice to maximize value output to be developed.

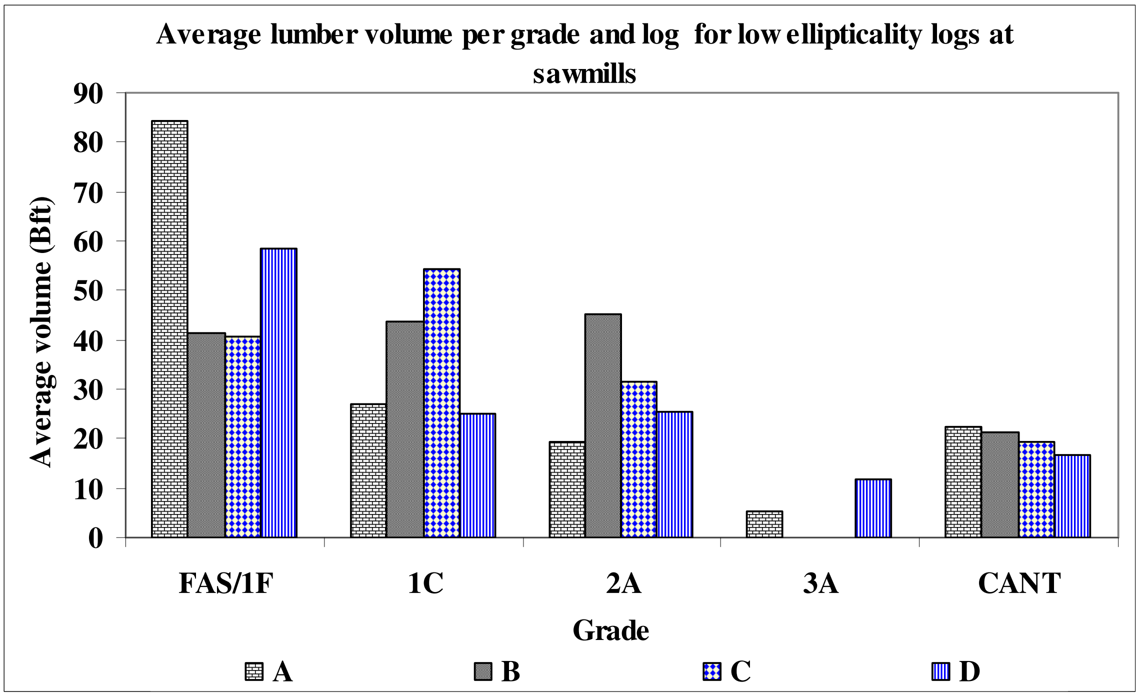

Figure 4.7. Average lumber volume per grade and log for low ellipticality logs at sawmills

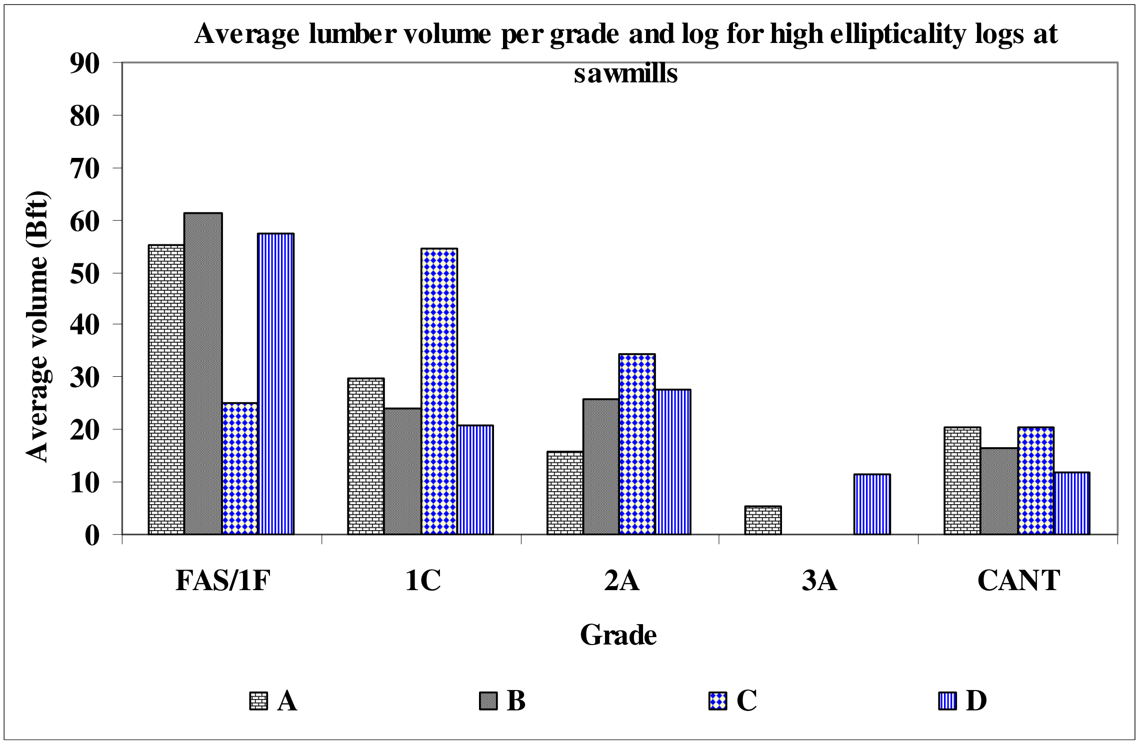

Figure 4.8. Average lumber volume per grade and log for high ellipticality logs at sawmills

4.6. 1 - FAS lumber grade

ANOVA was performed on the average lumber volume per grade and log produced by low and highly elliptical logs for FAS lumber grade at all sawmills. The null hypothesis was that the average lumber volume per log for FAS lumber grade for low and high ellipticality logs were equal. The alternative hypothesis was that the average lumber volume per log for FAS lumber grade for low and high ellipticality logs were not equal.

Table 4.12. Analysis of variance results for effect of ellipticality on the average lumber volume for FAS lumber grade per log

Source	DF	F Value	Pr > F
Sawmill	3	8.97	<0.01
Degree	1	1.26	0.26
Sawmill* Degree of ellipticality	3	4.32	<0.01

ANOVA results (Table 4.12) indicated that (p-value = 0.26) there was no significant difference between low and high ellipticality logs for the average lumber volume for FAS lumber grade production per log. However, there was a significant interaction between the degree of ellipticality and individual sawmill indicating that differences exist between the treatment effects (ellipticality) at individual blocks (sawmill) (Figure 4.9).

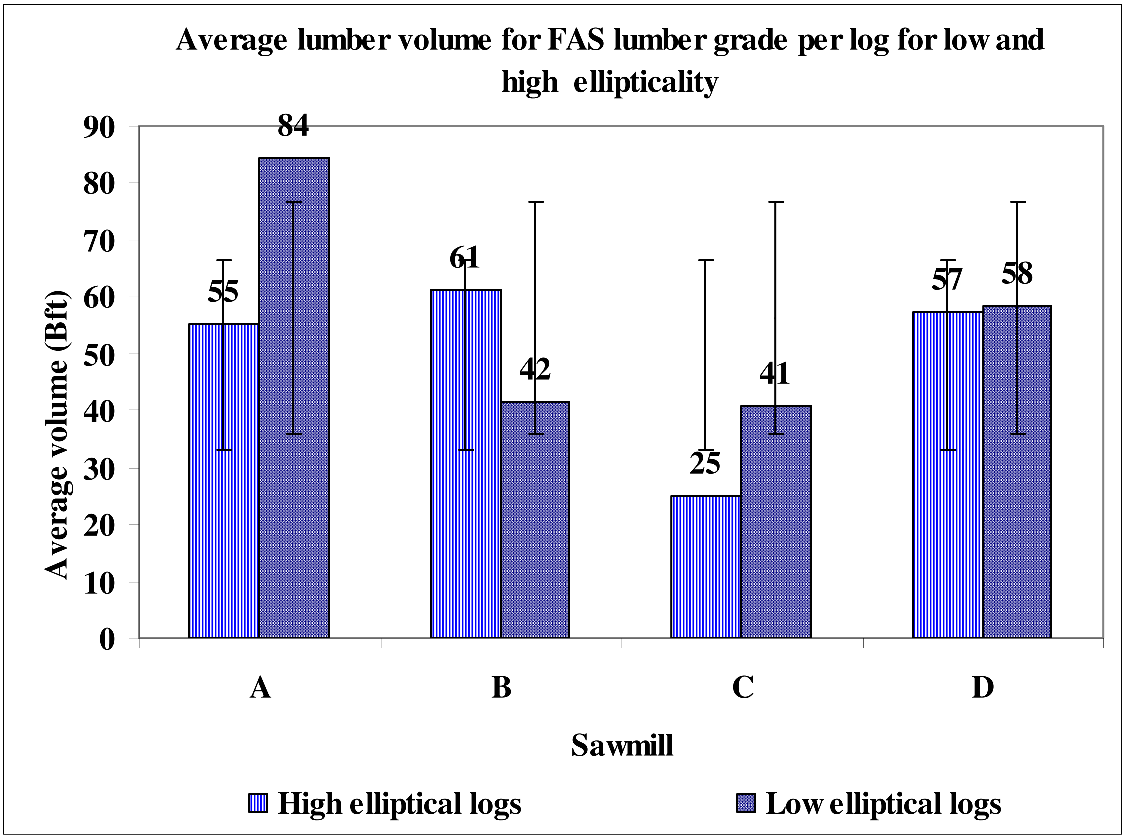

Figure 4.9. Average lumber volume for FAS lumber grade per log for low and high ellipticality

The 95% confidence interval of the average lumber volume for FAS lumber grade per log for low and high ellipticality logs is shown at each sawmill using a bar chart with error bars as illustrated in Figure 4.9. The error bars indicate potential error for the average FAS lumber volume per log graphically relative to low and high ellipticality logs.

Analysis of variance (Table 4.13) indicates a significant interaction between sawmill and the degrees of ellipticality at sawmill A. At sawmill A, logs with low ellipticality produced significantly more lumber volume of FAS (84 bft) than logs with high ellipticality (54 bft). At sawmill B, C, and D logs with low and high ellipticality did not produced significantly different FAS lumber volume. The failure of any of the four mills to produce more FAS from highly elliptical logs indicates that more FAS lumber cannot be processed from highly elliptical logs using current sawing methods.

Table 4.13. Output for ANOVA testing for the interaction at sawmill A, B, C, and D for the average lumber volume for FAS lumber grade per log

Sawmills	**DF**	**F Value**	**Pr > F**
A	1	8.14	<0.01
B	1	3.72	0.05
C	1	2.33	0.12
D	1	0.04	0.84

ANOVA using slice option was conducted between sawmills to determine if there is a difference upon sawing logs of each individual group of ellipticality. The null hypothesis was that the average lumber volume amounts at the four sawmills were equal for each degree of ellipticality of logs. The alternative hypothesis was that the average lumber volume amounts at the four sawmills were not equal for each degree of ellipticality.

Table 4.14. Test of effect sliced between sawmill with fixed degree of ellipticality for FAS lumber grade

Degree of ellipticality	DF	F Value	Pr > F
High	3	5.30	<0.01
Low	3	8.0	<0.01

When the treatment effect is fixed at low or high degrees of ellipticality, all sawmills produced significantly different FAS lumber volume (Table 4.14). The difference in FAS lumber volume produced at each mill indicates that individual sawmill processing practices have a significant impact on FAS lumber volume; however, as the previous analysis demonstrates, none of these processing differences result in greater production of FAS for highly elliptical logs (Table 4.13).

Analysis of FAS lumber volume amounts at each of the sawmills indicate that logs with high ellipticality do not produce more FAS lumber volume than logs with low ellipticality; even when different processing methods are used at each sawmill. It is actually possible to produce more FAS lumber volume with logs of low ellipticality.

4.6.2 - 1 Common and better lumber grade

ANOVA was performed on the average lumber volume per log produced by low and highly elliptical logs for 1Common and better lumber grade to determine if significant difference exists in the average 1 Common and better lumber volume per log produced by low and high ellipticality logs. The null hypothesis was that the average lumber volume per log for 1 Common and better lumber grade for low and high ellipticality were equal. The alternative hypothesis was that the average lumber volume per log for 1 Common and better lumber grade for low and high elliptical logs were not equal. Output data for lumber grade production for the four sawmills are indicated in Appendix 4.19, 4.20, 4.21, 4.22, 4.23, 4.24, 4.25, and 4.26.

ANOVA results (Table 4.15) indicated that (p-value = 0.10) there was no significant difference between low and high ellipticality logs for the average lumber volume per log for 1 Common and better lumber grade. However, there was a significant interaction between the degree of ellipticality and individual sawmill. The significant interaction indicates that differences must exist between the treatment effect (ellipticality) at individual blocks (sawmill) (Figure 4.11).

Table 4.15. ANOVA for the effect of ellipticality on the average lumber volume per log for 1 Common and better lumber grade

Source	DF	F Value	Pr > F
Sawmill	3	3.30	<0.01
Degree	1	2.74	0.10
Sawmill*Degree of ellipticality	3	2.33	0.07

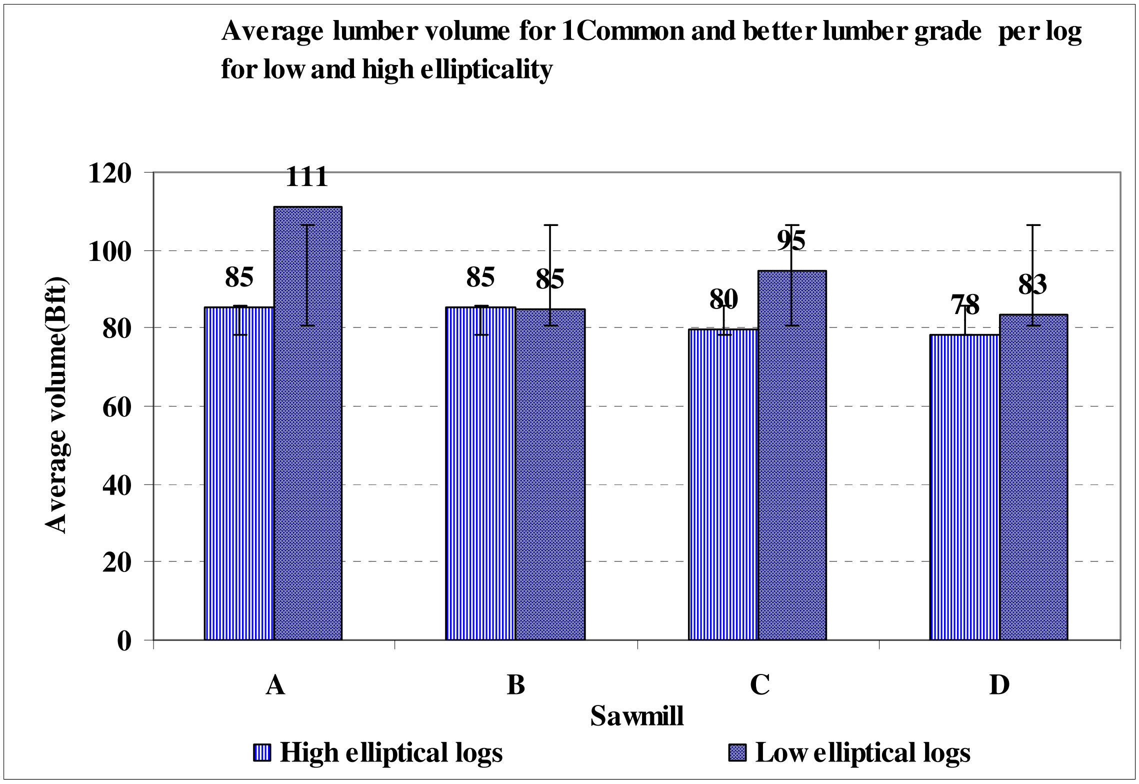

Figure 4.10. Average lumber volume for 1 Common and better lumber grade per log for low and high ellipticality

The 95% confidence interval of the average lumber volume for 1 Common and better lumber grade per log for low and high ellipticality logs is shown at each sawmill using a bar chart with error bars as illustrated in Figure 4.10. The error bars indicate potential error for the average lumber volume per log for 1 Common and better lumber grade graphically relative to low and high ellipticality logs.

Analysis of variance (Table 4.16) indicates significant interaction between sawmill and the treatment factor at sawmill A. The average 1Common and better lumber volume for log ellipticality differs for sawmill A. Low elliptical logs produced significantly more average 1Common and better lumber volume as compared to high elliptical logs at sawmill A.

Table 4.16. Output for ANOVA testing for the interaction at sawmill A, B, C, and D for the average lumber volume per log for 1 Common and better lumber grade

Sawmills	DF	F Value	Pr > F
A	1	7.32	<0.01
B	1	0.38	0.54
C	1	1.98	0.16
D	1	0.04	0.85

To further validate that different processing methods were used at each sawmill, resulting in different average 1Common and better lumber volume, an ANOVA using slice option was conducted between sawmills to determine if there is a difference upon sawing logs of each individual group of ellipticality. The null hypothesis was that the average lumber volume per log at the four sawmills were equal for each degree of ellipticality of logs. The alternative hypothesis is that the average lumber volume per log at the four sawmills were not equal for each degree of ellipticality.

When the treatment effect (high degree of ellipticality) is fixed, all sawmills did not produce significantly different average 1Common and better lumber volumes (Table 4.17). When the treatment effect (low degree of ellipticality) is fixed, all sawmills produce significantly different average 1 Common and better lumber volume. The difference in the average 1 Common and better lumber volume per log indicates that individual sawmill processing practices has a significant impact on the average 1 Common and better lumber volume production.

Table 4.17. Test of effect sliced between sawmill with fixed degree of ellipticality for 1Common and better lumber grade

Degree of ellipticality	DF	F Value	Pr > F
High	3	1.00	0.39
Low	3	4.62	<0.01

Analysis of the average 1 Common and better lumber volume per log at each of the sawmills indicates that logs with different degrees of ellipticality can produce different amounts of the average 1 Common and better lumber volume depending on how they are processed. These results confirm the findings of the previous section, where the average lumber value per log was analyzed for both low and high ellipticality logs.

4.6. 3 - Other lumber grades

An analysis was then carried out on other grades (1Common, 2A, and the cant) to determine which degree of ellipticality produced the highest average lumber volume. An ANOVA was performed on the average lumber volume per log produced by low and highly ellipticality logs for 1Common, 2A and cant lumber grade. The null hypothesis was that the average lumber volume per log for each lumber grade; 1Common, 2A and cant for low and high ellipticality were equal. The alternative hypothesis was that the average lumber volume per log for each lumber grade; 1Common, 2A and cant lumber grade for low and high elliptical logs were not equal.

ANOVA results indicated that there was no significant difference (p-value = 0.14) between low and high ellipticality logs for 1Common lumber grade production (Appendix 4.27), there was no significant difference (p-value = 0.89) between low and high ellipticality logs for 2A lumber grade production (Appendix 4.28), there was no significant difference (p-value = 0.20) between low and high ellipticality logs for cant lumber grade production (Appendix 4.29). However, for 1Common grade, 2A, and the cant lumber grade there was a significant interaction between the degree of ellipticality and individual sawmill. The significant interaction indicates that differences must exist between the treatment effects (ellipticality) at individual blocks (sawmill) (Figure 4.11, Figure 4.12, and Figure 4.13).

ANOVA using slice option indicates significant interaction between sawmill and the degree of ellipticality at sawmill B for 1Common lumber grade (Appendix 4.30). At sawmill B logs with low ellipticality produced significantly more 1Common lumber volume (44 bft) than logs with high ellipticality (24 bft). For 2A lumber grade, ANOVA using slice option also indicates significant interaction between sawmill and the degree of ellipticality at sawmill A and B (Appendix 4.31). At sawmill A and B logs with low ellipticality produced significantly more 2A lumber volume than logs with high ellipticality.

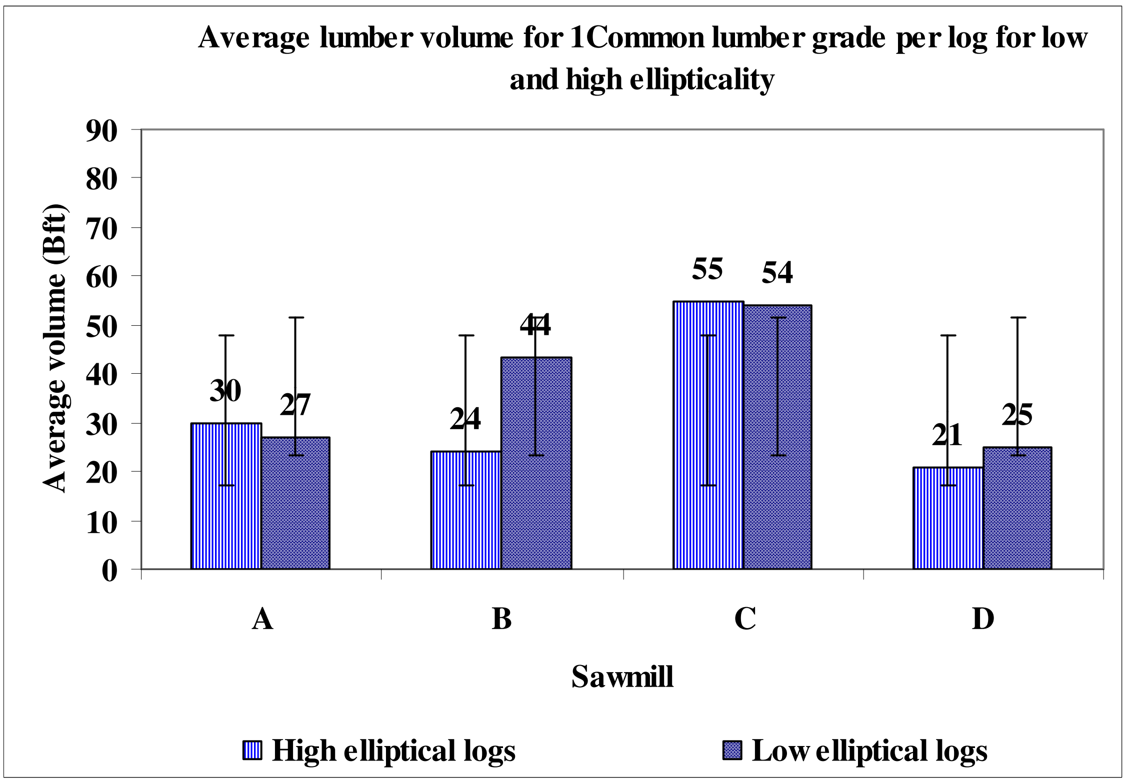

Figure 4.11. Average lumber volume for 1 Common lumber grade per log for low and high ellipticality

The 95% confidence interval of the average lumber volume per log for 1Common, 2A, and the cant lumber grade for low and high ellipticality logs is shown for each sawmill using a bar chart with error bars as illustrated in Figure 4.11, 4.12, and 4.13. The error bars indicate potential error for the average lumber volume per log for 1

Common, 2A, and the cant lumber grade graphically relative to low and high ellipticality logs.

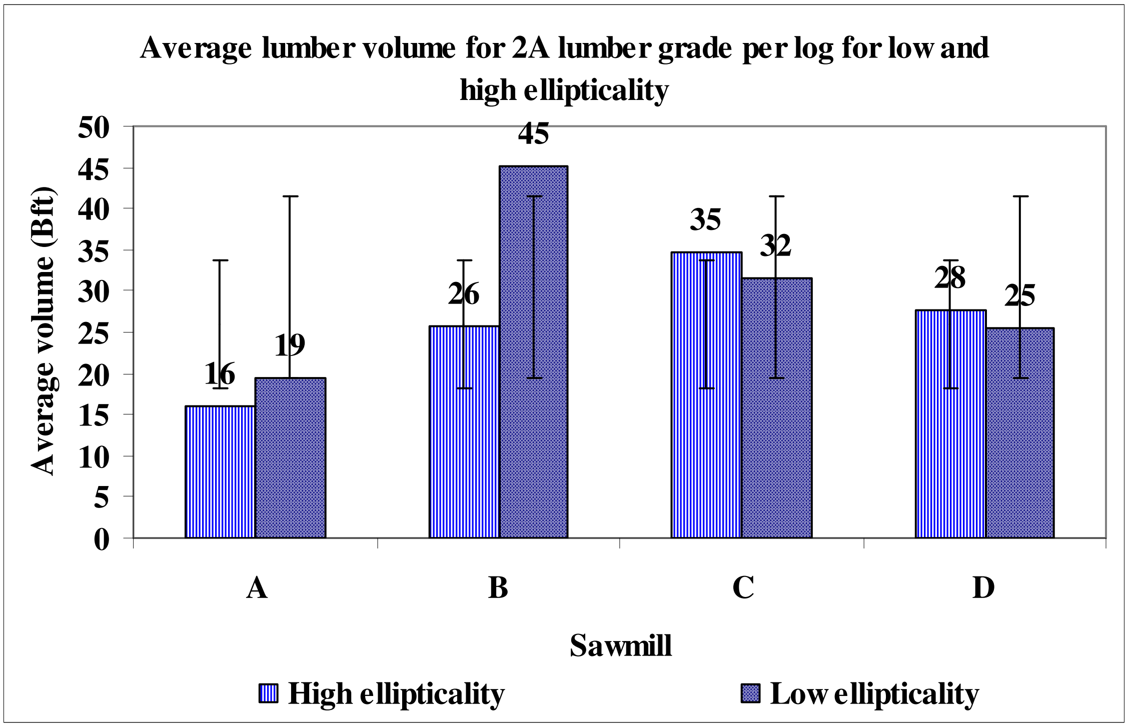

Figure 4.12. Average lumber volume for 2A lumber grade per log for low and high ellipticality

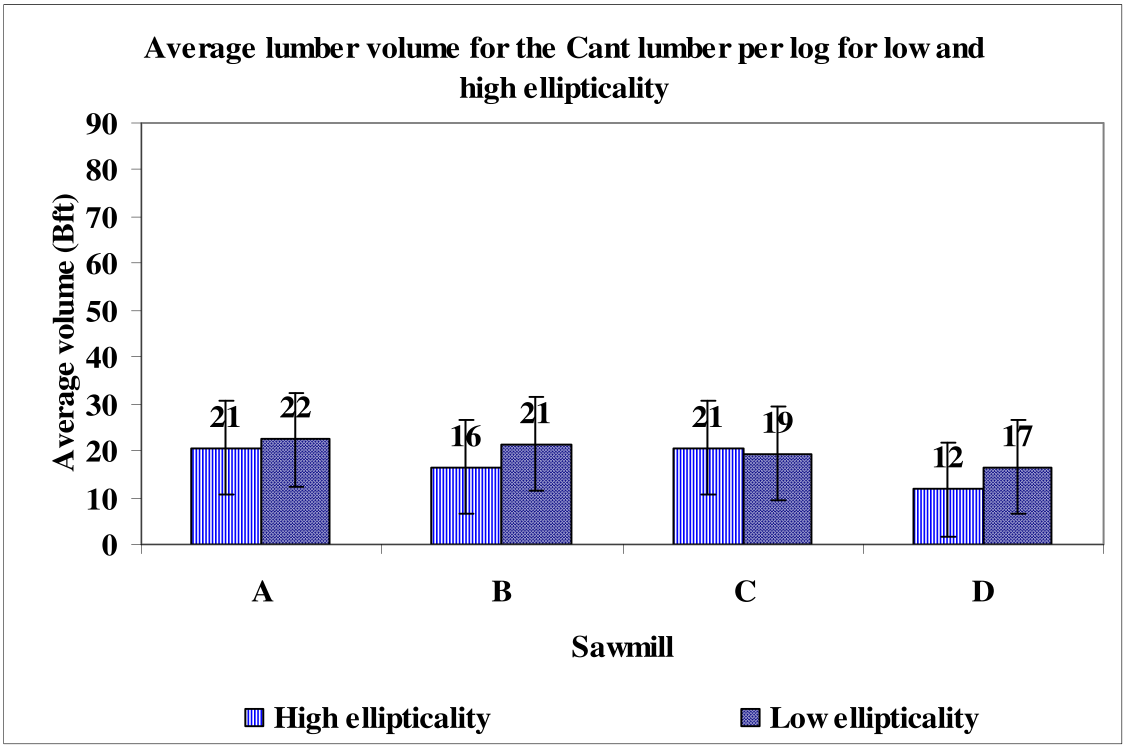

Figure 4.13. Average lumber volume for the cant lumber per log for low and high ellipticality

4.6.4 - Summary of overrun, lumber volume, and lumber value

There was no significant difference between the average overrun, lumber volume, and lumber values per log for low and high ellipticality logs for the four sawmills. However, for the average overrun, lumber volume, and lumber value per log, the analysis indicates a significant difference in the variable sawmill and a significant interaction between sawmill and the degree of ellipticality. The significant interaction indicated that difference exists between the treatment effects (ellipticality) at individual blocks (sawmills) (Figure 4.4, 4.5, and 4.6).

Analysis of average overrun values per log at each of the sawmills indicated that logs with different degrees of ellipticality can produce higher, lower and equal amounts of average overrun depending on how they are processed. Analysis of the average lumber volume per log indicated that while there was no significant difference in the average lumber volume between low and high ellipticality logs when comparing the average volume per log for all four sawmills, when comparing these variables at individual sawmills differences occurred. The differences between mills suggested that logs with low ellipticality can produce equal or higher average lumber volume output. Analysis of the average lumber value per log at each of the sawmills indicated that logs with a low degree of ellipticality produced either more or equal average lumber value per log.

Finally, analysis of the average 1 Common and better lumber volume per log at each of the sawmills indicated that logs with different degrees of ellipticality produced different amounts of the average 1 Common and better lumber volume depending on how they were processed.

4. 7 - Log processing variables

During sawing hardwood logs are generally processed on four faces by turning the log on the carriage between selected cuts in an effort to maximize the yield of higher-grade lumber. Since it is believed that sawyer's process elliptical logs using the same methods as round logs, focusing on external visible defects, a study to determine the impact of the degree of ellipticality on the processing method was carried out. The effect of ellipticality on log processing strategies was studied by quantifying the average number of turns at the headrig, the average number of sawlines, and the average elapsed time of sawing at the headrig. These three measures were compared at individual mill to determine if log ellipticality affected how logs were processed. Analysis of the data was carried out for each individual mill and included a total of 120 logs encompassing 60 logs of low ellipticality and 60 logs of high ellipticality. Tukey's (HSD) test was performed to compare means at alpha level equal 0.05.

4.7.1 - Number of log turns

Data was recorded for the average number of turns per log and the total elapsed time at the headrig (the total time the saw was in wood until when the square cant was unloaded), the average number of sawlines from the headrig to the band resaw and gangsaw (measured by the number of board that was produced at the gangsaw). Sawmill B (the fourth and last to be visited) was not included due the lack of assistance in data collection during that time period. Each sawmill had different equipment and layout (headrig, band resaw, and gangsaw). While all logs were sawn at the headrig at sawmill C (the gangsaw was not used during the study), for sawmill A and D logs were sawn at the headrig and the square cant was then conveyed to the band resaw. Figure 4.14 illustrates the average log turns per degree of ellipticality at individual mills.

The effect of the degree of ellipticality on the average number of log turns/rotation per log was tested for logs with low and high ellipticality. The null hypothesis was that the average number of log turns per log for low and high ellipticality were equal. The alternative hypothesis was that the average number of log turns per log for low and high elliptical logs were not equal.

For sawmills that utilized band resaws (Mills A and D) as a secondary breakdown method, there was a significant difference (p-value <0.01) between the average number of log turns per log for low and high ellipticality logs. On average, high elliptical logs required one more turn than low ellipticality logs. For the mill that processed all lumber on the headrig there was an average of two more turns per log for highly elliptical logs (Mill C). The significant difference between the average number of turns per log for low and high ellipticality logs indicates that the degree of ellipticality of log likely had an impact on the sawyer’s decision time when selecting how to turn individual logs.

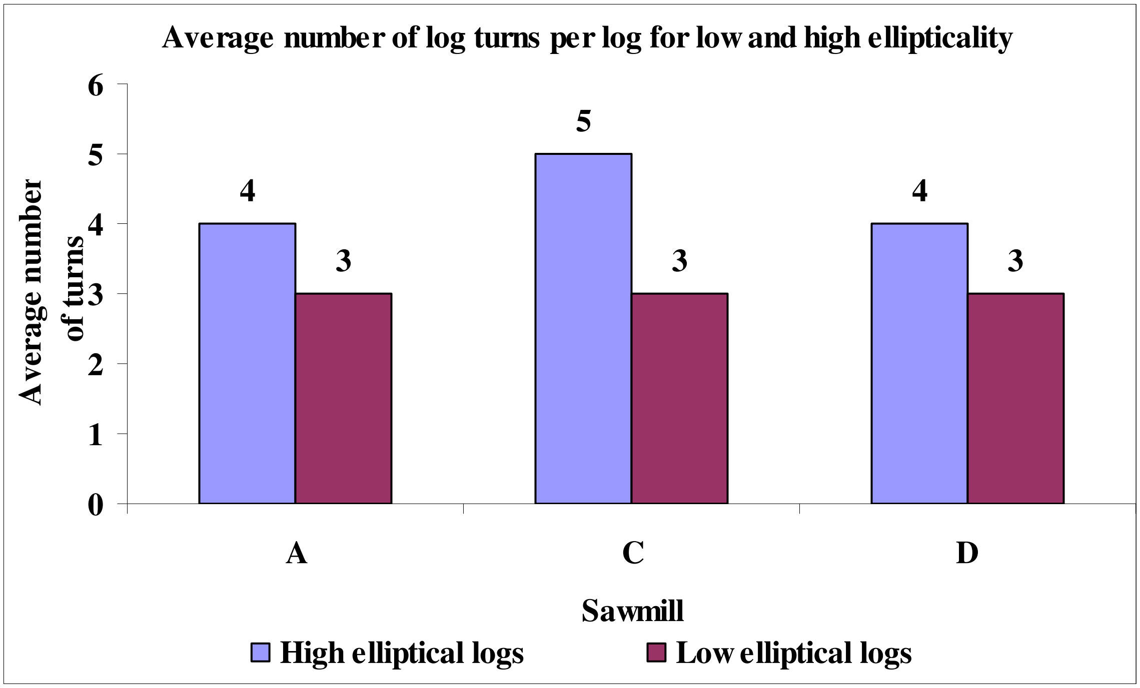

Figure 4.14. Average number of log turns per log for low and high ellipticality

4.7.2 - Number of sawlines

The average number of sawlines per log for low and high elliptical logs is illustrated in Figure 4.15. The effect of the degree of ellipticality on the average number of sawlines per log was tested for logs with low and high ellipticality. The null hypothesis was that the average number of sawlines per log for low and high ellipticality logs were equal. The alternative hypothesis is that the average number of sawlines per log for low and high ellipticality logs were not equal.

For sawmills that utilized band resaws (Mills A and D) as a secondary breakdown method, there was a significant difference (p-value = 0.03) between the average number of sawline per log for low and high ellipticality logs. On average, high elliptical logs required three more sawlines per log than low elliptical logs. For the mill that processed all lumber on the headrig, there was an average of two more sawlines per log for highly elliptical logs (Mill C). The significant difference between the average number of sawlines per log for low and high elliptical logs likely indicates that the degree of ellipticality of log had an impact on the sawyer's decision time when selecting how to process individual logs.

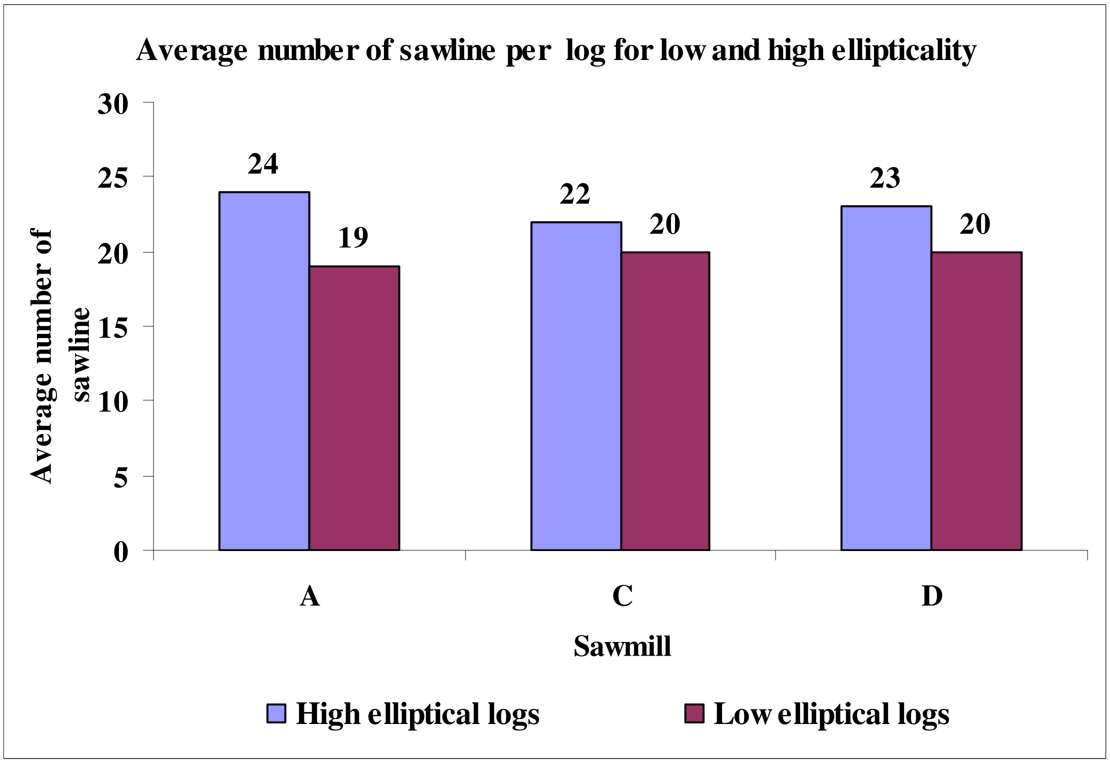

Figure 4.15. Average number of sawline per log for low and high ellipticality

4.7.3 - Sawing time

More sawing time was required at all three sawmills for logs with high ellipticality than for logs with low ellipticality (Figure 4.16). The effect of the degree of ellipticality on the average sawing time per log was tested using ANOVA for logs with low and high ellipticality. The null hypothesis was that the average sawing time per log for low and high elliptical logs were equal. The alternative hypothesis was that the average sawing time per log for low and high were not equal. For sawmills that utilized band resaws as a secondary breakdown method (Mills A and D), there was a significant difference (p-value = 0.03) between the average sawing time per log for low and high elliptical logs. At these two sawmills, on average, high elliptical logs required thirty-seven more seconds sawing time than low elliptical logs. For the mill that processed all lumber on the headrig, there was an average of thirty-two seconds more sawing time per log for highly elliptical logs (Mill C). The significant difference between the average sawing time per log for low and high elliptical logs indicates that the level of ellipticality of logs had an impact on the sawyer's decision time when selecting how to process individual logs.

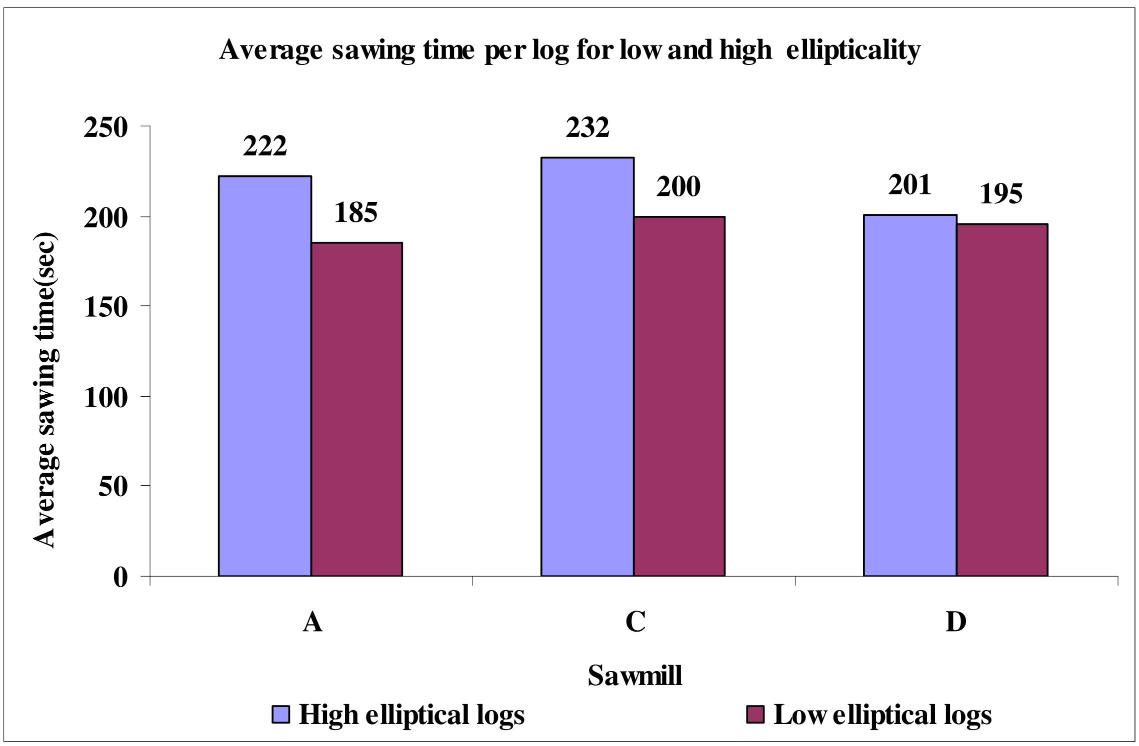

Figure 4.16 Average sawing time per log for low and high ellipticality

4.7.4 - Summary of processing variable differences

Each sawmill had different equipment and layout (headrig, band resaw, and gangsaw). While all logs were sawn at the headrig at sawmill C (the gangsaw was not used during the study), for sawmill A and D logs were sawn at the headrig and the square cant was then conveyed to the band resaw.

Low and high elliptical logs have significantly different processing variables (number of turns, sawing time and number of sawlines) at each individual mill. High ellipticality logs required more processing time than low ellipticality logs.

For sawmills that utilized band resaws (Mills A and D) as a secondary breakdown method, on average, high elliptical logs required one more turn, three more sawlines, and thirty-seven more seconds sawing time per log than low ellipticality logs. For the mill that processed all lumber on the headrig there was an average of two more turns, two more sawlines, and thirty-two seconds more sawing time per log for highly elliptical logs (Mill C).

While it was not possible to definitively determine if shape affected sawing decisions, high ellipticality logs did require more processing time due to differences in equipment used by individual sawmill, since the trend between low and high ellipticality logs is significant for turns, number of sawlines, and sawing time at the three sawmills, it is likely that the sawyer decision time was based on logs shape. Therefore sawing highly elliptical red oak logs for grade production call for more attention. Future studies will need to focus on controlling the sawmill equipment variables to be more conclusive.

4. 8 - Effect of sawline orientation on lumber grade for low and high elliptical logs

The position of the first sawline determines how the following cuts will be carried out and influences the lumber grade that will be produced. It is hypothesized that differences in sawline orientation such as sawing perpendicular to the major axis, sawing perpendicular to the minor axis, and sawing between the major and minor axis affects 1 Common and better lumber grade production for low and high ellipticality logs. If such a difference exists, then an ideal sawing method for highly elliptical logs could be developed.

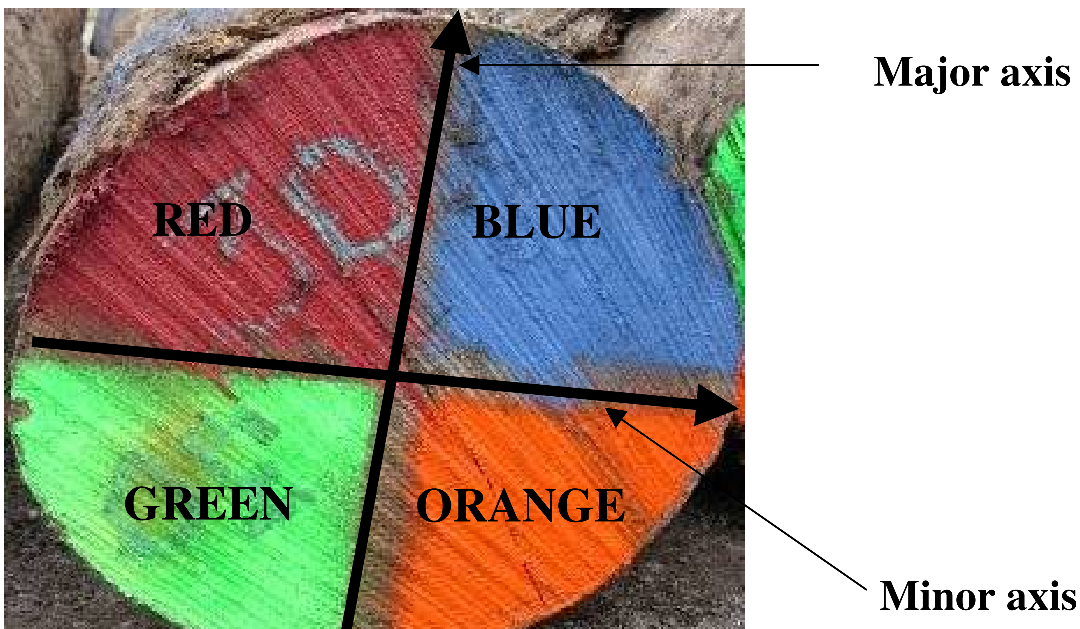

Figure 4.17. Major and minor axis of an elliptical log

Figure 4.17 indicates how color was mapped to sawline orientation. Sawlines oriented BR and GO have the same sawing orientation. These sawlines are perpendicular to the major axis. Sawlines oriented GR and OB have the same sawing orientation. These sawlines are perpendicular to the minor axis. Sawlines oriented BB, GG, OO, and RR have the same sawing orientation. These sawlines are located between the major and minor axis. There are 3 main sawlines orientation (GO, GR, and GG) illustrated in Table 4.22 that were used for analysis purposes.

A study was carried out on the average 1Common and better lumber volume produced by low and high elliptical logs to determine whether there were significant differences due to sawline orientation. Tukey's (HSD) test was performed to compare means at alpha level equal 0.05. The analysis was performed for the average 1 Common and better lumber volume produced for: (1) sawlines perpendicular to the major axis, (2) sawlines perpendicular to the minor axis, and (3) sawline oriented between the major and minor axis. The data for the average 1Common and better lumber volume produced by the two treatments factors (low and high degree of ellipticality) is presented in Table 4.18.

Table 4. 18. Average 1Common and better lumber volume production per sawline orientation for high and low ellipticality logs

Sawline orientation	High ellipticality logs (bft)	Low ellipticality logs (bft)
GO = sawline perpendicular to the major axis	35	35
GR = sawline perpendicular to the minor axis	32	24
GG = sawline between the major and minor axis	16	21

For low ellipticality logs, the null hypothesis was that the average 1 Common and better lumber volume amounts were equal for sawline perpendicular to the major axis, sawline perpendicular to the minor axis, and sawline between the major and minor axis. The alternative hypothesis was that the average 1 Common and better lumber volume amounts were not equal for sawline perpendicular to the major axis, sawline perpendicular to the minor axis, and sawline between the major and minor axis. ANOVA results (Table 4.19) indicated that (p-value = 0.02) there was significant difference in the average 1 Common and better lumber volume produced by sawing perpendicular to the minor axis, sawing perpendicular to the major axis and sawing between the major and minor axis for low elliptical logs. Sawing perpendicular to the major axis and sawing perpendicular to the minor axis did not produce significantly different 1 Common and better lumber volume. Sawing perpendicular to the minor axis and sawing between the major and minor axis did not produce significantly different lumber volume for low ellipticality logs. This result suggests that differences between sawing orientations have little effect on grade lumber production for low elliptical logs. Grade sawing or sawing with regard to defect location will likely have a greater impact on high grade lumber volumes than log shape.

Table 4.19. Effect of sawline orientation on 1Common and better lumber grade for low ellipticality logs

Sawline orientation*	Mean of 1 Common and better (bft)	Tukey's grouping at $\alpha = 0.05$	
GO= sawline perpendicular to the major axis	35	A	
GR = sawline perpendicular to the minor axis	24	A	B
GG = sawline between the major and minor axis	21		B

* Sawline orientations with the same letter (i.e. A or B) are not significantly different

For high ellipticality logs, the null hypothesis was that the average 1 Common and better lumber volume amounts were equal for sawline perpendicular to the major axis, sawline perpendicular to the minor axis, and sawline between the major and minor axis. The alternative hypothesis was that the average 1 Common and better lumber volume amounts were not equal for sawline perpendicular to the major axis, sawline perpendicular to the minor axis, and sawline between the major and minor axis. ANOVA results (Table 4.20) indicated that (p–value < 0.01) there was significant difference between sawline orientation for 1Common and better lumber volume production for highly elliptical logs. The significant difference in sawline orientation for highly elliptical logs indicates that different sawing orientations can produce different lumber volumes of high grade lumber. Sawing perpendicular to the major axis and sawing perpendicular to the minor axis did not produce significantly different average 1 Common and better lumber volume. Sawing between the major and minor axis produced significantly less average 1 Common and better lumber volume for high ellipticality logs than sawing perpendicular to the minor axis and the major axis.

Table 4.20. Effect of sawline orientation on 1Common and better lumber grade for high ellipticality logs

Sawline orientation*	Mean of 1 Common and better (bft)	Tukey's grouping at $\alpha = 0.05$	
GO = sawline perpendicular to the major axis	35	A	
GR = sawline perpendicular to the minor axis	32	A	
GG= sawline between the major and minor axis	16		B

*Sawline orientations with the same letter (i.e. A) are not significantly different

Figure 4.18 illustrates the distribution of the average 1Common and better lumber volume for the three main sawing orientations for low and high elliptical logs.

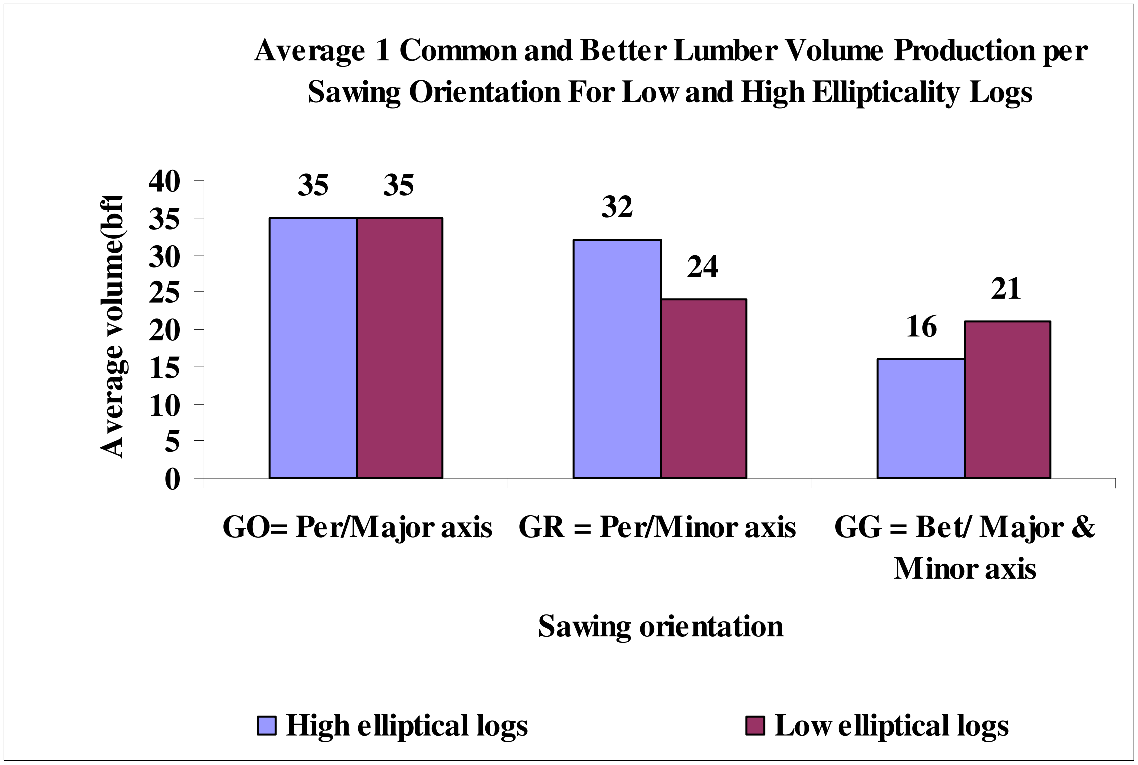

Figure 4.18. Average 1 Common and better lumber volume production per sawline orientation for low and high ellipticality logs

For high elliptical logs, there are two optimal processing methods for producing 1 Common and better lumber grade. These include: sawing the log perpendicular to the major axis and sawing the log perpendicular to the minor axis. These findings seem to follow Lewis' suggestions. Lewis (1985) suggested that the best way to recover the maximum lumber grade from elliptical logs is to position the major axis up (that is perpendicular to the minor axis) for extra width in the side pieces and a potential extra piece in the cant, or orienting the minor axis up (that is perpendicular to the major axis) in attempt to increase yield from wider cants and extra side pieces.

4.9. - Impact of painted ends on sawline orientation

During this study the small end of the logs were painted in order to keep track of the location where lumber grade was produced. As the mill studies progressed, it became a concern that the different colors selected (blue, green, orange, and red) to paint the logs may have impacted a sawyer's decision in choosing the first opening face. If the orientation of the colors impacted the sawyers' decision in selecting the first cut then they would introduce a bias in the sawline orientation analysis; therefore, an analysis was undertaken to determine if the colored quadrants impacted the sawyers' decision.

The first cut made on each of the one hundred twenty logs used for this study was analyzed. An analysis of the position of the first cut was carried out from images captured by the video camera used in analyzing processing variables. The data obtained was the number of sawlines made in one of three possible orientations. This data was categorical/count data and required the use of the Chi-square test (Ott and Longnecker, 2001). Chi-square test was conducted on the number of first sawlines perpendicular to the major axis, the number of sawlines perpendicular to the minor axis, and the number of sawlines oriented between the major and minor axis of the log. Table 4.21 indicates the number of originating sawlines recorded for high and low elliptical logs per orientation of the axis at three sawmills. Figure 4.20 depicts the orientation of first cut per axis for each degree of ellipticality.

Table 4.21. Number of sawline for low and high ellipticality logs per orientation of the axis

Sawline orientation	High ellipticality log	Low ellipticality log
Sawline perpendicular to the major axis of the log **(Perp/Maj. Axis)**	33	22
Sawline between the major and minor axis of the log **(Bet/Maj &Min axis)**	19	22
Sawline perpendicular to the minor axis of the log **(Perp/Min. axis)**	8	16
Total number of sawline	60	60

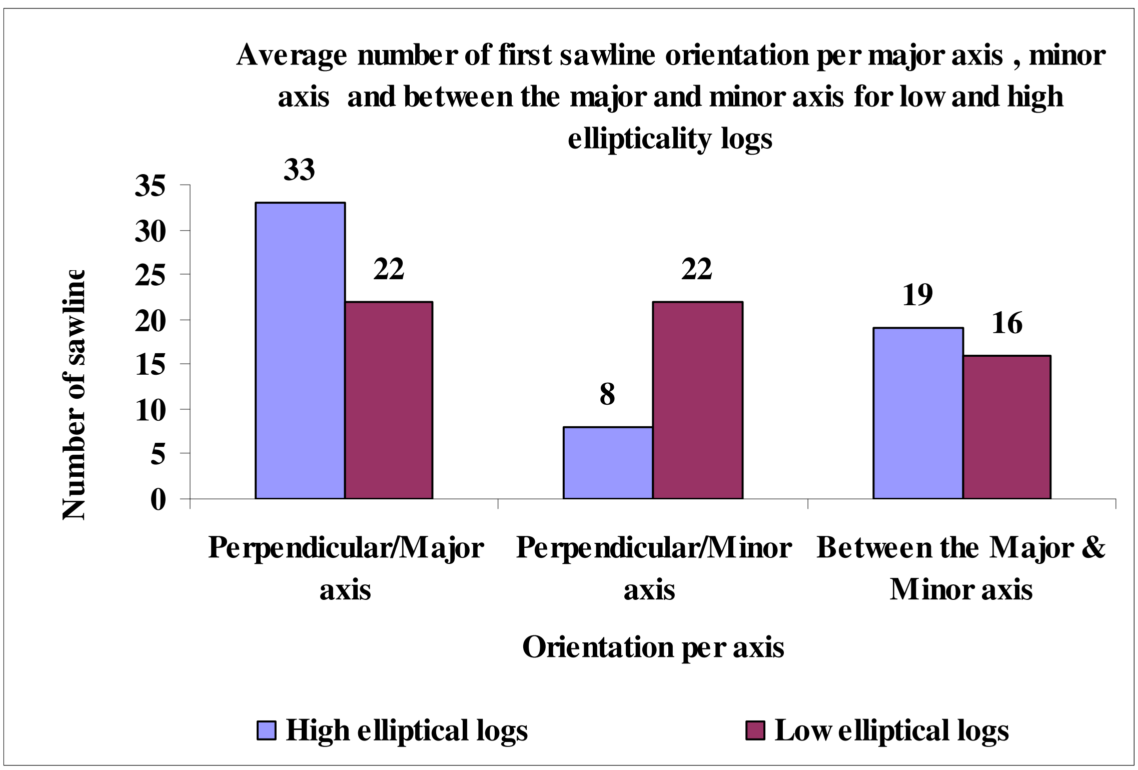

Figure 4.19. Average number of first sawline orientation per major axis, minor axis, and between the major and minor axis for low and high ellipticality logs

Perpendicular / Major Axis = Sawline perpendicular to the major axis of the log

Between the Major &Min axis = Sawline between the major and minor axis of the log

Perpendicular / Minor axis = Sawline perpendicular to the minor axis of the log

For low ellipticality logs, the null hypothesis was that the number of first sawlines for the three sawing orientation were equal. The alternative hypothesis was that the number of first sawlines for the three sawing orientation were not equal. The Chi-square test indicated that there is no significant difference ($p\text{-value} = 0.54$) between the orientation of first cut for low ellipticality logs. The lack of differences between first sawline orientation indicates that the color of the paint at the log small end did not influence the sawyer's decision when selecting the first cut since no one quadrant was chosen more often than another.

For high ellipticality logs, the null hypothesis was that the number of first sawlines for the three sawing orientation were equal. The alternative hypothesis was that the number of first sawlines for the three sawing orientation were not equal. There was a significant difference ($p\text{-value} < 0.01$) between orientations of first cut for high ellipticality logs. The significant difference between orientations of the first cuts for high ellipticality logs indicates that either shape or painted color on the logs influenced the sawyer's decision when making the first cut. Cuts perpendicular to the major axis were chosen more often than the others for high ellipticality logs.

Among the three sawing strategies there was much more variability in making the first cut for high than low ellipticality logs. While it is not possible to definitively determine that the painted end did not affect the sawyer decision for logs with high ellipticality, since the trend between high and low ellipticality logs was significantly different indicates that the sawyer decision was based more on log shape than on the painted color at the log small end.

4.10 – Summary of differences in ellipticality

There was no significant difference in the average overrun, lumber volume, lumber value, and lumber grade between low and high ellipticality logs for the four sawmills. There was a significant difference in the average overrun, lumber volume, lumber value, and lumber grade between low and high ellipticality logs for some of the individual sawmills. There was an interaction between the degree of ellipticality and sawmill. The strong interaction between the variables overrun, volume and value for the individual blocks (sawmills) made comparison of the treatment effect (ellipticality) necessary at each individual sawmills. This result strongly indicates that how logs are processed at individual mills influences the potential outcome for each variable tested.

High elliptical logs produced an average of 10% more overrun than low ellipticality logs at sawmill C but did not produce more average lumber volume than low elliptical logs. Logs with low ellipticality either produced equal average overruns (sawmills B and D) or 11% higher average overruns (A). Low elliptical logs either produced the same average volume as high (sawmills C and D) or 35 bft and 28 bft higher average volumes of lumber than high elliptical logs (Sawmills A and B). High elliptical logs produced the same average value of lumber output (sawmill B, C, and D) or $10 less average value (sawmill A). These results indicate that high elliptical logs can be expected to produce less or equal average volume and value of lumber than low ellipticality logs.

The goal of hardwood sawmills is to maximize value from sawing logs. This can be done by obtaining the maximum lumber grade, focusing on total lumber volume or some combination of these two strategies. This study indicates that high ellipticality logs do not produce more value than low ellipticality logs using current sawing methods. When determining the effectiveness of these two strategies the value of the total output was compared, it was determined that logs with high ellipticality do not produce more 1 Common and better lumber than logs with low ellipticality; even when different processing methods were used. It is actually possible to produce more 1 Common and better lumber with logs of low ellipticality. Highly elliptical logs do not produce more lumber of any grade than low elliptical logs.

High ellipticality logs required more processing time than low ellipticality logs in terms of log turns/rotation, total elapsed time at the headrig, and number of sawlines at the headrig. The increased processing time results in increased processing costs. For example, hardwood operating cost have been estimated between $2.25 per minute to more than $20 per minute for more sophisticated sawmill (Mayer and Wiedenbeck 2005) and highly elliptical logs require an average of 34 more seconds to produce or $1.28 to $11.33. The estimated cost per sawline is $0.68 for mills using sophisticated technology in processing logs (Peskar, 2002) and with high ellipticality logs requiring three additional sawlines on average, an estimated increased processing cost of $2.04 per log. High elliptical logs also require an average of one more turn than low elliptical logs and it has been estimated that one log turn costs $0.25 (Wengert, 1998). The estimated increased processing cost for a high ellipticality log is $1.28 to $11.33 per log. These costs are not offset by an increase in lumber volume nor lumber value; therefore, highly elliptical sawlogs are less desirable to process than low elliptical logs using current sawing methods.

There is likely more potential for producing 1 Common and better lumber grade with the grade sawing method for low ellipticality logs. Sawing perpendicular to the major axis or perpendicular to the minor axis considering log small end diameter produces greater 1 Common and better lumber grade for high ellipticality logs.

CHAPTER 5 – SUMMARY AND CONCLUSIONS

The purpose of this research was to determine if current sawing methods are sufficient for processing both low and high elliptical red oak sawlogs. The objectives were to determine if green lumber volume, grade and value recovery differences exist between low and highly elliptical red oak logs and to determine differences in the processing variables: number of turns, sawing time and number of sawlines for low and highly ellipticality logs

It was determined that there was no significant difference in overrun, lumber volume, lumber value, and lumber grade between low and high ellipticality logs when comparing the log output at all four sawmills. It was determined that how an individual sawmill processes logs affects the outcome between logs with high and low ellipticality. None of the sawmills produced more value for high elliptical logs than for low elliptical logs and it was possible to produce more lumber volume and value with low elliptical logs.

The study also determined differences in the processing variables: number of turns, sawing time and number of sawlines for low and highly ellipticality logs. Sawing practices at individual mills have shown a significant impact on lumber grade produced and lumber volume recovered. Two sawing orientations were observed under current sawing methodology for elliptical logs: sawing perpendicular to the major axis and sawing perpendicular to the minor axis. High ellipticality logs required more processing time than low elliptical logs in terms of log turns/rotation, total elapsed time at the headrig, and number of sawlines at the headrig. The increased processing time results in increased processing costs. The estimated increased processing cost for highly elliptical log was $1.28 to $11.33 per log. These costs are not offset by an increase in lumber volume nor lumber value; therefore, highly elliptical sawlogs are less desirable to process than low ellipticality logs using current sawing methods. Sawmills should be aware that this study indicates that there is no significant difference in green lumber value from processing low and high ellipticality logs and that processing costs are higher for high elliptical logs.

This study indicated that more 1 Common and better lumber grade can be derived from sawing elliptical logs perpendicular to their major axis (i.e. longest diameter) on the small end and more processing time was required for highly elliptical logs.

5-1 - Limitations

There were several limitations to this study. One was the small sample size of sawmills (four) that participated in the study that may have an impact on our findings. In addition, the sawmill processing equipment was not a controlled factor, logs were occasionally sawn by different sawyers, processing time was recorded for sawmills using different processing equipment as a secondary breakdown method. There were significant log scale differences between the two sample groups (low and high ellipticality); however, the statistical analysis used (Factorial ANOVA with length and scaling diameter) took into account this variability. Some boards may have been lost during the studies therefore influencing both volume and value comparisons. Most boards that were derived from slabs and did not meet the coverage criteria were not recorded for the quadrant study and may have influenced both lumber value and volume comparisons, in particular those for highly elliptical logs.

5-2 – Future research

Several areas can be covered for future work based upon ideas developed in this study. Among the many areas, approaches could include:

- Experimenting the two degrees of ellipticality with other log species besides red oak;
- Collecting lumber data at mills using the same type of sawing equipment;
- Collecting lumber data at more than four sawmills;
- Tallying only lumber data sawn by the same sawyer at each sawmill;
- Selecting sample logs with the same diameter and length;
- Expanding the range of the degree of ellipticality;
- And finally, determining the effect of the processing time for low and high ellipticality logs.

All of the above mentioned approaches could be of importance to determine the optimal processing solution for elliptical logs.

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APPENDIX

Appendix 4.1. Input data at sawmill A for low ellipticality logs

Log #	Major Axis (inches)	Minor Axis (inches)	Ellipticality	Length (ft)	Scaling Diameter (inches)	Log scale [(Int.1/4") bft]	Lumber volume (bft)	Overrun (%)
1	14.25	13.75	0.26	12	14	100	100	0.0
2	16	15.25	0.30	10	16	110	154	40.0
3	14	13.75	0.18	12	14	110	140	27.3
4	18	17.5	0.23	10	18	140	188	34.3
5	17	16.5	0.24	10	17	125	147	17.6
6	16.75	16.5	0.17	12	17	150	174	16.0
7	15.5	15	0.25	10	15	95	105	10.5
8	17	16.5	0.24	10	17	125	145	16.0
9	14.25	13.75	0.26	12	14	110	140	27.3
10	14.25	14.25	0	12	14	110	119	8.2
11	18.25	18	0.16	12	18	170	174	2.4
12	17.25	16.75	0.23	12	17	150	160	6.7
13	15.75	15.75	0	12	16	130	139	6.9
14	17.75	17.25	0.23	12	18	170	192	12.9
15	17	16.25	0.29	12	17	150	171	14.0
16	16.25	15.5	0.30	12	16	130	167	28.5
17	17	16.25	0.29	12	17	150	190	26.7
18	18	17.25	0.28	10	18	140	153	9.3
19	17.5	16.75	0.29	12	17	150	173	15.3
20	18.5	18	0.23	10	18	140	165	17.9
Total						2655	3096	
Average			0.22	11	16	133	155	16.9

Appendix 4.2 . Input data at sawmill A for high ellipticality logs

Log #	Major Axis (inches)	Minor Axis (inches)	Ellipticality	Length (ft)	Scaling diameter (inches)	Log scale (Int.1/4") (bft)	Lumber volume (bft)	Overrun (%)
21	18	15.75	0.48	10	17	125	120	-4
22	16.5	14.75	0.44	10	16	110	142	29.1
23	14.5	13.25	0.40	12	14	100	98	-2
24	16	14.5	0.42	10	15	95	125	31.6
25	16.5	15	0.41	10	16	110	141	28.2
26	17.5	13.5	0.63	10	16	110	130	18.2
27	14.5	13.25	0.40	12	14	100	94	-6
28	18.25	16.25	0.45	12	17	150	131	-12.7
29	16	14	0.48	12	15	115	115	0
30	14.5	13	0.44	10	14	80	88	10
31	15.5	14	0.42	12	15	115	96	-16.5
32	14.5	13.25	0.40	12	14	100	100	0
33	18	16.25	0.43	10	17	125	116	-7.2
34	16	14.5	0.42	12	15	115	100	-13
35	15	13.75	0.4	12	14	100	102	2
36	16.5	15	0.41	10	16	110	113	2.7
37	16	14.5	0.42	12	15	115	115	0
38	17	15.25	0.44	12	16	130	136	4.6
39	18	16.5	0.4	10	17	125	184	47.2
40	17.5	16	0.40	12	17	150	157	4.7
Total						2280	2403	
Average			0.43	11	15	114	120	5.8

Appendix 4.3 . Input data at sawmill B for low ellipticality logs

Log #	Major Axis (inches)	Minor Axis (inches)	Ellipticality	Length (ft)	Scaling Diameter (inches)	Log scale (Int.1/4") (bft)	Lumber volume (bft)	Overrun (%)
1	16.25	15.75	0.24	12	16	130	140	7.7
2	16	15.25	0.30	12	16	130	142	9.2
3	16	15.75	0.17	12	16	130	141	8.5
4	18.25	17.5	0.28	12	18	170	184	8.2
5	18.25	18	0.16	12	18	170	190	11.8
6	18.25	17.75	0.23	10	18	140	157	12.1
7	18.25	18	0.16	10	18	140	170	21.4
8	18.25	18	0.16	12	18	170	183	7.6
9	18.25	18	0.16	10	18	140	172	22.9
10	14	13.75	0.18	10	14	80	101	26.3
11	15	14.5	0.25	12	15	115	123	7
12	18	17.75	0.16	12	18	170	180	5.9
13	17.5	17	0.23	12	17	150	165	10
14	16.5	16	0.24	12	16	130	140	7.7
15	16.5	16	0.24	10	16	110	121	10
16	17	16.25	0.29	12	17	150	170	13.3
17	18	17.5	0.23	10	18	140	139	-0.7
18	17.25	17	0.17	10	17	125	135	8
19	16.5	16	0.24	12	16	130	135	3.8
20	18	17.25	0.28	10	18	140	151	7.9
Total						2760	3039	
Average			0.22	11	17	138	152	10.4

Appendix 4.4 . Input data at sawmill B for high ellipticality logs

Log #	Major Axis (inches)	Minor Axis (inches)	Ellipticality	Length (ft)	Scaling diameter (inches)	Log scale (Int.1/4") (bft)	Lumber volume (bft)	Overrun (%)
21	18.25	16.75	0.39	12	18	170	162	-4.7
22	19	17	0.44	10	18	140	152	8.6
23	14.75	13.5	0.40	10	14	80	83	3.8
24	15.25	13.75	0.43	12	15	115	113	-1.7
25	18.75	16.25	0.49	10	18	140	120	-14.3
26	15	13.75	0.40	10	14	80	98	22.5
27	18	16	0.45	12	17	150	148	-1.3
28	14.75	13.5	0.40	12	14	100	104	4
29	18.5	17	0.39	12	18	170	151	-11.2
30	16	14.5	0.42	10	15	95	118	24.2
31	18.5	17	0.39	12	18	170	156	-8.2
32	16	14.25	0.45	12	15	115	131	13.9
33	16	14	0.48	10	15	95	106	11.6
34	14.5	13.25	0.40	10	14	80	89	11.3
35	15.5	14	0.42	10	15	95	90	-5.3
36	18.5	17	0.39	12	18	170	142	-16.5
37	17	15.5	0.41	12	16	130	149	14.6
38	17	15.5	0.41	10	16	110	120	9.1
39	15.5	14	0.42	12	15	115	128	11.3
40	17	15.5	0.41	10	16	110	119	8.2
Total						2430	2479	
Average			0.42	11	16	122	124	4

Appendix4.5 . Input data at sawmill C for low ellipticality logs

Log #	Major Axis (inches)	Minor Axis (inches)	Ellipticality	Length (ft)	Scaling diameter (inches)	Log scale (Int.1/4") (bft)	Lumber volume (bft)	Overrun (%)
21	15.75	15.5	0.17	12	16	130	171	31.5
22	16	15.5	0.24	12	16	130	151	16.2
23	15	14.75	0.18	12	15	115	110	-4.3
24	17.25	17	0.17	10	17	125	140	12.0
25	17	16.25	0.29	10	17	125	159	27.2
26	15.5	15	0.25	10	15	95	116	22.1
27	16.5	16	0.24	10	16	110	112	1.8
28	17	17	0	10	17	125	135	8.0
29	17	16.5	0.24	12	17	150	161	7.3
30	18	17.25	0.28	12	18	170	197	15.9
31	17.75	17.5	0.16	12	18	170	177	4.1
32	16	15.5	0.24	12	16	130	151	16.2
33	16	15.75	0.17	12	16	130	141	8.5
34	16.75	16.25	0.24	12	17	150	162	8.0
35	18.75	18	0.28	12	18	170	175	2.9
36	16.25	15.75	0.24	12	16	130	115	-11.5
37	15	15	0	12	15	115	133	15.7
38	17.25	17	0.17	12	17	150	173	15.3
39	15	14.75	0.18	12	15	115	128	11.3
40	15.5	15	0.25	12	15	115	110	-4.3
Total						2650	2917	
Average			0.20	12	16	133	146	10.2

Appendix 4.6 . Input data at sawmill C for high ellipticality logs

Log #	Major Axis (inches)	Minor Axis (inches)	Ellipticality	Length (ft)	Scaling Diameter (inches)	Log scale (Int.1/4") (bft)	Lumber volume (bft)	Overrun (%)
1	17.25	15.5	0.43	12	16	130	179	37.7
2	16	14.5	0.42	12	15	115	154	33.9
3	17	15.25	0.44	12	16	130	138	6.2
4	16.75	15.25	0.41	12	16	130	151	16.2
5	18	16	0.45	12	17	150	147	-2
6	17	15.5	0.41	12	16	130	154	18.5
7	15	13.75	0.40	12	14	100	133	33
8	15	13	0.49	10	14	80	91	13.8
9	16	14.5	0.42	10	15	95	116	22.1
10	16	14.25	0.45	12	15	115	143	24.3
11	17	15	0.47	12	16	130	141	8.5
12	15	13.5	0.43	12	14	100	140	40
13	15	13.25	0.46	12	14	100	103	3
14	15	13	0.49	12	14	100	136	36
15	14.75	13.25	0.43	12	14	100	96	-4
16	15.25	13.75	0.43	12	15	115	158	37.4
17	15.25	13.5	0.46	10	14	80	109	36.3
18	18	15	0.55	12	17	150	216	44
19	16	14	0.48	10	15	95	79	-16.8
20	15	13.5	0.43	12	14	100	114	14
Total						2245	2698	
Average			0.45	12	15	112	135	20.1

Appendix4.7 . Input data at sawmill D for low ellipticality logs

Log #	Major Axis (inches)	Minor Axis (inches)	Ellipticality	Length (ft)	Scaling diameter (inches)	Log scale (Int.1/4") (bft)	Lumber volume (bft)	Overrun (%)
21	15.75	15	0.30	10	15	95	110	15.8
22	17.25	16.75	0.23	10	17	125	144	15.2
23	17.25	17	0.17	12	17	150	153	2.0
24	17	16.5	0.24	12	17	150	137	-8.7
25	14.25	13.75	0.26	12	14	100	97	-3.0
26	14.25	14.25	0	12	14	100	79	-21.0
27	15	14.5	0.25	12	15	115	142	23.5
28	17	16.25	0.29	10	17	125	122	-2.4
29	16	15.25	0.30	10	16	110	77	-30.0
30	16.25	16.25	0	10	16	110	121	10.0
31	16.5	15.75	0.29	10	16	110	153	39.1
32	16	15.5	0.24	12	16	130	105	-19.2
33	18	17.75	0.16	12	18	170	152	-10.6
34	14.25	14.25	0	10	14	80	95	18.8
35	16.5	16	0.24	10	16	110	110	0.0
36	17.5	17.5	0	10	18	140	197	40.7
37	18.5	18	0.23	12	18	170	156	-8.2
38	18.25	18	0.16	12	18	170	150	-11.8
39	17.75	17	0.28	10	17	125	125	0.0
40	16.5	16	0.24	10	16	110	132	20.0
Total						2495	2557	
Average			0.19	11	16	125	128	3.5

Appendix 4.8 . Input data at sawmill D for high ellipticality logs

Log #	Major Axis (inches)	Minor Axis (inches)	Ellipticality	Length (ft)	Scaling Diameter (inches)	Log scale (Int.1/4") (bft)	Lumber volume (bft)	Overrun (%)
1	15.25	13	0.52	10	14	80	76	-5.0
2	18.5	16.25	0.47	10	17	125	127	1.6
3	17	15.25	0.44	10	16	110	162	47.3
4	15.5	14.25	0.39	12	15	130	155	19.2
5	15	13.25	0.46	10	14	80	89	11.3
6	17	15.5	0.41	10	16	110	92	-16.4
7	16.75	13	0.63	10	15	95	83	-12.6
8	16	13	0.58	12	15	115	111	-3.5
9	18.25	15.75	0.50	12	17	150	153	2.0
10	16.75	14.25	0.52	10	16	110	133	20.9
11	17.5	14.5	0.56	10	16	110	152	38.2
12	19.25	17.25	0.44	10	18	140	137	-2.1
13	18.75	17	0.42	10	18	140	152	8.6
14	15.75	14	0.45	12	15	115	109	-5.2
15	16.5	15	0.41	12	16	130	135	3.8
16	18.5	16.75	0.42	12	18	170	138	-18.8
17	18.75	17	0.42	12	18	170	158	-7.1
18	17	14.25	0.54	10	16	110	142	18.3
19	18.5	15.25	0.56	12	17	150	139	-7.3
20	15.25	13.5	0.46	12	14	100	109	9.0
Total						2440	2552	
Average			0.48	11	16	122	128	5.6

Appendix 4.9. Test of effect slices between low and high for overrun

Sawmill	Degree	Degree	Estimate	Adjp
D	H	L	2.13	0.99
B	H	L	-7.37	0.68
C	H	L	10.36	0.25
A	H	L	-11.97	0.11

Appendix 4.10. Least square estimates for low and high ellipticality per sawmill for overrun

Effect	Sawmill	Degree	Estimate
Sawmill	D		3.23
Sawmill	B		6.80
Sawmill	C		16.82
Sawmill	A		11.41
Degree		H	8.71
Degree		L	10.42
Sawmill*Degree	D	H	4.30
Sawmill*Degree	D	L	2.16
Sawmill*Degree	B	H	3.11
Sawmill*Degree	B	L	10.48
Sawmill*Degree	C	H	22.01
Sawmill*Degree	C	L	11.64
Sawmill*Degree	A	H	5.43
Sawmill*Degree	A	L	17.40

Appendix 4.11. Test of effect slices between sawmills with fixed degrees of ellipticality for overrun.

Degree	Sawmill	Sawmill	Estimate	Adjp
H	D	B	1.19	1.00
H	D	C	-17.70	<0.01
H	D	A	-1.12	1
L	D	B	-8.31	0.54
L	D	C	-9.47	0.38
L	D	A	-15.23	0.01
H	B	C	-18.90	<0.01
H	B	A	-2.31	0.99
L	B	C	-1.15	1
L	B	A	-6.91	0.75
H	C	A	16.58	<0.01
L	C	A	-5.76	0.88

Appendix 4.12. Tests of Effect Slices between degrees of ellipticality for lumber volume

Sawmill	Degree	Degree	Estimate	Adjp
D	H	L	2.38	0.99
B	H	L	-13.10	0.22
C	H	L	8.89	0.72
A	H	L	-17.60	0.02

Appendix 4.13. Least square estimates for low and high ellipticality per sawmill for lumber volume

Effect	Sawmill	Degree	Estimate
Sawmill	D		127.71
Sawmill	B		132.74
Sawmill	C		144.26
Sawmill	A		138.82
Degree		H	133.45
Degree		L	138.31
Sawmill*Degree	D	H	128.9
Sawmill*Degree	D	L	126.52
Sawmill*Degree	B	H	126.19
Sawmill*Degree	B	L	139.29
Sawmill*Degree	C	H	148.7
Sawmill*Degree	C	L	139.81
Sawmill*Degree	A	H	130.02
Sawmill*Degree	A	L	147.62

Appendix 4.14. Test of effect slices between sawmills with fixed degrees of ellipticality for lumber volume.

Degree	Sawmill	Sawmill	Estimate	Adjp
H	D	B	2.71	0.99
H	D	C	-19.79	<0.01
H	D	A	-1.11	1
L	D	B	-12.76	0.24
L	D	C	-13.28	0.20
L	D	A	-21.09	<0.01
H	B	C	-22.51	<0.01
H	B	A	-3.83	0.99
L	B	C	-0.52	1
L	B	A	-8.32	0.76
H	C	A	18.68	0.01
L	C	A	-7.8074	0.81

Appendix 4.15. Tests of effect slices between degrees of ellipticality for lumber value

Sawmill	Degree	Degree	Estimate	Adjp
D	H	L	4.86	0.99
B	H	L	7.57	0.91
C	H	L	5.49	0.98
A	H	L	-16.93	0.10

Appendix 4.16. Least square estimates for low and high ellipticality per sawmill for lumber value per degree of ellipticality

Effect	Sawmill	Degree	Estimate
Sawmill	D		87.47
Sawmill	B		90.33
Sawmill	C		93.17
Sawmill	A		103.56
Degree		H	93.75
Degree		L	93.50
Sawmill*Degree	D	H	89.90
Sawmill*Degree	D	L	85.03
Sawmill*Degree	B	H	94.12
Sawmill*Degree	B	L	86.55
Sawmill*Degree	C	H	95.92
Sawmill*Degree	C	L	90.42
Sawmill*Degree	A	H	95.08
Sawmill*Degree	A	L	112.02

Appendix 4.17. Test of effect slices between sawmills with fixed degrees of ellipticality for lumber value

Degree	Sawmill	Sawmill	Estimate	Adjp
H	D	B	-4.22	0.99
H	D	C	-6.01	0.97
H	D	A	-5.18	0.98
L	D	B	-1.51	1
L	D	C	-5.38	0.98
L	D	A	-26.98	<0.01
H	B	C	-1.79	1
H	B	A	-0.96	1
L	B	C	-3.87	0.99
L	B	A	-25.47	<0.01
H	C	A	0.83	1
L	C	A	-21.59	<0.01

Appendix 4.18. Test of effect slices between sawmills with fixed degrees of ellipticality for lumber value per board foot.

Degree	Sawmill	Sawmill	Estimate	Adjp
H	D	B	-0.05	0.81
H	D	C	0.05	0.75
H	D	A	-0.03	0.97
L	D	B	0.05	0.77
L	D	C	0.03	0.98
L	D	A	-0.07	0.33
H	B	C	0.10	0.05
H	B	A	0.01	0.99
L	B	C	-0.02	0.99
L	B	A	-0.12	<0.01
H	C	A	-0.08	0.15
L	C	A	-0.10	0.03

Appendix 4.19 . Lumber grade volume and value for low ellipticality logs sawmill A

Log #	FAS (bft)	$0.96	1C (bft)	$0.65	2A (bft)	$0.47	3A (bft)	$0.4	CANT (bft)	$0.31
1	54	51.84	11	7.15	14	6.58	0	0	21	6.51
2	42	40.32	64	41.6	21	9.87	7	2.8	20	6.2
3	68	65.28	44	28.6	7	3.29		0	21	6.51
4	126	131.1	14	9.1	24	11.28		0	24	7.44
5	113	114.3	14	9.1	0	0		0	20	6.2
6	129	123.8	9	5.85	15	7.05		0	21	6.51
7	31	32.04	32	20.8	22	10.34		0	20	6.2
8	87	89.46	10	6.5	23	10.81	5	2	20	6.2
9	63	60.48	38	24.7	12	5.64	6	2.4	21	6.51
10	68	65.28	18	11.7	6	2.82	6	2.4	21	6.51
11	102	106.6	35	25.51	13	6.11	0	0	24	7.44
12	59	56.64	8	5.2	58	27.26	14	5.6	21	6.51
13	24	24.8	24	15.6	67	31.49		0	24	7.44
14	159	152.6	6	3.9	6	2.82		0	21	6.51
15	127	121.9	19	12.35	4	1.88		0	21	6.51
16	83	79.68	26	16.9	37	17.39		0	21	6.51
17	89	87.89	63	40.95	14	6.58		0	24	7.44
18	84	86.98	23	14.95	26	12.22		0	20	6.2
19	109	104.6	15	9.75	7	3.29		0	42	13.02
20	71	73.14	63	50.15	11	6.16		0	20	6.2
Total	1688	1669	536	360.36	387	182.9	38	15.2	447	138.57
Average	84	83.44	26	18.01	19	9.14	5	0.76	22	6.92

Appendix 4.20 . Lumber grade volume and value for high ellipticality logs sawmill A

Log #	FAS (bft)	$0.96	1C (bft)	$0.65	2A (bft)	$0.47	3A (bft)	$0.41	Cant (bft)	$0.31
21	88	84.48	11	7.15	0	0	0	0	21	6.51
22	83	79.68	39	25.35	3	1.41		0	17	5.27
23	32	30.72	19	12.35	5	2.35		0	42	13.02
24	71	71.58	34	22.1		0		0	20	6.2
25	90	95.5	26	16.9	5	2.35		0	20	6.2
26	36	34.56	31	20.15	36	16.92	7	2.87	20	6.2
27	28	26.88	28	18.2	17	7.99		0	21	6.51
28	86	82.56	13	8.45	11	5.17	0	0	21	6.51
29	22	21.12	35	22.75	42	19.74		0	16	4.96
30	47	45.12	22	14.3	19	8.93		0	0	0
31	51	48.96	18	11.7		0	6	2.46	21	6.51
32	46	44.16	33	21.45		0		0	21	6.51
33	77	74.73	19	12.35	0	0		0	20	6.2
34	7	6.72	21	13.65	48	22.56		0	24	7.44
35	57	54.72	24	15.6		0		0	21	6.51
36	37	37.5	39	25.35	17	7.99		0	20	6.2
37	18	17.28	42	27.3	20	9.4	14	5.74	21	6.51
38	27	25.92	66	42.9	16	7.52	6	2.46	21	6.51
39	125	120	23	14.95	12	5.64		0	24	7.44
40	77	73.92	55	35.75	4	1.88		0	21	6.51
Total	1105	1076	598	388.7	255	119.9	33	13.53	412	127.72
Average	55	53.81	29	19.43	15	5.99	5	0.67	20	6.38

Appendix 4.21 . Lumber grade volume and value for high ellipticality logs sawmill B

Log #	FAS (bft)	$0.96	1C (bft)	$0.65	2A (bft)	$0.47	CANT (bft)	$0.31
21	8	7.68	85	55.25	45	21.15	24	7.44
22	88	88.88	18	11.7	26	12.22	20	6.2
23	5	4.8	19	12.35	39	18.33	20	6.2
24	84	83.72	5	3.25		0	24	7.44
25	75	75.3	16	10.4	9	4.23	20	6.2
26	58	57	7	4.55	13	6.11	20	6.2
27	0	0	21	13.65	103	48.41	24	7.44
28	57	54.72	18	11.7	29	13.63	0	0
29	115	115.02	0	0	36	16.92	0	0
30	92	92.72	17	11.05	9	4.23	0	0
31	119	120.18	13	8.45		0	24	7.44
32	75	75.96	14	9.1	18	8.46	24	7.44
33	50	51.08	13	8.45	23	10.81	20	6.2
34	5	4.8	35	22.75	29	13.63	20	6.2
35	50	48	15	9.75	5	2.35	20	6.2
36	94	92.44	42	27.3	22	10.34	0	0
37	76	75.38	37	24.05	12	5.64	24	7.44
38	60	60.9	23	14.95	17	7.99	20	6.2
39	8	7.68	68	44.2	28	13.16	24	7.44
40	105	103.88	14	9.1	0	0	0	0
Total	1224	1220.1	480	312	463	217.6	328	101.68
Average	61	61	24	15.6	25	10.88	16	5.08

Appendix 4.22 . Lumber grade volume and value for low ellipticality logs sawmill B

Log #	FAS (bft)	$0.96	1C (bft)	$0.65	2A (bft)	$0.47	CANT (bft)	$0.31
1	57	56.7	37	24.05	17	7.99	24	7.44
2	45	45.18	18	11.7	55	25.85	24	7.44
3	21	20.16	66	47.4	30	14.1	24	7.44
4	57	57.36	97	63.05	30	14.1	0	0
5	61	58.56	63	40.95	42	19.74	24	7.44
6	95	97.14	30	19.5	12	5.64	20	6.2
7	72	75.06	71	46.15	7	3.29	20	6.2
8	52	52.12	83	53.95	24	11.28	24	7.44
9	75	74.2	32	20.8	65	30.55	0	0
10	45	44.3	15	9.75	21	9.87	20	6.2
11	0	0	11	7.15	64	30.08	48	14.88
12	99	100.8	28	18.2	28	13.16	24	7.44
13	0	0	88	57.2	53	24.91	24	7.44
14	0	0	51	33.15	65	30.55	24	7.44
15	34	33.74	0	0	67	31.49	20	6.2
16	0	0	82	53.3	64	30.08	24	7.44
17	29	29.71	57	37.05	33	15.51	20	6.2
18	14	14.98	0	0	101	47.47	20	6.2
19	74	73.9	3	1.95	34	15.98	24	7.44
20	0	0	38	24.7	93	43.71	20	6.2
Total	830	833.9	870	570	905	425.35	428	132.68
Average	41	41.69	43	28.5	45	21.26	21	6.63

Appendix 4.23 . Lumber grade volume and value for high elliptical logs sawmill C

Log #	FAS (bft)	$0.96	1C (bft)	$0.65	2A (bft)	$0.47	CANT (bft)	$0.31
21	0	0	73	47.45	82	38.54	24	7.44
22	52	49.92	88	57.2	14	6.58	0	0
23	29	27.84	78	50.7	31	14.57	0	0
24	0	0	65	42.25	65	30.55	21	6.51
25	33	31.68	54	35.1	36	16.92	24	7.44
26	59	56.64	72	46.8	9	4.23	14	4.34
27	23	22.08	62	40.3	34	15.98	14	4.34
28	21	20.16	20	13	14	6.58	36	11.16
29	30	28.8	60	39	21	9.87	5	1.55
30	0	0	76	49.4	40	18.8	27	8.37
31	20	19.2	83	53.95	26	12.22	12	3.72
32	57	54.72	33	21.45	18	8.46	32	9.92
33	0	0	38	24.7	58	27.26	7	2.17
34	54	51.84	31	20.15	23	10.81	28	8.68
35	0	0	20	13	67	31.49	9	2.79
36	64	61.44	62	40.3	27	12.69	5	1.55
37	0	0	4	2.6	29	13.63	76	23.56
38	17	16.32	86	55.9	40	18.8	73	22.63
39	15	14.4	39	25.35	23	10.81	2	0.62
40	27	25.92	49	31.85	35	16.45	3	0.93
Total	501	481	1093	710.45	692	325.2	412	127.7
Average	25	24.05	54	35.52	34	16.26	20	6.38

Appendix 4.24 . Lumber grade volume and value for low elliptical logs sawmill C

Log #	FAS (bft)	$0.96	1C (bft)	$0.65	2A (bft)	$0.47	Cant (bft)	$0.31
1	29	27.84	123	79.95	17	7.99	2	0.62
2	6	5.76	100	65	31	14.57	14	4.34
3	56	53.76	36	23.4	6	2.82	12	3.72
4	51	48.96	60	39	7	3.29	22	6.82
5	34	32.64	50	32.5	75	35.25	0	0
6	0	0	31	20.15	62	29.14	23	7.13
7	0	0	9	5.85	96	45.12	7	2.17
8	0	0	8	5.2	67	31.49	60	18.6
9	53	50.88	58	37.7	26	12.22	24	7.44
10	69	66.24	80	52	20	9.4	28	8.68
11	93	89.28	47	30.55	23	10.81	14	4.34
12	61	58.56	62	40.3	25	11.75	3	0.93
13	60	57.6	46	29.9	8	3.76	27	8.37
14	103	98.88	31	20.15	0	0	28	8.68
15	83	79.68	92	59.8	0	0	0	0
16	41	39.36	41	26.65	20	9.4	13	4.03
17	52	49.92	28	18.2	29	13.63	24	7.44
18	0	0	81	52.65	48	22.56	44	13.64
19	0	0	75	48.75	11	5.17	42	13.02
20	22	21.12	26	16.9	62	29.14	0	0
Total	813	780.5	1084	704.6	633	297.5	387	120
Average	40	39.02	54	35	31.65	14	19.35	5.99

Appendix 4.25 . Lumber grade volume and value for low elliptical logs sawmill D

Log #	FAS (bft)	$0.96	1C (bft)	$0.65	2B (bft)	$0.45	2A (bft)	$0.47	3A (bft)	$0.4	3B (bft)	$0.22	Cant (bft)	$0.31
21	81	77.76	19	12.35					5	2			5	1.55
22	55	52.8	27	17.55	31	13.95	12	5.64	19	7.6				0
23	81	77.76	28	18.2			20	9.4	12	4.8			12	3.72
24	69	66.24	16	10.4			23	10.81	17	6.8			12	3.72
25		0	16	10.4	14	6.3	40	18.8	9	3.6			18	5.58
26	55	52.8	16	10.4			8	3.76		0				0
27	20	19.2	39	25.35			41	19.27	31	12.4	5	1.1	6	1.86
28	19	18.24	40	26	14	6.3	29	13.63	5	2			15	4.65
29	39	37.44	3	1.95	17	7.65		0		0	12	2.64	6	1.86
30	69	66.24	21	13.65	16	7.2		0		0	5	1.1	10	3.1
31	60	57.6	49	31.85			27	12.69		0			17	5.27
32	8	7.68	43	27.95			30	14.1	6	2.4			18	5.58
33	99	95.04	16	10.4			22	10.34		0			15	4.65
34	37	35.52	27	17.55			21	9.87	5	2			5	1.55
35	60	57.6	14	9.1			10	4.7	21	8.4			5	1.55
36	94	90.24	44	28.6			43	20.21	13	5.2			3	0.93
37	98	94.08	28	18.2			6	2.82	6	2.4			18	5.58
38	22	21.12	21	13.65			23	10.81		0			84	26.04
39		0	9	5.85			68	31.96	9	3.6			39	12.09
40	85	81.6	23	14.95			9	4.23	5	2			10	3.1
Total	1051	1009	499	324.35	92	41.4	432	203	163	65.2	22	4.84	298	92.38
Aver.	58	50.45	24	16.22	18	8.28	25	10.69	11	3.26	7	1.61	16	4.62

Appendix 4.26 . Lumber grade volume and value for high elliptical logs sawmill D

Log #	FAS (bft)	$0.96	1C (bft)	$0.65	2A (bft)	$0.47	3A (bft)	$0.4	2B (bft)	$0.45	Cant (bft)	$0.31
1	20	19.2	10	6.5	6	2.82	20	8			20	6.2
2	66	63.36	8	5.2	47	22.09		0			6	1.86
3	77	73.92	33	21.45	24	11.28	14	5.6			14	4.34
4	12	11.52	10	6.5	55	25.85	55	22			23	7.13
5	45	43.2	7	4.55	19	8.93	6	2.4			12	3.72
6	39	37.44	28	18.2		0	5	2	10	4.5	10	3.1
7	23	22.08	10	6.5	6	2.82	6	2.4	32	14.4	6	1.86
8	50	48	13	8.45	30	14.1	11	4.4			7	2.17
9	97	93.12	11	7.15	41	19.27		0	4	1.8		0
10	63	60.48	25	16.25	22	10.34	10	4	8	3.6	5	1.55
11	57	54.72	22	14.3	59	27.73	14	5.6				0
12	73	70.08	19	12.35	33	15.51	6	2.4			6	1.86
13	119	114.2	14	9.1	5	2.35	9	3.6			5	1.55
14	49	47.04	31	20.15	12	5.64	5	2			12	3.72
15	40	38.4	45	29.25	29	13.63	7	2.8			14	4.34
16	105	100.8	12	7.8	6	2.82	6	2.4			9	2.79
17	111	106.6	15	9.75	10	4.7	8	3.2			14	4.34
18	64	61.44	56	36.4	12	5.64	10	4				0
19	6	5.76	14	9.1	93	43.71	11	4.4			15	4.65
20	32	30.72	33	21.45	17	7.99	6	2.4			21	6.51
Total	1148	1102	416	270.4	526	247.2	209	83.6	54	24.3	199	61.69
Aver.	57	55.1	20	13.52	27	12.36	11	4.18	13	6.07	11	3.08

Appendix 4.27. ANOVA table for 1 Common lumber grade

Source	DF	F Value	Pr > F
Sawmill	3	16.01	<0.01
Degree	1	2.13	0.14
Sawmill* Degree of ellipticality	3	2.15	0.09

Appendix 4.28. ANOVA for 2A lumber grade

Source	DF	F Value	Pr > F
Sawmill	3	15.63	<0.01
Degree	1	0.02	0.89
Sawmill* Degree of ellipticality	3	5.35	0.01

Appendix 4.29. ANOVA for the Cant lumber grade

Source	DF	F Value	Pr > F
Sawmill	3	3.70	0.01
Degree	1	1.59	0.20
Sawmill*Degree of ellipticality	3	0.52	0.66

Appendix 4.30. Effect sliced by sawmill for 1 Common lumber grade

Sawmill	DF	F Value	Pr > F
A	1	0.20	0.65
B	1	8.01	<0.01
C	1	0.00	0.94
D	1	0.36	0.54

Appendix 4.31. Effect sliced by sawmill for 2A lumber grade

Sawmill	DF	F Value	Pr > F
A	1	3.83	0.05
B	1	11.51	<0.01
C	1	0.21	0.65
D	1	0.52	0.47

Vita

Roncs Ese-Etame, the son of late Christian Etame Ebouki and Tapita Fongue was born in Mbanga (Cameroon) on March 10th, 1960. After graduating in 1983 from Bonaberi Polyvalent Grammar School (Cameroon), Mr. Ese-Etame went on to the Yaoundé National Advanced School of Agriculture (University of Dschang) where he received the Engineering degree in Forestry and Wildlife Science in 1988. Mr. Ese-Etame worked with the Government of Cameroon and as a consultant for private corporations from 1988 to 2004. Mr. Ese-Etame continued his education at Virginia Polytechnic Institute and State University by earning a Master of Science degree in Wood Science and Forest Products in 2006. Mr. Ese-Etame will be working in the forest management and forest products trade as a Consultant.