VALUE RECOVERY AND PRODUCT SORTING IN THE SOUTHEASTERN UNITED STATES: A COMPARISON OF CONVENTIONAL AND MODIFIED TREE-LENGTH SYSTEMS

by

AMANDA KATE HAMSLEY

(Under the Direction of W. Dale Greene)

ABSTRACT

Some timber harvesting systems in the southeastern USA have started using harvesters to buck and sort products. A 2007 survey indicated that most Georgia loggers bucked logs using chainsaws or sawbucks. Forty-five percent of respondents estimated product dimensions with some measurement.

We compared value recovery and cost of a modified tree-length (MTL) logging system that measures product dimensions with a harvester to that of a tree-length (TL) system that estimates dimensions. Processing TL loads of product with a harvester on a yard did not increase load value. Although not statistically significant, MTL did recover slightly more residual timber value per acre than TL on two of three sites despite estimated $2/ton higher logging costs. MTL also showed consistent, but not significantly different (alpha = 0.10), increases over TL percent of cruised value harvested. The individual stem analysis showed similar value recoveries ranging from 67% to 78% for MTL compared to 73% to 78% for TL.

INDEX WORDS: Logging, timber, value recovery, product sorting, United States

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AMANDA KATE HAMSLEY

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AMANDA KATE HAMSLEY

Major Professor:	W. Dale Greene
Committee:	Laurence R. Schimleck Richard F. Daniels Michael L. Clutter

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
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DEDICATION

I dedicate this thesis to my parents Danny and Ann Hamsley. Both of you have been a tremendous inspiration to me. As foresters you taught me the importance of the land and the forest, and that no matter where you go your roots always pull you back home. I love you both.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

Independent logging contractors provide most of the raw materials to forest products facilities in the southeastern United States (Greene et al. 2001). Product sorting, separating stems into two or more products, is important as the correct product mix can maximize harvested value while inadequate product sorting can substantially reduce the value returned to the landowner (Gingras 1996). The comparison of the value of harvested material to its optimum value is termed value recovery. Although correct product sorting is crucial to the landowner, those performing the sorting are often not compensated for the additional effort it takes to properly sort raw forest products (Gingras 1996). The number of product markets in the Southeast appears to be increasing, creating a greater need to properly sort raw materials in the woods (S. Baldwin, personal communication, September 27, 2006).

Overall there are two primary types of harvesting systems: tree-length (TL) and cut-to-length (CTL). Tree-length systems fell trees and transport the stems to a landing where they are processed and loaded onto trucks for transport. In the southeastern US, these systems generally utilize feller-bunchers to fell and group trees into bunches that grapple skidders drag to a landing. At the landing the felled trees are processed and then loaded onto trucks with a knuckleboom loader. In tree-length systems the loader operator often sorts the products with ocular estimation by placing stems of each product in separate piles primarily based on size, quality, and species (Greene 2005). CTL systems fell and process trees at the stump with a harvester. In these systems, the harvester operator sorts products usually with the aid of computer scanners in the harvester head that make length and diameter measurements. Sorts are again based largely on size and species. Bucked logs are typically transported to roadside on a forwarder where self-loading trucks deliver them to manufacturing facilities. CTL systems are common in Sweden, Finland, Europe, Canada, and New Zealand. There are two types of CTL systems in Canada (1) the most common uses harvesters to cut, delimb, measure and buck the stems; (2) feller-bunchers fell and buck or windrow stems and processors delimb, measure, and buck them (Puttock et al. 2005). Some systems in the Southeast are starting to use harvesters to aid in product sorting and bucking at roadside. These otherwise tree-length operations produce bucked logs similar to a CTL operation and will be referred to in this discussion as modified tree-length (MTL) systems.

PRODUCT SORTING

Most harvesting systems in the southeastern US have five phases: felling, in-woods transport, processing, loading, and hauling (Greene 2005). During the processing phase, felled trees are prepared for transport from the harvest location. The degree of processing depends on the harvesting system employed and the final product specifications. Product specifications vary with the mill accepting the wood, but some common sorting criteria are: species, quality, size, and end-product (Gingras 1996). The most common product produced in the southeastern US today is the tree-length stem that has been topped and delimbed. Stems can be cut into logs or pulpwood bolts as well in a process called bucking.

Products produced in the woods have different values, with products produced from larger, straighter sections typically having the highest value. Harvesting systems benefited economically from increasing the number of sorts from a pulpwood-only harvest to a harvest that includes higher value products (Blinn and Sinclair 1986). Also, stands with higher proportions of larger diameter trees were more economical to sort (Graves et al. 1977). Theoretical value recovery increased substantially for five markets across the United States with an increase in number of product sorts until five product sorts were achieved (Murphy et al. 2003). Increasing the number of sorts beyond five increased theoretical value recovery but at a much slower rate than with five or less sorts. Productivity decreased about four percent per sort for a harvester in Canada; productivity decreased the greatest when number of sorts increased from one to two (Gingras and Favreau 2005). Productivity increased with increasing length of processed log sorts.

LOCATION OF BUCKING/SORTING

Bucking and sorting can occur at different locations, both in the woods and off-site, and can occur by different harvesting machines. Gingras (1996) provides an excellent summary of Forest Engineering Research Institute of Canada (FERIC) work that studied the effects of sorting on the productivity of various harvesting machines in Canada. The act of product sorting creates more work for the machines involved and thus reduces system productivity. For tree-length harvesting, sorting can be performed by the felling, skidding, delimbing, and loading functions. Feller-bunchers can only make a rough sort of species or sizes because they work rapidly. Feller-buncher productivity, measured in stems/productive machine hour (PMH), decreased 7.5 to 10.6% in Ontario from sorting stems into two and three products, respectively (Gingras 1996). To sort products during skidding the only realistic system configuration is manual felling and skidding with a cable skidder as sorting with grapple skidders is unproductive. Stroke delimbers can sort two, three, or four products and studies in Canada indicate that separation of two products can decrease delimber productivity between 5-10%. A third separation can increase cycle time for the delimber by 15% (Gingras 1996).

Sorting for cut-to-length systems can be performed by harvesters or processors. Because it only handles one stem at a time, a single-grip harvester can easily separate products. It can create piles with minimal impact on productivity (Gingras 1996). Single-grip processors can sort with minimal impacts on productivity, while making piles of product is more difficult with a two-grip processor.

A simulation trial compared a full-tree system with a delimber and slasher, a CTL with a two-grip harvester, and a CTL with a single-grip harvester (Gingras 1996). The full-tree system had the lowest total system cost but had the highest additional sorting cost of 14.5% above baseline with one product sort. CTL with the single grip harvester had the second highest overall system cost but had the lowest additional sorting cost of 4.2% above baseline with one product.

Most product sorting in Canada occurs at the harvesting site. Productivity decreases as the number of product sorts increases (Table 1.1) (Gingras 2006). A processor with a Waratah processing head sorting logs at roadside in British Columbia appeared to lose productivity with three or more sorts (Dyson and Forrester 2005). Processor productivity decreased by 25% when making four sorts and decreased an additional 12% with five sorts. A summary of processor productivity studies in eastern Canada showed a six percent decrease in productivity per additional sort for greater than three sorts (Gingras and Favreau 2007).

Sorting typically occurs at the harvesting site in the southeastern US as well. A survey of West Virginian loggers found that all bucking and sorting was done on the landing with chainsaws or sawbucks (Wang et al. 2007). Bucking with a sawbuck was standard practice for 82%, 86%, and 100% of small, medium, and large logging companies, respectively. A majority of the companies, 71%, reported bucking from the loader without ground inspection, although operators usually measured veneer logs.

When stem taper functions were used to estimate sawtimber volumes for different log sorting strategies, a study found that logging rates increased with each sorting alternative (Greene and Carruth 1994). The logging rate was lowest for the tree length four-inch top at \$15.88 per ton, increased to \$16.15 per ton for tree-length eight-inch top, increased to \$16.37 per ton for 16-foot sawlog multiples, and was the highest when the contractor chipped everything at \$17.00 per ton. A simulation that tested the effects of tree size, stand density, and product sorting intensity on harvesting system productivity of five harvesting systems common in northern US hardwoods also found productivity decreases corresponding to increases in product sorting intensity (Blinn et al. 1986). Increasing the product sorting intensity from a pulpwood-only harvest to a fully-integrated product sorting intensity that included pulpwood, firewood, sawbolts, and sawlogs decreased the productivity of three of the four systems tested by 6%, 10%, and 11%. The additional time needed to produce different product sorts decreased productivity in those cases. Adding sorting capabilities to tree-length logging and whole-tree systems added an average of \$6.26 to cost per cunit (Hazenstab et al. 1987).

Bucking and sorting does not necessarily have to occur in the woods. Another option is to haul tree-length material to centralized log sort yards (Dramm et al. 2002). Log sort yards use mechanized log merchandisers with log scanning technology to buck tree-length and long logs into various log products to maximize log value. Some small to medium log sort yards use processors similar to those used in CTL systems to merchandize logs. The decision to sort logs in the woods or in a sort yard depends on the cost of each along with a host of other factors. Fixed-site merchandisers such as those used in sort yards were found to sort, buck, and chip more volume than systems in the woods, although they do have a high investment cost (Sibal et al. 1984). For a case study in the Pacific Northwest, sorting at the landing in the woods was less expensive than sorting in a centralized yard (Sessions et al. 2005).

SORTING IN CTL SYSTEMS

FERIC has performed some of the most recent research on product sorting, primarily for CTL systems. Their studies found that CTL systems can sort multiple products with a lower additional sorting cost than tree-length systems, although tree-length systems have the lowest net cost at roadside (Gingras 1996; Gingras and Soucy 1999). For a CTL system, it is more cost-effective to sort with a harvester than a forwarder (Gingras and Godin 1997). As the number of sorts increases, the productivity of a harvester and forwarder decreases (Gingras and Favreau 2002). Sorting at the stump with a feller-buncher decreased the productivity of the bunching and skidding phases (Gingras and Godin 2001). A roadside processor may be a cost-effective alternative (Gingras and Godin 2001).

The stump-to-landing cost of a single-grip harvester and forwarder thinning a mixed wood stand in southern Ontario was US\$10/m^3 and tree size had the greatest influence on unit cost of harvesting (Puttock et al. 2005). A CTL system that performed a second thinning in a loblolly pine plantation (*Pinus taeda*) in central Alabama had a total system productivity of six cords/PMH and a cost of \$22.50/cord excluding transportation (Tufts and Brinker 1993). The harvester's cost was \$85/PMH or \$13.35/cord and the forwarder's cost was \$51/PMH or \$9.27/cord. Another study of a CTL system harvesting a loblolly pine stand in Alabama estimated the cost for the harvester was \$81/PMH and the cost for the forwarder was \$53.24/PMH (Tufts 1997). The CTL system was more expensive when harvesting small diameter trees less than five inches DBH than larger trees in a ponderosa pine (*P. ponderosa*) dominated site in the Coconino National Forest in Arizona (Klepac et al. 2006). Cost of harvesting sawlogs was \$0.88 per cubic foot contrasted to \$9.62 per cubic foot for harvesting biomass.

COMPARISON OF CTL AND TL SYSTEMS

Although CTL systems may be able to sort products at a lower additional cost, tree-length harvesting systems appear to be more productive than CTL systems. Of two thinning systems in southern Alabama the forwarder system producing both cut-to-length pulpwood (14-20 ft.) and 7.5 foot pulpwood lengths was slightly less productive than the skidder system producing 7.5 foot pulpwood lengths (249 cords/week and 200 cords/week compared to 261 cords/week) (Lanford and Stokes 1996). The cost per cord was slightly lower for the forwarder system using CTL wood compared to skidder (difference of \$0.14) and higher for the forwarder system in 7.5 foot wood (difference of \$3.77). Of three modeled systems with five harvest prescriptions in three simulated hardwood stands in central Appalachia a feller-buncher/grapple skidder system was more productive and cost-effective for harvesting small diameter hardwood (cost \$12/m^3) compared to chainsaw/cable skidder (cost \$13/m^3) and harvester/forwarder (cost \$17/m^3) (Li et al. 2006). In a northern Idaho mixed conifer stand a whole-tree (WT) harvesting system was more productive than a CTL system because specific tasks were assigned to each machine in the WT system (Adebayo et al. 2007). Although the hourly machine rate for the WT system was slightly higher than that of the CTL system, its higher productivity resulted in overall lower harvesting costs for the WT system. The harvesting costs of the WT system were \$0.22/ft^3 and \$0.33/ft^3 while the harvesting costs of CTL were \$0.34/ft^3 and \$0.36/ft^3. For a ground-based processing trial in which a Waratah 234 served as a processor to a tree-length crew, the percentage of logs in each log class that differed from mill specifications by ± 5 cm were 80-88% (Evanson and McConchie 1996). The productivity of the Waratach was 77 m^3/PMH with an average tree size of 1.63 m^3.

BUCKING MODELS

Since the 1960s optimally bucking tree stems has been a topic of interest in forestry and operations research (Pnevmaticos and Mann 1972). Tree bucking models have varying levels of focus from individual stem models to single stand models to multiple-stand models that include a set of stands to be harvested (Kivinen and Uusitalo 2002). Individual stem models often use dynamic programming (Pnevmaticos and Mann 1972; Gobakken 2000). Bobrowski compared the modeling methodologies of branch-and-bound and dynamic programming on their time to solution and accuracy of solution (Bobrowski 1994). He found that dynamic programming could come to a solution quicker, but branch-and-bound could find a more accurate solution when bucking-to-value. Linear programming has been used to buck individual stems and help loggers address market demands (Smith and Harrell 1961). Dynamic programming has also been used to determine the location of bucking cuts on tree stems and the method to saw logs into boards (Faaland and Briggs 1984). Whole-stand models are typically set up as two level problems with linear programming as the first level and dynamic programming as the second level (Eng et al. 1986). Linehan and Corcoran (1994) even developed a stand level program that uses system cost, machine cost, product prices, and timber costs to determine the cost to the logger, amount of money to give the landowner, and profit for the logger from stand cruise information prior to harvest. A computer model that used timber cruise data could estimate bucking strategies and calculate product yields based on various merchandizing strategy inputs for loblolly pine stands (Greber and Smith 1986).

Harvester bucking programs follow one of two methodologies: bucking-to-value or bucking-to-order (Kivinen and Uusitalo 2002). Bucking-to-value indicates bucking the stem into products to maximize the value of the stem based on product prices at the time of harvest. Bucking-to-order, also called bucking-to-demand, bucks the stem according to market demand for products. The harvester continuously updates a list of products cut and determines products needed to fulfill a market order. Order book constraints are usually a combination of market and production constraints (Murphy et al. 2006). Models have been developed to meet order-book constraints (Sessions et al. 1989; Kivinen and Uusitalo 2002; Murphy et al. 2006).

VALUE RECOVERY OF MANUAL SYSTEMS

To increase profit, managers can increase either value or volume produced, or can decrease cost to satisfy the equation PROFIT = VOLUME × (VALUE – COST) (Twaddle and Goulding 1989). The traditional focus on profit maximization has been to reduce costs or increase volume, but improved value recovery can also increase profits. The primary causes of value loss are complex product specifications, increased allocation errors from a large number of sorts, lack of incentives for loggers, lack of training, and lack of decision aids such as diameter or branch measuring tools (Twaddle and Goulding 1989).

Manual bucking with a chainsaw is still a common practice in many parts of the world. Loggers can increase value recovery when bucking manually by using informational or computer-based aids. For log buckers working in radiata pine (*P. radiata*) in New Zealand the value of logs marked at landing and stump were both significantly lower than the optimal value from the log optimization program AVIS (Murphy and Olsen 1988). When the value recovery of loggers in New Zealand was compared with AVIS, the loggers fell short by 26% with no training and only 11% with some instruction (Geerts and Twaddle 1984). Using handheld computers to aid in bucking decisions at the stump when using chainsaws to harvest and buck trees in Oregon increased log value by 12 to 14% (Sessions et al. 1989). In another study optimal bucking of Douglas-fir (*Pseudotsuga menziesii*) by the computer program BUCK increased value 9.3% for 85 trees compared to the cutter's bucking choices (Bowers 1998). The time required to make additional measurements and input data into the computer increased costs by $10 per tree for one old-growth trial and $3.50 for a second-growth trial; however, net value increased by $97 per tree for the old-growth trial and $6 per tree for the second-growth trial (Sessions et al. 1989).

Suggested value increases in hardwood stands in Michigan from using the optimization program HW-BUCK were between 39-55% (Pickens et al. 1992). Compared to the model logging contractors only recovered 65-72% of the optimal value determined by HW-BUCK. Programs like HW-BUCK can be used as training tools for log buckers and can give buckers general rules to practice such as cut to reduce sweep, cut more cull sections to remove serious defects rather than downgrading large sections, and place defects near the end of sawlogs (Pickens et al. 1993).

VALUE RECOVERY OF MECHANIZED SYSTEMS

While manual bucking is prominent in some parts of the world, mechanized bucking is becoming increasingly popular (Murphy 2003). One disadvantage of manual felling can be high stump heights which reduce value recovery. A mechanical feller-buncher felling *P. elliottii* and *P. taeda* in South Africa had higher value recovery than chainsaw felling by 6.8% from lower stump heights and less breakage with the feller-buncher (Kewley and Kollegg 2001). Likewise, mechanized felling with a continuous disk feller-buncher in British Columbia subalpine fir (*Abies lasiocarpa*) and scattered white spruce (*Picea glauca X Picea engelmannii*) had significantly lower (8.8 cm lower) stump heights than manual felling with a chainsaw (Hall and Han 2006). This resulted in an additional CN$0.33/tree from mechanical felling of sawlogs.

There is a large variability of length and diameter accuracy in mechanized CTL operations and long-log operations in British Columbia (Andersson and Dyson 2001). Several factors contribute to this variation. Controllable factors include emphasis on accuracy at the logging site, calibration of equipment, and computer target settings. Uncontrollable factors include design limitations of the equipment, stand and tree characteristics, and weather conditions. The diameter and length measuring accuracy of a harvester is important as there is a lower probability of cutting off-grade products corresponding to higher measurement accuracy (Chiorescu and Gronlund 2001). A strict trim allowance, such as 50 mm, will always yield off-grade boards, but when the trim allowance is increased small improvements in harvester length measurement accuracy had significant influence on board grade. Diameter measurement accuracy had a greater effect on sawmill value recovery than length accuracy. Six harvesting operations in three pine species (*P. ponderosa*, *P. taeda*, and *P. radiata*) lost between 3-23% of potential value from measurement errors (Marshall et al. 2006). The average value loss of length, diameter, and bucking errors was 18%. For the five studies in which diameters were underestimated, losses from diameter errors were greater than those from other measurement errors. Because overmeasured logs can be rebucked without having to be downgraded to a lower value product, undermeasuring length has higher value losses than overmeasuring length.

Although mechanization has given operators diameter and length measuring aids, operators must visually assess quality changes along the stem (Murphy et al. 2005). Ultimately the operator must decide which product types to cut from a stem with or without the aid of a bucking optimization system. A logging contractor in New Zealand had a similar machine configuration as the MTL system mentioned earlier: Waratah HTH 626 processor on Caterpillar 330 CL excavator base, Timbco T445 feller-buncher, grapple skidder, loader (Murphy et al. 2005). The processor did not have optimal log-making software installed. Harvesting costs were estimated at $11.89 per cubic meter to $6.29 per cubic meter. The combined gross value recovery at two sites was 90.2%. Researchers detected no effect of operating speed on value recovery in the range of 430 to 610 cubic meters per day. Operators in a Swedish study indicated that they had difficulties seeing defects in logs at the current feeding speed of 4 m/s (Gellerstedt 2002). Researchers determined that a skilled operator is someone that can observe the entire system in a relaxed state and maintain a fast, reliable motor-sensory reaction.

Value loss averaged 21% and varied from 1% to 68% across 39 mechanized operations studied in the world (Murphy 2003). A study of bucking practices in Finnish birch stands (*Betual pendula* and *B. pubescens*) found that bucking stems into large diameter sawlogs and small diameter pulpwood increased value per cubic meter by 10-40% compared to conventional veneer and pulpwood products (Heräjärvi and Verkasalo 2002). Value of stems increased when shorter lengths were cut.

A Hahn Harvester in the Pacific Northwest had a value loss of 7.5% when compared with the BUCK computer program (Olsen et al. 1991). A CTL operation harvesting ponderosa pine in Oregon lost 17% of value and a ground-based operation with a processor on the landing harvesting Douglas-fir in Washington lost 8% of optimal value compared to the BUCKIT optimal bucking program (Marshall and Murphy 2004). At both sites fully scanning stems before bucking led to maximum net value recovery but the full scan procedure also had the highest breakeven cost of the five scanning procedures evaluated.

A study in the southeastern US found that a CTL final harvest operation recovered 94% of the value while a CTL thinning operation only recovered 58% of the value (Boston and Murphy 2003). The latter system's poor value recovery was caused by poor length measurement by the bucking system. Another southeastern US study found that the value recovery of three CTL systems was 90%, 93%, and 94% (Conradie et al. 2004). The harvesters cut longer logs than the optimum solution at two sites, which could be a result of the South's affinity for tree-length logs. Average value loss for five crews harvesting hardwood in Virginia and West Virginia was 20.7% compared to HW-BUCK optimization results (Haynes and Visser 2004). Value loss ranged from 17 to 35%.

VALUE RECOVERY AT SAWMILLS

Several studies have examined value recovery at sawmills. Bucking is often performed at the sawmill in North America while it is generally done at the harvesting site in Scandinavia (Nordmark 2005). While dynamic programming is often used to buck logs optimally, inner properties can be determined by computer-tomography-based (CT) scanning systems. Researchers ran simulations of 48 Scots pine (*P. sylvestris*) with dynamic programming to evaluate manual, 2-dimension (2D), 3D, and CT methods to buck logs at a sawmill and looked at sorting based on diameter, 3D, and CT (Nordmark 2005). The value recovery by manual and 2D bucking methods was lower than 3D bucking methods, but the highest value recovery was from CT bucking. For log sorting, diameter gave the lowest values and CT gave the highest values.

Bucking systems in sawmills that scanned for sweep in two planes had 7.3% higher value recovery than those that did not measure for sweep while measuring for sweep in only one plane improved value recovery by 3.6% (Wang and Giles 1989). Value recovery increased 1.4% when nominal spacing of saws decreased from four feet to two feet. Lumber yield from full-tree and CTL systems in Quebec were compared and the value recovery per merchantable cubic meter was slightly higher for CTL than full-tree by 2.4% (Plamondon and Pagé 1997). The full-tree system did, however, produce 11% more merchantable volume per stem than the CTL system.

SUMMARY

Tree-length systems are the primary harvesting method used in the southeastern United States. Since 1987 over 70% of logging contractors in Georgia have used feller-buncher/grapple skidder systems; this percentage increased to over 80% after 1992 (Baker and Greene in press). There are currently limited published data describing product sorting of harvesting systems in the Southeast.

Some systems in the Southeast are starting to use harvesters to aid in product sorting and bucking at roadside. These otherwise tree-length operations produce bucked logs similar to a CTL operation and will be referred to in this discussion as modified tree-length (MTL) systems. Numerous studies have found that CTL systems recover more value at a lower additional sorting cost than tree-length systems, but most mills in the southeastern US demand tree-length products (Gingras 1996; Gingras and Soucy 1999). Other studies have shown that CTL systems in the Southeast can recover up to 90-94% of the optimum value of a harvested stand (Boston and Murphy 2003; Conradie et al. 2004). Advantages of using a harvester to measure and buck logs may be higher value recovery for the landowner, measurements and information about products from the harvesting site, and increased loader production by allocating the product sorting function to the harvester. Disadvantages may be higher logging costs from adding a high-cost piece of equipment to a system and lack of markets in the Southeast for cut log products. No studies have examined the cost or value recovery of modified tree-length systems in comparison to tree-length systems in the Southeast. MTL systems may cost-effectively recover more value than TL systems in the southeastern US. The study of the modified tree-length system will evaluate these issues compared to those of a conventional tree-length operation.

OBJECTIVES

The first objective was to use information from a survey of loggers to describe the current status of product sorting in Georgia. Specifically we would document the number of sorts loggers make, report any incentives used to encourage proper sorting, determine the equipment used to make bucking cuts, and describe how loggers determine product dimensions (i.e. measurement or estimation).

The second objective was to determine if there was a difference in value recovery and cost between modified tree-length systems that measure product dimensions and tree-length systems that estimate product dimensions. To meet this objective we would conduct paired field comparisons of tree-length and modified tree-length crews on a series of harvest tracts. Next, we would compare the value of tree-length loads to their value after bucking and sorting with a harvester. This study would also compare the value recovery of tree-length and modified tree-length crews with PC AVIS log optimization model. Lastly, we would develop a cost model to estimate the harvesting cost per unit of MTL and TL systems.

HYPTOHESES

Most of the loggers (>50% respondents) in Georgia will estimate product dimensions and have no incentives to encourage proper bucking. The modified tree-length system will produce a higher average value per ton than the tree-length system. The modified tree-length system will have a higher cost per ton than the tree-length system. The additional value per ton produced by the modified tree-length system will exceed its additional cost per ton.

ORGANIZATION OF THESIS

This document contains three chapters that describe three studies conducted to meet the objectives of this research effort. Chapters 2 and 3 are in general format while chapter 4 is in manuscript style. Chapter 5 is a summary of all three studies.

Table 1.1. Effect of sorting on machine productivity (% loss compared with one product). From Gingras, J. F. 2006. Maximum value throughout the wood supply chain: the RAID concept. *29th Council on Forest Engineering, July 30-August 2, Coeur d'Alene, Idaho.*

	Number of products separated			
	2	3	4	5
Feller-bunchers	5-10	9-11	15	n.a.
Delimbers	5-10	10-15	15-25	n.a.
Harvesters and Processors	1-4	2-8	3-12	4-16
Forwarders	3-8	8-13	12-20	16-27

CHAPTER 2

PRODUCT SORTING STRATEGIES OF GEORGIA LOGGERS

INTRODUCTION

The product sorting or processing phase of logging is perhaps the most important phase to extract monetary value from a harvest site. The determination of products from a tree stem could maximize the value of that stem or could cause a value loss; value maximization or loss depends upon the placement of bucking cuts and sorting of products for delivery to the correct destination. This addition to a survey of Georgia loggers aimed to describe current product sorting strategies of loggers in Georgia and determine possible methods to improve value recovery. The information gathered here was part of the 2007 Georgia Logger Survey (Baker and Greene in press).

METHODS

The survey was conducted as part of the 2007 Georgia Logger Survey, a survey administered by the Warnell School of Forestry and Natural Resources at the University of Georgia. Because the Georgia Logger Survey has been administered every five years since 1987, loggers were familiar with it and were likely to respond. Previous response rates have been between 20 and 30%. Before mailing the surveys, we obtained approval from the Institutional Review Board of the University of Georgia to include human subjects in our study. In January 2007, we sent the survey to 878 logging firm owners or managers that participated in the Georgia Master Timber Harvester educational program. The survey for the product sorting project incorporated the following questions:

1) How many product sorts do you make in a typical week? ___ 1-3 ___ 4-6 ___ 7-9
___ 10+
2) When cutting and sorting wood, how do you determine diameter and length? *Check ONE*
____ Measure each log _____ Estimate log diam & length
_____ Estimate most logs/measure a few
3) Are you paid a higher rate per ton when asked to perform additional product sorts?
___ Yes ___ No
4) List the number and ages (years) of each type of equipment you use.

Delimbing & Bucking	No.	Ages
Chainsaws		
Delimbing Gate		
Pull-through delimber		
Buck / Slasher saws		
Cut-to-length processor		
Stroke delimber		
Chain-flail delimber		
Whole-tree chipper		
Horizontal or Tub grinder		

We computed the percent of total responses that checked a specific response to get a general idea about trends. Although the survey only applied to Georgia, it provided some background about product sorting in a southeastern state. As with any survey, a low survey response is a potential pitfall. We mailed follow-up surveys to non-respondents in February of 2007 after the first mailing to encourage response.

RESULTS

We received 103 responses from the first mailing followed by 108 responses from the second mailing for a total of 211 responses with a total response rate of 24%.

Equipment

There were 206 responses to the question about equipment used to buck and sort logs. A majority of respondents use pull-through delimbers (62%), chainsaws (47%) and buck/slasher saws (45%) to buck and sort logs (Fig. 2.1). Only 3% of the respondents use a cut-to-length processor illustrating the rarity of this piece of equipment in Georgia. These include both cut-to-length and modified tree-length crews.

Number of Sorts

There were 204 responses to the question about number of sorts in a typical week. The majority of respondents (88%) have 6 or fewer sorts in a typical week (Fig. 2.2).

Measurement vs. Estimation

Survey responses to the question about measurement versus estimation totaled 204. We expected most (> 50%) respondents to estimate dimensions; however, only 31% of respondents strictly estimate dimensions (Fig. 2.3). 45% of respondents estimate most and measure a few while 24% of respondents measure dimensions. Because this question had three categories of response we do not know how many “a few” logs are or how often respondents of this category measure logs.

Compensation for Additional Sorts

The question “Are you paid a higher rate per ton when asked to perform additional product sorts?” had 211 responses. 64% answered no while 36% answered yes. There are some issues with this question. 1) We do not know what loggers consider additional sorts. 2) We do not know how often loggers are asked to make additional sorts. 3) We do not know how much more loggers are paid when asked to make additional sorts. What we can gain from this question is that the majority of respondents either are not compensated or do not feel that they are compensated for making more sorts than typical.

DISCUSSION

The common use of pull-through delimbers, chainsaws, and buck/slasher saws in Georgia to buck logs is consistent with the use of sawbucks and chainsaws in West Virginia (Wang et al. 2007). The limited use of a cut-to-length processor further illustrates the prevalence of the feller-buncher/skidder system in Georgia (Baker and Greene in press).

Our finding that 45% of respondents estimate most dimensions but measure a few is similar to the practice of West Virginian loggers to estimate dimensions from the loader cab but measure veneer logs.

CONCLUSIONS

We saw from the survey that most Georgia logging contractors buck logs using chainsaws or sawbucks. Most loggers have up to six product sorts in a week. There was almost an even split between estimating and measuring product dimensions with the highest percentage of respondents estimating dimensions with some measurement. Most loggers are not compensated for additional sorts.

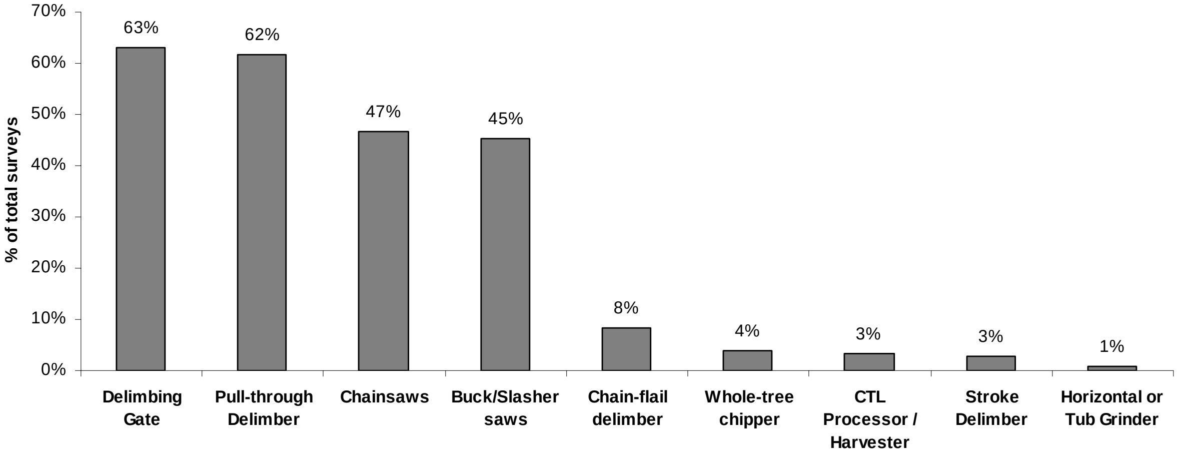

Figure 2.1. Equipment use for bucking and sorting in Georgia, 2007.

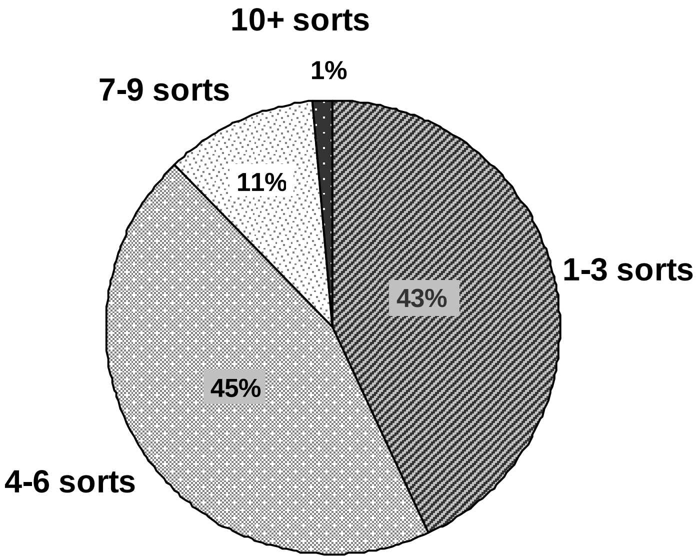

Figure 2.2. Percent of total surveys that had 1-3, 4-6, 7-9, and 10+ sorts per week.

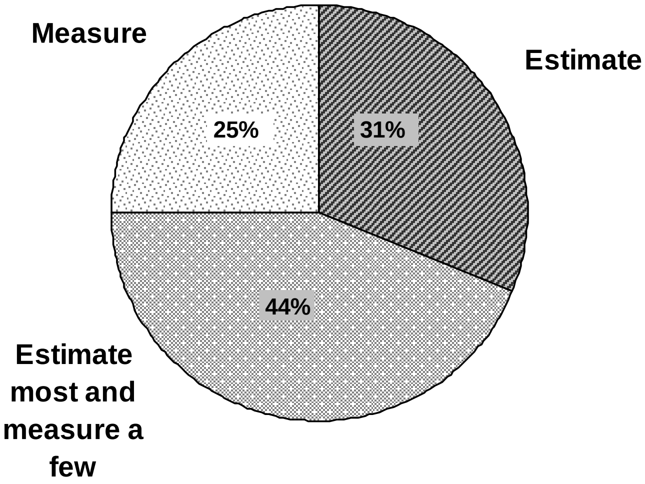

Figure 2.3. Percent of total surveys that estimated or measured product dimensions.

CHAPTER 3

POTENTIAL VALUE UPLIFT OF TREE-LENGTH LOADS BY PROCESSING WITH A PROCESSOR

INTRODUCTION

Some systems in the Southeast are starting to use harvesters to aid in product sorting and bucking at roadside. These otherwise tree-length (TL) operations produce bucked logs similar to a cut-to-length (CTL) operation and will be referred to in this discussion as modified tree-length (MTL) systems. Numerous studies have found that CTL systems recover more value at a lower additional sorting cost than tree-length systems, but most markets in the southeastern US demand tree-length products (Gingras 1996; Gingras and Soucy 1999). Other studies have shown that CTL systems in the Southeast can recover up to 90-94% of the optimum value of a harvested stand (Boston and Murphy 2003; Conradie et al. 2004). We were interested in the potential value uplift a harvester with diameter and length measuring capabilities could provide to tree-length loads of product. In other words what is the additional value that a harvester can produce above the value produced by a tree-length system?

METHODS

We compared the value of tree-length loads from two harvesting operations to their value after processing with a harvester at a merchandizing yard. Because the focus of this study was to determine potential value uplift from a harvester, we did not examine the cost to implement a merchandizing yard. Sample units were loads hauled into the yard. The target sample size was four loads of pine pulpwood (PPW) from each logger and four loads of pine chip-n-saw (PCNS) from each logger for a total of eight pine pulpwood and eight pine chip-n-saw loads. Ideally the loads were to be from clearcuts or second thinnings. The yard was actually a cleared spot on the Thompson Tract (one of our paired harvest sites) located in Wilkinson County, Georgia. We used the harvester owned by the MTL logger and utilized his mobile loader, trucks, and trailers with on-board scales as well. The harvester operator, loader operator, and truck drivers were all employees of the MTL crew. We also used certified scales at a nearby lumber mill to weigh trucks in and out of the yard. Trucks bound to the yard stopped by the lumber mill first to get a loaded weight, or weight in, and proceeded to the yard to be unloaded. After trucks were unloaded with the mobile loader they stopped by the lumber yard again to get an unloaded weight or weight out.

After the tree-length wood was unloaded each load was painted with a number to keep loads separated. Seven of the eight CNS loads were measured for length and the number of “out-of-spec” stems was determined for each load (Table 3.1). An out-of-spec stem did not meet at least one of the mill’s requirements for minimum length, minimum top diameter, or minimum large end diameter. When stems judged by the harvester operator from the cab at production speed appeared to have potential product upgrade, they were re-processed with a Waratah 622 head. The operator made bucking decisions using diameter and length measurements from sensors but did not use optimization software available on the harvester. CNS stems that were too short to meet mill specifications were processed into 16’6” CNS logs and pine top double-bunk pulpwood (PDB).

Once all stems on a load were re-processed, products cut from loads were weighed in-woods using log trailers with electronic on-board scales. Partial loads were mixed on a trailer and weights recorded to obtain weights by each source load. To minimize the impact of weighing error, product percentages by weight from on-board scales were applied to net weight from certified scales to determine the weight of products from each load.

The value of each load before processing was compared to its value after processing to determine any value uplift. Load value was determined by applying residual timber values to the weight of products. Residual timber value was determined by subtracting logging cost from the delivered price for each product. Prices reported here were determined by applying observed market price differentials to Timber Mart-South (TMS) delivered prices for 2007 Georgia averages (Harris et al. 2008). Pulpwood load value of inbound loads was determined by multiplying product weight (loaded – unloaded weight) by the residual timber value. Because some CNS logs did not meet mill specifications, CNS load value of inbound loads was determined by three different methods: no degrade, weighted, and degrade.

CNS Valuation Methods (Value Inbound):

1) No degrade - The load was valued as the intended product, regardless of out-of-spec stems.

2) Weighted - The percentage of the load that was out of spec, as determined by a stem count, was valued at the next lowest product value while the remainder of the load (the wood that met spec) was valued as the intended product. For example, if 40% of a load intended as CNS-A to Mill B did not meet spec, then 60% was valued as CNS-A and 40% was valued as CNS-B (lower value CNS).

3) Degrade - If more than 25% (assumed value) of the stems in each load were out of spec then the entire load was degraded to the next lowest product value. For example, if 50% of a load intended as CNS-A to Mill B did not meet spec, the entire load was valued as CNS-B.

Pulpwood load value out was determined by adding TL PW and PDB top volumes for each load and multiplying by the residual timber value. Again to account for product mis-sorts, CNS load value out was determined by two methods: actual and adjusted.

CNS Valuation Methods (Value Outbound):

1) Actual - Processed products from each load were valued as cut.

2) Adjusted - Precut CNS and PDB top from out-of-spec stems were valued as TL CNS. This method assumed that the processor did not have to downgrade CNS stems from mis-sorts. Adjusted value was determined for all loads using no degrade, weighted, and degrade methods. To avoid double jeopardizing the tree-length loads for mis-sorts, adjusted value for TL CNS was downgraded accordingly for weighted and degrade analyses. In other words, if value inbound was downgraded then adjusted value outbound was downgraded by the same method. For example, for adjusted value using the weighted method if 45% of the stems on a TL load of CNS were too short for CNS-A specifications, then value inbound was calculated by valuing 55% of the weight as CNS-A (TL residual timber value) and 45% as CNS-B. Adjusted value outbound for CNS valued 55% CNS as CNS-A (MTL residual timber value) and 55% as CNS-B instead of simply valuing all CNS outbound as CNS-A and giving the processor an advantage.

A Wilcoxon signed-rank test in SAS was used to compare load value in (before processing on yard) to load value out (after processing) (SAS Institute Inc. 2002-2004).

Product Sorts

All products analyzed were pine, specifically loblolly pine (*Pinus taeda*), except for one hardwood pulpwood sort (Table 3.1). The products were defined as follows and are listed from most valuable to least valuable:

- **Pole:** seven to eight inch top diameter, minimum 11 inch diameter at breast height (DBH), length 32 feet to 77 feet in increments of five feet.
- **Sawtimber 1 (ST1):** minimum eight inch top diameter, lengths of 25 feet, 29 feet, or 33 feet and greater.
- **Sawtimber Precut 1 (ST Precut1):** minimum eight inch top diameter in lengths of 12 foot six inches and 16 foot six inches.
- **Sawtimber Precut 2 (ST Precut2):** minimum 10 inch top diameter, minimum 12 inch butt diameter, lengths of 12 foot six inches, 14 foot six inches, or 16 foot six inches.
- **Sawtimber 2 (ST2):** minimum eight inch top diameter, minimum 12 inch butt diameter, minimum 25 foot length.
- **Chip-N-saw A (CNS A):** minimum five inch top diameter, minimum length of 29 feet.
- **Chip-N-saw B (CNS B):** minimum five inch top diameter, minimum length 21 feet.
- **Chip-N-saw Precut 1 (CNS Precut1):** six inch top diameter, 16 foot six inch length
- **Chip-N-saw (CNS):** minimum nine inch butt diameter, minimum five inch top diameter, minimum length 29 feet.
- **Chip-N-saw Precut 2 (CNS Precut2):** minimum six inch top diameter, 16 foot six inch length.
- **Pine Super Pulpwood (PSP):** seven to nine inch butt diameter, minimum five inch top diameter, minimum 25 foot length.

- **Pine Pulpwood (PPW):** minimum three inch top diameter, maximum diameter outside bark (DOB) of 26 inches, tree-length minimum length 20 feet, double-bunk (DB) length 12 feet.
- **Hardwood Pulpwood (HPW):** six to 22 inch butt diameter, minimum three inch top diameter, minimum length 21 feet.
- **Post:** six to 10 inch butt diameter, 2.5 to three inch top diameter, minimum length of 24 feet.

RESULTS

Logger 1 hauled a total of seven loads of TL product: three loads of PPW and four loads of PCNS to the yard (Table 3.2). Logger 2 hauled a total of five loads of TL product: one load of PPW and four loads of PCNS to the yard. Because of market and time constraints study participants only sent a total of four loads of PPW to the yard. Logger 1 was on a first thinning and logger 2 had difficulty finding PPW to send to the yard from the tract he was harvesting at the time.

An average of 35% of the stems on each CNS load did not meet mill length specifications (Table 3.2).

Weight differences between loads before processing and after processing were minimal overall, although two loads lost over 14% of their weight and one load gained 13% of its weight into the yard (Table 3.3). Because of these weight differences product percentages by weight from on-board scales were applied to net weight from certified scales to determine the weight of products from each load.

While the harvester operator was able to make 63 product upgrades, they represented a small percentage of overall load weight (Fig. 3.1). The operator made 24 CNS precuts and 2 sawtimber precuts from PPW loads. PCNS loads yielded 34 sawtimber precuts. The CNS precuts made from PCNS loads were made from stems that did not meet mill length specifications to ensure delivery.

No degrade

There was no significant difference in PPW load value before processing and after processing (Fig. 3.2). Because the value out adjustment only affects CNS loads, PPW load actual value out was the same as its adjusted value out for all methods. There was a significant decrease in value of CNS loads after processing for both actual and adjusted loads at an alpha of 0.05.

Weighted

Again, PPW value before processing was statistically the same as its value after processing (Fig. 3.3). PCNS actual and adjusted value before processing was significantly lower than its value after processing (alpha =0.05).

Degrade

PPW values were the same as the previous two methods. When the value of the entire tree-length load with over 25% of the stems out-of-spec was downgraded, the value before processing was statistically the same as the actual and adjusted value after processing (alpha = 0.05) (Fig. 3.4).

DISCUSSION

We did not find an increase in value by re-processing TL CNS or PPW stems with a Waratah processor. Processing did not change the value of TL pulpwood loads. When TL CNS loads were not downgraded for out of spec stems, processing actually decreased value, demonstrating both an actual value decrease and an adjusted value decrease. Processing decreased value of weighted TL CNS loads but adjustments for processing out of spec wood provided no change in value after processing. When TL CNS loads were fully downgraded if more than 25% of the stems did not meet spec, processing did not change the value of TL CNS.

Several factors may have influenced the findings of this study: non-random load selection, thinnings as a source of wood, numerous out-of-spec stems, prices, and weight losses.

Loads were not selected randomly from a range of logging contractors; instead, two tree-length contractors were asked to provide all loads. The loggers were aware of the nature of our study as well as a previous internal study by our research cooperator and efforts to improve value recovery. Likely the logging contractors sought to make minimal sorting errors when loading wood for the study.

The source of the wood could have also affected the study results. The study plan called for loads to come from clearcuts or second thinnings. Market conditions had one of the logging contractors on a first thinning during the study and we had to use thinning sales as a wood source. In an attempt to find wood for our study, especially CNS logs, contractors were probably overly aggressive at sorting logs and overlooked stems that were too short. The numerous out-of-spec stems hindered the ability of the processor to uplift value. The first load of CNS had so many stems that were too short that no attempt was made to process it yet the mill accepted the wood with no degrade. The second load of this nature was accepted, but grudgingly and with a warning about future loads meeting spec. In seven of the eight CNS loads 4% to 54% of the stems were too short while the average was 35%. If the mill ignores their own product specifications and takes these loads, then processing cannot possibly increase value.

Product prices also contributed to the lack of a value increase from processing. Timber prices were calculated by subtracting logging cost from delivered prices. Loads with out-of-spec logs were merchandized into 16’6” CNS with PDB top. These are two products that returned lower residual timber values than TL CNS (Table 3.1). Mills give little or no premium for cut logs over their tree-length counterparts in current southeastern US markets, thus higher MTL logging costs reduce net residual timber for the same product classes. These findings coincide with Greber and Smith’s observation that when the production of high valued products generates a large amount of low-valued products, such as pulpwood topwood, it may be preferable to omit the highest valued product (1986). Rule-based bucking calls for cutting the highest value products first and then bucking the remainder of the stem. In these cases foregoing production of the highest valued product can result in a net increase in tract value if the volume of the second highest valued product surpasses volume of the highest valued product and, in turn, reduces pulpwood volume.

Lastly, inconsistencies in load weights could have masked the findings of this study. Overall weight losses were very small (2%) because stems were handled within one to two days of arrival; however, six loads had weight change up or down by more than 5% between arrival and departure. Moisture losses probably contributed little to the weight changes as overall losses were small and some loads actually gained weight after processing. These weight differences are likely some combination of recording error and error using both in-woods scales and certified scales for load weights. The in-woods scales used in the study record weights to the nearest 100 pounds while the certified scales record weights to the nearest 10 pounds.

CONCLUSIONS

Processing TL loads of PPW and PCNS with a Waratah processor did not increase load value. Because of issues with non-random load selection, thinnings as a source of wood, numerous out-of-spec stems, prices, and weight losses we recommend making few operational decisions based on this study. Future studies of this type should ensure random selection of loads and use wood from clearcuts or later thinnings if possible. Greater attention to labeling and load separation in future studies could reduce error in weight data. This could slow down the study, increase costs, or force a small sample size.

Table 3.1. Mill specifications for sort yard products, prices adjusted TMS 2007 GA Avg.

Product	Mill	Specs	Timber TL ($/ton)	Timber MTL ($/ton)
Pole	A	7-8" top, 11" DBH, lengths 32’ to 77’ in 5’ increments	$58.32	$56.26
ST1	B	Min 8" top in lengths of 25', 29', or 33' and greater	$40.00	$37.94
ST Precut1	B	Min 8" top in lengths of 12'6" and 16'6" only	$40.00	$37.94
ST2	C	Min 8" top, min 12" butt, min 25' length	$37.00	$34.94
ST Precut2	C	Min 10" top, min 12" butt; length 12'6",14'6", or 16'6"	$40.00	$37.94
CNS A	D	5.0" top, minimum length 29'	$18.62	$16.56
CNS B	D	5.0" top, minimum length 21'	$16.62	$14.56
CNS Precut1	D	6" top, 16'6" in length	$18.62	$16.56
CNS	E	9" butt, 5" top, minimum length 29'	$21.62	$19.56
CNS Precut2	E	16.5" length	$21.62	$19.56
PSP	F	7-9" butt; 5" top; minimum length 25'	$12.87	$10.81
PPW	G	3.0 " top, min length 20' TL, min length 12' DB**, max DOB 26"	$6.62	$4.56
HPW	H	6.0-22.0" butt; 3" top; minimum length 21'	$7.47	$5.41
Post	I	6-10" butt; 2.5-3" top; min 24' length	N/A	$4.16*

*Product market only available to MTL
**DB = double bunk

Table 3.2. Total loads delivered to sort yard.

Load #	**Logger**	**Product**	**Loaded Weight (tons)**	**Unloaded Weight (tons)**	**Load Weight In (tons)**	**% out of spec**
1	1	PPW	36.9	14.5	22.4	
2	1	PCNS	37.2	14.7	22.5	
3	1	PPW	39.5	14.0	25.5	
4	1	PPW	38.1	14.2	23.9	
5	1	PCNS	38.1	14.6	23.5	45%
6	1	PCNS	38.7	14.6	24.1	31%
7	1	PCNS	34.9	14.0	20.9	54%
8	2	PCNS	38.4	15.8	22.6	15%
9	2	PCNS	34.3	14.9	19.3	45%
10	2	PCNS	37.6	14.8	22.8	4%
11	2	PCNS	33.7	14.4	19.3	54%
12	2	PPW	30.2	14.7	15.5	
					Mean of observed:	**35%**

Table 3.3. Weight in-bound vs. weight out-bound for all loads.

Load #	**Logger**	**Product**	**Weight In (tons)**	**Weight Out (tons)**	**Wt Diff (tons)**	**% Difference**
1	1	PPW	22.41	22.00	-0.41	-1.83%
2	1	PCNS	22.48	23.35	0.87	3.87%
3	1	PPW	25.46	26.06	0.60	2.36%
4	1	PPW	23.90	22.15	-1.75	-7.32%
5	1	PCNS	23.49	22.80	-0.69	-2.94%
6	1	PCNS	24.07	20.65	-3.42	-14.21%
7	1	PCNS	20.91	19.65	-1.26	-6.03%
8	2	PCNS	22.60	21.85	-0.75	-3.32%
9	2	PCNS	19.33	20.90	1.58	8.15%
10	2	PCNS	22.82	25.75	2.93	12.84%
11	2	PCNS	19.29	15.85	-3.44	-17.81%
12	2	PPW	15.48	15.65	0.17	1.10%
		Totals	262.23	256.66	-5.57	-2.12%

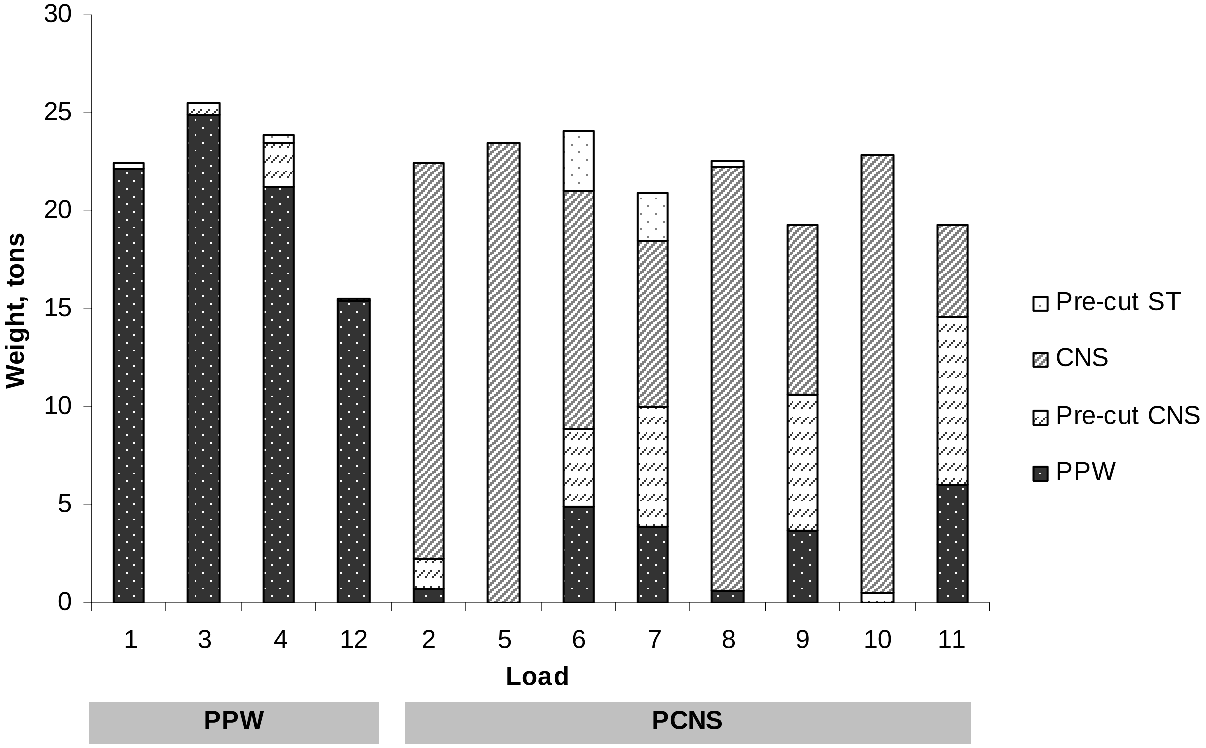

Figure 3.1. Actual processed product breakdown by weight.

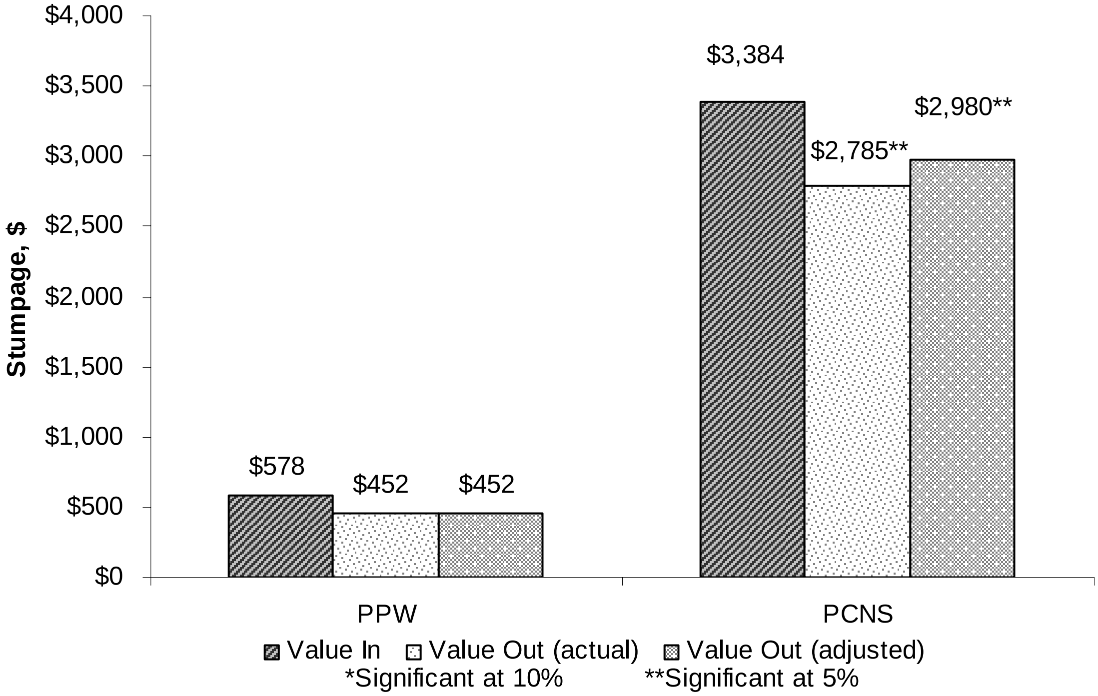

Figure 3.2. No degrade method value in vs. value out.

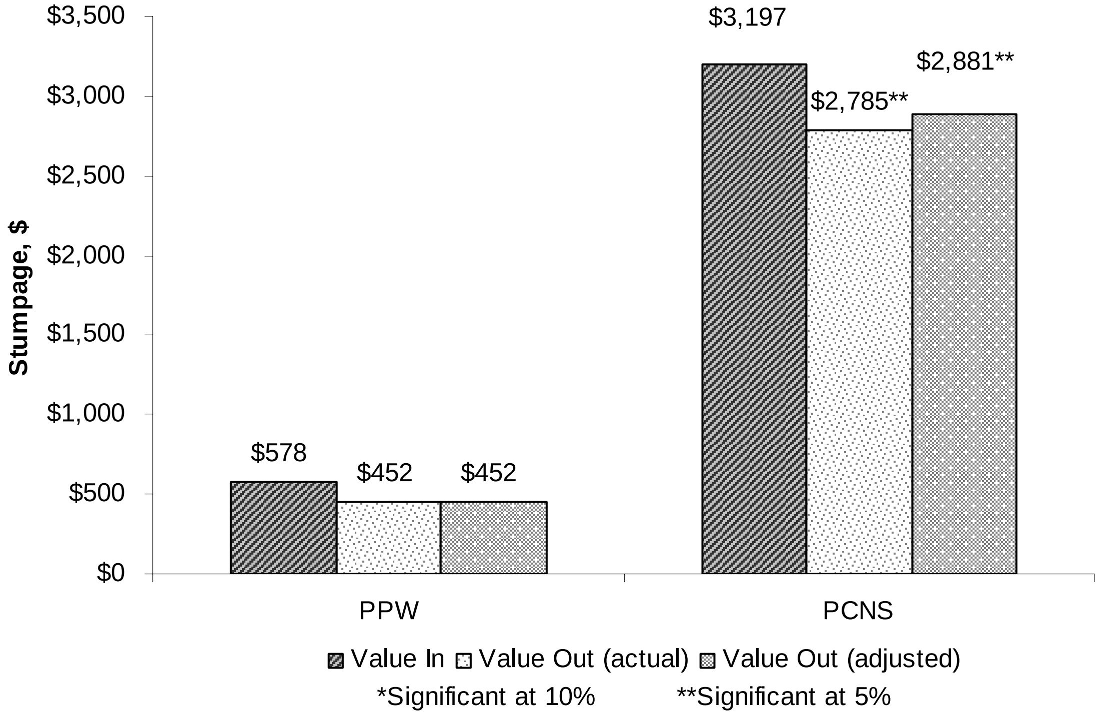

Figure 3.3. Weighted method value in vs. value out.

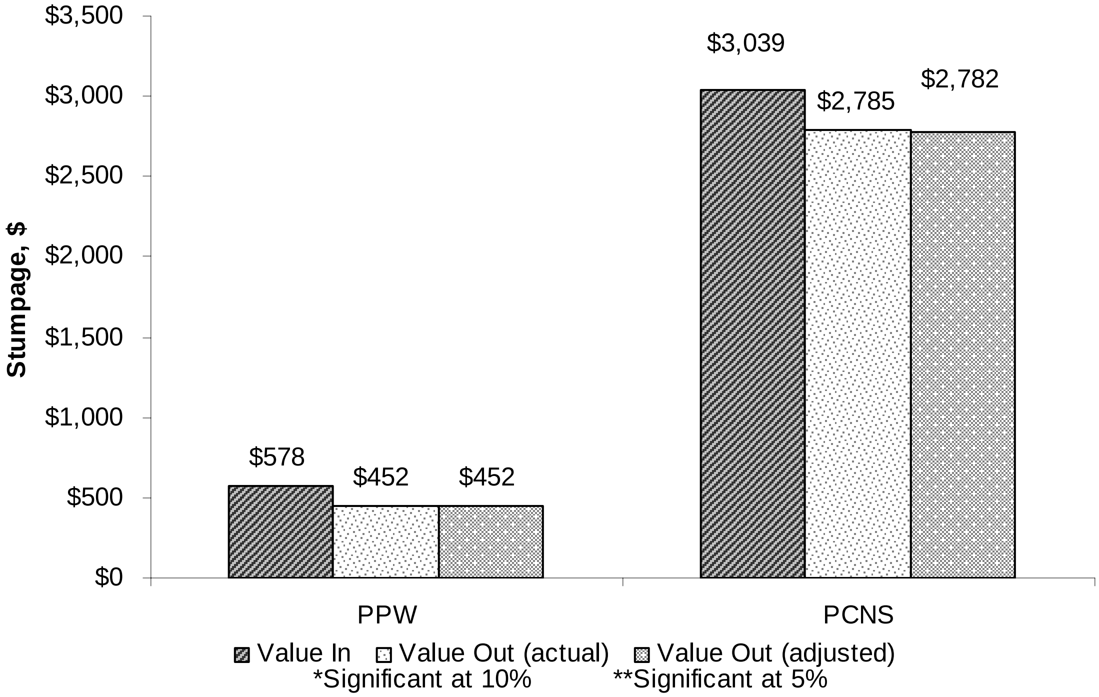

Figure 3.4. Degrade method value in vs. value out.

CHAPTER 4

VALUE RECOVERY AND PRODUCT SORTING IN THE SOUTHEASTERN UNITED STATES: A COMPARISON OF CONVENTIONAL AND MODIFIED TREE-LENGTH SYSTEMS

Hamsley, A.K., Greene, W.D., Baker, S., Murphy, G.E. To be submitted to *International Journal of Forest Engineering*.

ABSTRACT

Some systems in the southeastern USA are starting to use harvesters to aid in product sorting and bucking. We compared value recovery and cost of a modified tree-length (MTL) logging system that measures product dimensions with a Waratah harvester to that of a tree-length (TL) system that estimates dimensions. One field test involved paired comparisons of residual timber value per harvested acre on a series of three planted pine clearcuts. One half of each site was harvested with a TL crew and the other half with a MTL crew. The second field test compared the actual value cut to the maximum potential value suggested by the log bucking optimization program AVIS for 25 felled trees on each site in the paired harvest study. We also developed a cost model to compare the cost of TL and MTL systems.

Although not statistically significant, MTL did recover slightly more residual timber value per acre than TL on two of the three sites despite estimated $2/ton higher logging costs. The modeled $1/ton increase in harvesting cost for MTL would still produce a lower value per acre on one tract by $26, but the value per acre increase on two tracts of $120 and $401 show promise for MTL. MTL also showed consistent increases (not statistically significant) over percent cruised value compared to TL. The individual stem analysis with AVIS showed MTL and TL to have similar value recoveries ranging from 67% to 78% for MTL and 73% to 78% for TL.

INTRODUCTION

Some systems in the Southeast are starting to use harvesters to aid in product sorting and bucking at roadside. These otherwise tree-length operations produce bucked logs similar to a CTL operation and will be referred to in this discussion as modified tree-length (MTL) systems. Numerous studies have found that CTL systems recover more value at a lower additional sorting cost than tree-length systems, but most markets in the southeastern US demand tree-length products (Gingras 1996; Gingras and Soucy 1999). Other studies have shown that CTL systems in the Southeast can recover up to 90-94% of the optimum value of a harvested stand (Boston and Murphy 2003; Conradie et al. 2004).

Advantages of using a harvester to measure and buck logs may be higher value recovery for the landowner, measurements and information about products from the harvesting site, and increased loader production by allocating the product sorting function to the harvester. Disadvantages may be higher logging costs from adding a high-cost piece of equipment to a system and lack of markets in the Southeast for cut log products. No studies have examined the cost or value recovery of modified tree-length systems in comparison to tree-length systems in the Southeast. MTL systems may cost-effectively recover more value than TL systems in the southeastern US. This study of the modified tree-length system will evaluate these issues compared to those of a conventional tree-length operation using a tract level paired harvest approach and individual stem comparisons.

METHODS

Logging Contractors

The TL crew's equipment consisted of two grapple skidders, a John Deere 643G2 and a John Deere 643G3, a John Deere 843H feller-buncher, a Husky 235 knuckleboom loader, two chainsaws, and a delimbing gate. At times the TL crew used a Franklin KBL-28 loader instead of the Husky loader. The feller-buncher felled and bunched stems that the skidders backed through a delimbing gate before skidding to the landing. The loader operator sorted the stems on the landing, separating stems that included potential sawtimber precut products. The chainsaw operators measured the length of the sawtimber precuts and bucked the precuts. Chainsaw operators also topped trees and cleaned up loads on the trucks.

The MTL crew's equipment consisted of a John Deere 2054 shovel with a 622 Waratah harvester head operated as a processor on the landing, a John Deere 648G3 grapple skidder, a Tigercat 230B knuckleboom loader, and a Tigercat 724D feller-buncher with a 5500 felling head. This contractor shared the feller-buncher between two crews, although only one crew participated in this study. The feller-buncher felled trees before the rest of the crew arrived at a tract and would attempt to stay one to two days ahead of the rest of the crew. The skidder moved stems to the landing where the processor delimbed, sorted, and bucked logs. The processor operator utilized diameter and length measuring technology in the harvester head to aid his decision-making but did not use a log optimization program to make bucking decisions. The processor operator had four years of experience operating a processor. The loader loaded trucks and moved piles of product to keep the landing neat for the processor to work.

Study Sites

To conduct the paired comparisons on harvest tracts, we identified four tracts that our industry cooperator had scheduled for clearcut in 2007: the Belote, Bryan, Wood and Thompson tracts. Each tract was divided roughly in half to form two blocks of approximately equal acreage on each tract. TL or MTL were randomly assigned to each block. For this test we used the same TL crew and MTL crew for all replicates.

All study sites were loblolly pine (*Pinus taeda* L.) plantations located in central Georgia. The Belote Tract was 26-years-old with a TL block of 43 acres and a MTL block of 74 acres. The Bryan Tract was 25-years-old and was divided into a TL block of 53 acres and a MTL block of 65 acres. The Wood Tract was 24-years-old; TL block was 46 acres and MTL block was 56 acres. The Thompson Tract was 33-years-old with a 67 acre TL block and 61 acre MTL block.

Paired Harvests

Each tract was cruised with a 10 basal area factor prism by the industry cooperator. The cruise for each tract was re-worked for each block using the point data from each half. Timber value was applied to cruised volumes per acre to obtain cruised value per acre. Prices were determined by applying observed price differentials to TMS delivered prices for 2007 Georgia averages (Harris et al. 2008). The residual timber value for each product class was calculated by subtracting harvesting cost from the delivered price (Table 4.1). MTL system's harvesting cost was an estimated $2/ton higher than TL's which resulted in $2/ton lower residual timber for MTL compared to TL. Where multiple markets existed for the same product, the median residual timber value for that product class was used (Table 4.2). The median residual timber value was used because the median is less influenced by extreme values, such as the higher precut prices, than the mean. As both systems primarily produce TL products, the median was preferred to the mean. Harvested values were compared to pre-harvest cruise estimates to determine the percentage of pre-harvest cruise value actually harvested by each logger on each block. The percentage of cruised value harvested by each logger was compared with a t-test in SAS (SAS Institute Inc. 2002-2004). The number of loads and tons each system harvested of each product by block was recorded along with product tons and values for each block. After the harvests were complete, a paired t-test and Wilcoxon signed rank test in SAS were used to compare tons per acre harvested, average residual timber value per ton harvested, and average residual timber value per acre harvested by each system (SAS Institute Inc. 2002-2004).

Product Sorts

All products analyzed were pine, specifically loblolly pine, except for one hardwood pulpwood sort (Table 4.1). The products were defined as follows and are listed from most valuable to least valuable:

- **Pole:** seven to eight inch top diameter, minimum 11 inch diameter at breast height (DBH), length 32 feet to 77 feet in increments of five feet.
- **Sawtimber 1 (ST1):** minimum eight inch top diameter, lengths of 25 feet, 29 feet, or 33 feet and greater.
- **Sawtimber Precut 1 (ST Precut1):** minimum eight inch top diameter in lengths of 12 foot six inches and 16 foot six inches.
- **Sawtimber Precut 2 (ST Precut2):** minimum 10 inch top diameter, minimum 12 inch butt diameter, lengths of 12 foot six inches, 14 foot six inches, or 16 foot six inches.

- **Sawtimber 2 (ST2):** minimum eight inch top diameter, minimum 12 inch butt diameter, minimum 25 foot length.
- **Chip-N-saw A (CNS A):** minimum five inch top diameter, minimum length of 29 feet.
- **Chip-N-saw B (CNS B):** minimum five inch top diameter, minimum length 21 feet.
- **Chip-N-saw Precut 1 (CNS Precut1):** six inch top diameter, 16 foot six inch length
- **Chip-N-saw (CNS):** minimum nine inch butt diameter, minimum five inch top diameter, minimum length 29 feet.
- **Chip-N-saw Precut 2 (CNS Precut2):** minimum six inch top diameter, 16 foot six inch length.
- **Pine Super Pulpwood (PSP):** seven to nine inch butt diameter, minimum five inch top diameter, minimum 25 foot length.
- **Pine Pulpwood (PPW):** minimum three inch top diameter, maximum diameter outside bark (DOB) of 26 inches, tree-length minimum length 20 feet, double-bunk (DB) length 12 feet.
- **Hardwood Pulpwood (HPW):** six to 22 inch butt diameter, minimum three inch top diameter, minimum length 21 feet.
- **Post:** six to 10 inch butt diameter, 2.5 to three inch top diameter, minimum length of 24 feet.

Sensitivity Analysis of Paired Harvests

We performed a sensitivity analysis comparing the mean difference in value per acre between MTL and TL systems using different price ratio scenarios. Delivered value per acre and residual timber value per acre were examined. For the sensitivity analysis, all ST1 and ST2 product volumes were valued at ST1 delivered price to have only one tree-length ST product (Table 4.1). Likewise, ST precut1 and ST precut2 were valued at ST precut1 delivered price. TL CNS products (CNS A, B, and CNS) were valued at CNS A delivered price. CNS precut1 and CNS precut2 were valued at CNS precut1 delivered price. Price ratios were calculated by dividing each delivered product price by the delivered PPW price. PSP was excluded from the analysis. The base case was the mean difference in value per acre calculated by multiplying actual harvested product volumes from the paired harvest study by their respective prices described above.

We examined the effect of increasing the ST and CNS precut ratios by 5%, 10%, and 20% on the mean difference in delivered and residual timber value per acre between MTL and TL with a paired t-test in SAS (SAS Institute Inc. 2002-2004).

Individual Stem Comparisons

25 stems were marked on each contractor's paired harvest block, for a total of 200 trees. DBH was recorded on the standing trees. Each selected tree was felled at the time the block was harvested. A 100' tape was attached to the butt of each stem and the following measurements were taken after felling:

1) Large-end diameter (LED) over bark;
2) Diameter over bark in 10 ft. increments up the stem to a 2 in. top;
3) Quality factors such as sweep, knot size and number, and cankers/defects with their corresponding beginning and ending lengths from the large end;
4) Total tree height, excluding stump.

After the felled trees were measured, they were processed and sorted into product categories. The loader operator on the TL crew sorted products and set aside stems to be bucked into shorter logs by the chainsaw operators on TL blocks. The processor operator on the MTL crew processed and sorted selected trees on MTL blocks. After processing, the product type and destination for all products was recorded as well as their corresponding actual small-end diameters (SED), LED, and lengths. On MTL blocks, the researcher sat in the cab with the operator and recorded product types and processor estimates of diameters and lengths as well as measured actual product dimensions after processing.

To determine the value recovery of each system we used AVIS (Assessment of Value by Individual Stems) optimization software (New Zealand Forest Research Institute 1995). Value recovery is the percentage of optimum value that the actual logger solution produces. AVIS was developed to determine actual value loss in the woods (Geerts and Twaddle 1984). Developed in the late 1970s-1980s, AVIS uses dynamic programming to optimally buck individual stems given specifications and stem characteristics. The software contains six programs: three programs that create input files for the optimization program and two summary programs (New Zealand Forest Research Institute 1995). AVIS has been used for research and industry purposes for many years (Geerts and Twaddle 1984; Boston and Murphy 2003; Conradie et al. 2004).

Our industry cooperator provided mill dimension and quality product specifications (Table 4.1). Prices were determined by applying observed price differentials to TMS timber prices for 2007 Georgia averages (Harris et al. 2008). These inputs, along with site considerations and stem data, were entered into AVIS to obtain the optimal solution for each stem by site (Appendices A, B, C, D, E). We also entered each contractor’s bucking solution to compare the contractor's actual solution to the optimal solution. Measurements were taken in English units but were converted to metric units prior to entry into AVIS.

AVIS Inputs

PC AVIS uses the Peterson height function to estimate total tree height and calculate under-bark diameters (New Zealand Forest Research Institute 1995). Two coefficients for this height function are required as inputs. The Peterson height function is in the form:

$$H = 1.4 + (hb_1 + hb_2/DBH)^{-2.5}$$

Where,

H = estimated total tree height in meters

DBH = diameter at breast height over bark in centimeters

hb_1 = coefficient

hb_2 = coefficient

The coefficients hb_1 and hb_2 were estimated for each site from DBH and total tree height data using non-linear regression (Table 4.3) (Conradie 2003). Total height for trees harvested by TL, and trees harvested by MTL on Belote and Wood, was the same as the measured height of felled stems as stump height was very short (1-2 in.). An average stump height of five in. was added to the measured height for trees harvested by MTL on the Bryan Tract and an average stump height of four in. was added to the measured height for trees harvested by MTL on the Thompson Tract to obtain a total height measurement. Some stems broke as they hit the ground and lost their associated tops when they were placed on the ground for measurement. These stems were excluded from the calculation of Peterson height coefficients.

PC AVIS calculates under bark diameters with a regression equation that requires seven coefficients. The regression equation is in the form (Gordon 1983):

$$\ln(B/D) = b_0 + b_1(1-h/H)b_2 + b_3(h/H)b_4H + b_5DBH + b_6H/DBH$$

Where,

D = diameter over bark (dob) in centimeters

d = diameter inside bark (dib) in centimeters

B = D - d, double bark thickness in centimeters

H = total height in meters

DBH = diameter at breast height over bark in centimeters

h = height above the ground in meters

b_0 to b_6 = coefficients

Product specifications used over bark measurements. In a few cases specifications cited inside bark measurements but contractors produced products based on over bark measurements. The seven coefficients were manipulated so that B/D approximately equaled zero to ensure that over and under bark diameters were the same (Conradie 2003). Coefficients b_1, b_2, b_3, b_4, b_5 and b_6 were set to approximately zero (0.000001). When $B/D \approx 0$, $\ln(0.000001) = -13.82$; therefore, $b_0 = -13.82$.

Product prices used in this study were in \$/ton, but AVIS uses product prices in \$/m^3. Following the methodology of Conradie (2003) we assumed one ton to be approximately equal to one m^3 and did not adjust product prices.

AVIS Downgrades

In some cases, the actual solution for a stem had greater value than the optimal solution because the contractor deviated from mill specifications. In these instances, we downgraded out-of-spec logs to reflect their value as if they had been bucked correctly. We allowed a tolerance of one inch for diameter and three inches for length.

Three stems were excluded from the analysis: stems 59 (TL Belote) and 147 (MTL Wood) were excluded because AVIS could not process them due to a power thickness error while calculating bark thickness. Stem 72 (TL Belote) was also excluded because the logger solution for this stem was higher than the AVIS solution without logger errors. Stems 73 (TL Belote) and 110 (TL Wood) were forked and the fork of each was entered as a separate stem (stems 273 and 210).

We compared the net value recovery of each system with a t-test and Wilcoxon two sample test in SAS (SAS Institute Inc. 2002-2004). We also compared the individual stem value recovery of each system with a t-test.

Cost Model

We adapted the Auburn Harvesting Analyzer to compare the harvesting cost per ton of MTL and TL systems using the machine rate method (Miyata 1980; Tufts et al. 1985). We assumed that both systems had the same basic equipment configuration including a feller-buncher, grapple skidder, and knuckleboom loader. Two key differences separated the systems: the MTL crew had an additional harvester to serve as a processor on the landing and the TL crew had two saw-hands to be consistent with the crew in the study. We assumed a five percent return on assets as profit, a $6,000 monthly owner salary, and incorporated cost for one entrance, one push-out and a half-mile of road for each system (Appendix F).

Machine rate assumptions for the feller-buncher were as follows: $194,000 purchase price, 25% salvage value, five year economic life, 65% utilization rate, maintenance and repair as 100% of depreciation costs, six gal/PMH fuel usage, and lubrication costs as 40% of fuel costs. Skidder assumptions were: $165,000 purchase price, 20% salvage value, five year economic life, 60% utilization rate, maintenance and repair as 100% of depreciation costs, fuel usage of 5.2 gal/PMH, and lubrication costs as 40% of fuel costs. Loader assumptions were: $112,000 purchase price, 20% salvage value, 10 year economic life, utilization rate of 65%, maintenance and repair as 100% of depreciation costs, fuel usage of 3.6 gal/PMH, and lubrication costs as 40% of fuel costs. Harvester/processor assumptions were as follows: $388,000 purchase price, 25% salvage value, six year economic life, 65% utilization rate, maintenance and repair as 100% of depreciation costs, fuel usage of 6 gal/PMH, and lubrication costs as 40% of fuel costs.

RESULTS

Paired Harvests

In May 2007 a fire burned portions of the Thompson Tract. The fire burned approximately 60% of MTL block compared to only 25% of TL block. Because the fire appeared to affect the study areas unevenly, and thus affect the value of each block unevenly, we decided to remove this tract from the analysis and only report results for the three remaining study sites.

Cruised product volumes (tons/acre) were compared on each tract block with 95 percent confidence intervals (Figure 4.1). The volume 95 percent confidence intervals were as follows expressed in tons per acre: 53 to 78 for TL on the Belote Tract, 50 to 66 for MTL on Belote Tract; 33 to 48 for TL on Wood Tract, 32 to 49 for MTL on Wood Tract; 41 to 59 for TL on Bryan Tract, and 50 to 65 for MTL on Bryan Tract. TL and MTL blocks had volumes on all study sites that were not significantly different. Cruised product values ($/acre) were compared on each crew's section and were found to be equivalent for all study sites with 95 percent confidence intervals (Figure 4.2). The residual timber value 95 percent confidence intervals were as follows expressed in US$ per acre: $1,045 to $1,571 for TL on Belote Tract, $851 to $1,204 for MTL on Belote Tract; $732 to $1,157 for TL on Wood Tract, $733 to $1,147 for MTL on Wood Tract; $1,430 to $2,037 for TL on Bryan Tract, and $1,540 to $1,978 for MTL on Bryan Tract.

MTL system harvested significantly more tons per acre on all three tracts than the TL system at an alpha of 0.10 but not 0.05 with the paired t-test (Figure 4.3). The p-value of 0.25 reported by the Wilcoxon signed rank test is the best possible p-value for a sample size of three (Hollander and Wolfe 1999). Although the MTL system moved more tons per acre than the TL system, there was no significant difference in per acre value produced by the two systems (Figure 4.4). The higher cost associated with the additional equipment (processor) in the MTL system combined with the greater production of MTL shown by more tons per acre harvested caused the MTL system to produce a significantly lower value per ton compared with the TL system at an alpha of 0.05 (Figure 4.5).

When the harvested value was compared to the cruised value, there was no significant difference between the MTL and the TL system at alpha = 0.10 (Figure 4.6). For two study blocks both systems recovered at or above 100 percent of the cruised value (Wood, TL and MTL; Bryan, TL and MTL). One explanation for this over-recovery is that some of the products that were harvested were not inventoried in the cruise; for example, pine poles and pine super pulpwood were not included in the cruise but were harvested. Another explanation is that the cruise inaccurately surveyed the product volumes in each block. Because the cruises were conducted by the same individuals on each tract, there should be no bias or inaccuracy between study blocks from the same tract.

Sensitivity Analysis

Delivered Value per Acre

With the modified price matrix, the base case had a nearly statistically significant positive mean difference between MTL and TL of $514 per acre with a p-value of 0.103 (Figure 4.7) In the base case ST and ST Precut have the same delivered price that is 2.37 times greater than PPW (Table 4.4). CNS and CNS Precut also have the same delivered price that is 1.46 times greater than that of PPW. The delivered value per acre comparison does not consider differences in harvesting cost between MTL and TL; it is interesting that this mean difference is borderline significant at alpha = 0.10. MTL almost harvested more delivered value per acre when harvesting cost was not considered.

Increasing ST and CNS precut prices by 5%, 10%, and 20% all yielded significant mean differences between MTL and TL at alpha = 0.10 but not alpha = 0.05 (Figure 4.7).

Residual Timber Value per Acre

As residual timber value was calculated for each system by subtracting harvesting cost from delivered prices, comparisons of harvested residual timber value per acre consider cost differences of the two systems. The base case showed no significant difference between residual timber value per acre recovered by MTL and TL at alpha = 0.10 (Figure 4.8). Increasing ST and CNS precut price ratios by 5%, 10%, and 20% did not yield significant mean differences between the residual timber value per acre harvested by MTL and TL at alpha = 0.10.

Individual Stem Comparisons

Tree-length System

The TL system recovered 78%, 73%, and 77% of the total optimum value on Belote, Wood, and Bryan sites respectively after downgrades for out-of-spec logs (Figure 4.9). Value losses of 25%, 7%, and 12% resulted from downgrades on Belote, Wood, and Bryan sites (Appendices G, H, I).

TL Belote Tract

A large number of out-of-spec logs on the Belote site caused the observed over-recovery of 3% of optimum value before downgrades (Figure 4.9). A total of 23 logs out of 50 did not meet mill specifications: eight poles, eleven ST C, one CNS B, one CNS E, and two PPW pieces. All 23 logs had SEDs that were too small, and four poles along with nine ST C logs had quality problems such as ring knots or too many branches (more than 3) within four feet of each other. Before value adjustments for out-of-spec logs, the actual solution cut 270% more value in PST than the optimal solution, and only 33% less value in PPoles than the optimal solution (Table

4.6). After value adjustments, the actual solution cut 84% less value in PST than the optimal solution and cut 82% less value in PPoles than the optimal solution.

Before adjustments, the actual solution cut no ST precuts or CNS precuts, but did cut seven more PST pieces than optimal (Table 4.6). Adjustments for out-of-spec logs created 10 more waste pieces in the actual solution, increased ST precuts to 4, and increased CNS precuts to 6. Adjustments reduced the poles in the actual solution from eight pieces to two. After adjustments, the largest value losses compared to optimal were from failure to optimize pine poles ($223) and PST ($54). TL merchandized ST C from seven sample stems of which the optimal solution merchandized poles. Other losses occurred from ST precuts ($30) and CNS ($29).

TL Wood Tract

Before downgrades TL recovered 77% of the optimum value on the Wood Tract (Figure 4.9). TL cut no ST precuts or CNS precuts, although TL did cut 14 pieces of ST while the optimal solution cut no pieces of ST (Table 4.7). Before adjustments TL cut $336 less value in poles than optimal but cut $305 more value in ST than optimal. Value losses resulted from failure to optimize poles, ST precuts, CNS, and CNS precuts.

A total of 16 logs out of 58 did not meet mill specifications: five poles, three ST B, seven ST C, and one PPW. All but three of the logs had smaller SEDs than specified and 10 of the 16 had substandard quality sections: 2 contained cankers and the rest had ring knots or too many branches (more than 3) within four feet of each other. Adjustments decreased the number of poles in the actual solution from seven to five, decreased the number of ST pieces, increased ST precuts, increased CNS and CNS precuts, and increased PPW and waste pieces. Value recovery for TL after adjustments decreased from 77% to 73% of optimal. The largest value loss of $389 from failure to optimize poles was somewhat offset by an additional $232 from ST that the optimal solution did not produce; however the difference of $157 is still quite large and accounts for 92% of the value loss. TL cut ST C from nine stems and cut ST B from two stems of which the optimal solution made poles.

TL Bryan Tract

TL recovered 84% of the optimum value from sample trees on the Bryan Tract before downgrades (Table 4.8). The actual solution cut fewer poles, ST precuts, and CNS precuts than optimal but cut more ST and CNS than optimal. Similar to the other two sites, TL cut more value in ST than optimal but less value in poles than optimal; this resulted in 85% of the overall value loss. The optimal solution cut poles from seven stems of which the actual solution made other products: one ST B precut, two ST C, and four ST B. Other value losses resulted from failure to optimize ST precuts and CNS precuts.

A total of 16 logs out of 68 did not meet mill specifications: one pole, six ST B, two ST B precuts, three ST C, one CNS B, two CNS E, and one CNS E precut. Two ST B and the two ST B precuts had length errors, one ST B had a smaller SED than specified, and the rest of the pieces had quality errors. Three pieces had excessive knots while nine contained small cankers. Adjustments decreased the number of ST and CNS pieces in the actual solution, increased ST precuts and CNS precuts, and increased the number of PPW and waste pieces in the actual solution. Reductions in ST value from adjustments contributed largely to the 12% reduction in value from adjustments.

Modified Tree-length System

The MTL system recovered 76%, 78%, and 67% of the total optimum value on Belote, Wood, and Bryan sites respectively after downgrades for out-of-spec logs (Figure 4.10). Value losses of 10%, 10%, and 2% resulted from downgrades on Belote, Wood, and Bryan sites (Appendices J, K, L).

MTL Belote Tract

MTL recovered 86% of optimal value from Belote Tract sample trees before downgrades (Table 4.9). Poles were excluded from input files to not penalize MTL as MTL had no pole quota at the time of data collection. The actual solution cut less ST and ST precuts than optimal but cut more CNS and CNS precuts than optimal. Value losses from ST and ST precuts resulted in the value loss before downgrades.

A total of 11 logs out of 80 cut did not meet mill specifications: two ST B with length errors and one ST B with sweep errors, two CNS C with quality sweep errors and one CNS A with quality sweep errors, two posts with SEDs smaller than spec, and three PPW tops with SEDs too small. Adjustments reduced the volume of ST B in the actual solution and thus reduced the actual value produced from ST B. Adjustments increased the number of ST precuts, CNS precuts, and PPW while they reduced the number of CNS pieces. The increases in ST precut value and CNS precut value were off-set by decreases in ST value and CNS value, contributing to the additional overall 10% value loss after adjustments.

MTL Wood Tract

Before adjustments for out-of-spec logs, MTL recovered 88% of the optimum value on the Wood Tract (Table 4.10). The actual solution cut fewer poles, ST, ST precuts and CNS precuts than the optimal but cut more CNS, PPW, and waste pieces than the optimal solution. The overall value loss resulted from failure to optimize poles, ST, and ST precuts. For two stems the optimal solution cut poles while the actual solution made ST B. The optimal solution made ST precuts from five stems of which the actual solution made CNS. Likewise, the optimal solution made three ST B pieces from stems of which the actual solution made ST precuts.

A total of five logs out of 84 did not meet mill specifications: three ST B pieces, one with length and quality (knot) errors, one with a canker, one with length errors and two poles, both with length errors and one with length and quality (knot) errors. One of the ST B logs was downgraded to PPW because of sweep and quality. Sweep was measured on the logs before processing. In some cases, when a stem with some sweep was fed through the processor the processor would “shave off” part of the log to make it straighter. This was not necessarily the operator’s choice but happened by design of the processor head. It is possible that these swept pieces did get delivered to the mill, but for our study purposes we downgraded logs based on measurements before processing. This was most likely the case with this particular ST B product. The downgrade to PPW lost $14.23, 15% of the overall difference between optimal and actual after downgrade (Table 4.9). The two poles were downgraded to ST B resulting in a value loss of $23.14, 24% of the overall difference between optimal and actual solutions.

MTL Bryan Tract

MTL recovered 69% of the optimal value of sample trees on the Bryan Tract (Table 4.11). MTL cut fewer poles but more ST than the optimal solution on the Bryan Tract resulting in a value loss. The optimal solution made 19 poles with a value of $831 while the actual solution made only 4 poles with a value of $189. The actual solution did make more sawtimber than optimal—15 logs with a value of $375 compared to 3 logs with a value of $64—but the value of the sawtimber was not great enough to offset the loss from sub-optimal pole merchandizing.

A total of five logs out of 98 did not meet mill specifications: three ST B pieces, one with length and quality (barber chair) errors, one with excessive sweep, one with length errors, and one CNS A with a quality (knot) error and one CNS C with a quality (sweep) error. Adjustments only reduced value recovery by 2%.

System Comparison

A t-test and Wilcoxon two sample test comparing the mean total value recovery of all sample stems by tract of both systems after downgrades for out-of-spec logs, MTL 0.74 ± 0.068, TL 0.76 ± 0.031, showed no significant difference between TL and MTL at an alpha of 0.05 or 0.10 (Figure 4.11). The total value recovery for all sample trees was not statistically different for the two systems; however, a test of the average value recovery per stem (actual/optimal value for each stem) provides a different insight. A t-test comparing the mean value recovery per stem of each system, MTL 0.73 ± 0.044, TL 0.80 ± 0.038, showed that TL had a significantly higher value recovery than MTL at alpha = 0.05, MTL n=74, TL n=75 (Figure 4.12). If the stems are divided into groups by site, TL has a significantly higher value recovery per stem on Belote and

Bryan Tracts but not the Wood Tract at alpha = 0.05. Average value recoveries per stem for each logger by site are as follows: Belote Tract MTL 0.76 ± 0.081, TL 0.86 ± 0.069; Wood Tract MTL 0.76 ± 0.065, TL 0.78 ± 0.069; Bryan Tract MTL 0.67 ± 0.078, TL 0.77 ± 0.057.

Cost Model

Our adaptation of the Auburn Harvesting Analyzer modeled the MTL system harvesting cost at $10.94/ton and the cut and haul cost at $15.74/ton. TL system harvesting cost was $10.01/ton and the cut and haul cost was $14.81/ton. Our model showed a cost difference of about $1/ton, half of the estimated cost we used in the analysis.

DISCUSSION

Paired Harvests

Because we used the same MTL and TL crews throughout the study and did not replicate the systems, it is impossible to separate the impacts of operator decisions from those of the equipment configuration. Replicating crews was not feasible at the time of study, but the operators performing product sorting were both experienced operators and considered to have similar experience and expertise with sorting.

Unfortunately, the wood markets did not remain static during the course of the study (Table 4.12). Harvest plans and commitments, as well as space and logistics concerns, caused the crews to harvest blocks from the same tract at different times. These uneven product quotas likely affected the results to some extent. It is interesting to compare the market restrictions to the product values harvested by each crew in each study block. MTL crew had no pole quota for three weeks on the Belote Tract, and this is illustrated by the absence of poles harvested (Table

4.13). TL crew had no pole quota for one and a half weeks on the Bryan Tract and produced fewer poles than MTL on this tract.

The product PCNS was not restricted by the market at the time of the study, yet MTL consistently produced less PCNS value than TL on all tracts. Alternatively, MTL produced more PST value on all tracts than TL. One possible explanation is that the MTL crew upgraded wood that would usually be classified as PCNS to the PST or PPOLE classifications because of the measurement capability of the harvester. For example, on the Belote Tract MTL produced 11 tons less of CNS per acre ($299 less per acre) than TL but produced 6 tons more per acre of ST ($238 more per acre) (Table 4.14). On the other hand, MTL produced 13 more tons per acre of PPW than TL on the Belote Tract. Some PCNS could have been downgraded to PPW. Another explanation for the additional PPW is that it is PPW topwood from CNS precuts. MTL produced more PCNS precuts than TL on all tracts.

The small sample size (n=3) also made statistical comparisons difficult; however, increasing the sample size was not operationally feasible. Nonparametric tests are usually tests of choice for small sample sizes, but in this case the sample size was so small that the smallest p-value attainable with a Wilcoxon signed rank test was 0.25 (Hollander and Wolfe 1999). We had to rely upon the paired t-test results for significant differences. The small sample size is difficult to test for normality to assure that the assumptions of a parametric paired t-test were met.

The cruises showed that the value of products available to both crews were not significantly different for all three tracts; therefore, the additional tons per acre that the MTL system recovered could be attributed to the system's measuring ability. Increases in PPW made up most of the difference between tons per acre recovered by MTL and TL (Table 4.14). Perhaps the measuring ability of this system allows it to capture marginal material.

We found no significant difference in value per acre recovered by MTL compared with TL, but MTL moved more tons per acre while TL had a higher average residual timber value per ton. The higher residual timber value per acre for TL was offset by MTL recovering more tons per acre. Although not statistically significant, MTL did recover slightly more residual timber value per acre than TL on two out of the three sites despite $2/ton higher logging costs; on the other site, MTL was impaired by limited pole quota (Figure 4.4).

The t-test did not detect a significant difference between the percent of cruised value recovered by MTL and TL at alpha=0.10; however, as previously stated significant differences are very difficult to detect with small sample sizes (Figure 4.6). The sample size for each system is three observations. MTL showed consistent increases over percent cruised value compared to TL: 13% on Belote, 9% on Wood, and 15% on Bryan Tracts. It is possible that with a larger sample size these increases would become statistically significant. These increases, while not significantly different, are probably enough to get a forest manager interested. Product breakdowns for the cruises were estimated by the cruisers based on tree size and obvious quality features. Errors in estimating the product breakdown volumes could have affected the comparison of harvested value to cruised value. If the cruises were not accurate then an increase in value from harvesting may be attributed to poor estimation in the woods prior to harvest, not value uplift potential of MTL or TL systems. In this study we assumed equivalent bias for each contractor's harvest block; therefore, we could make comparisons between the two systems.

Our cost model shows about $1/ton difference in harvesting cost between MTL and TL but we used an estimated cost of $2/ton in the analysis. Although still not significant, the $1/ton difference would still produce a lower residual timber value per acre on Belote Tract from MTL by $26, but the residual timber value per acre difference on Wood and Bryan Tracts would increase to $120 and $401 respectively (Figure 4.13). This gives encouraging evidence to suggest that MTL can recover more value than its system cost compared to TL under similar market conditions.

Sensitivity Analysis

The sensitivity analysis looked at the effect of increasing precut product prices on actual harvested values per acre. In reality, changing the price relationships between products would also change the loggers' bucking and sorting decisions. While we did not model the changes in harvested product breakdowns that would occur with changes in price, it is still interesting to look at how increases in precut prices affect value per acre harvested in our study.

Again, the small sample size of this study made statistical comparisons difficult. It is possible that a larger sample size would show less dramatic changes in price needed to yield a significant difference in value between MTL and TL. Even with the small sample size, the sensitivity analysis with delivered prices suggests that MTL can recover more value than TL with current markets or a 5% increase in precut product price considering only value recovery potential, not harvesting cost differences.

When the estimated additional harvesting cost of $2/ton for MTL was considered in the residual timber value analysis, MTL could not recover more value than TL when precut price ratios were increased by 5%, 10%, and 20%. The additional cost of the MTL system was a factor as well as the small sample size which requires larger differences to detect significance.

Individual Stems

TL recovered 78%, 73%, and 77% of optimum value compared to AVIS on Belote, Wood, and Bryan Tracts, respectively after downgrades for out-of-spec logs. MTL recovered 76%, 78%, and 67% of optimum value on those sites after downgrades for out-of-spec logs. Value losses for both systems resulted from lower volumes of the highest value product (pole or ST) in the actual solution compared to optimal. Value losses from downgrades ranged from 2-10% in most cases although TL on Belote had the highest value loss of 25% from downgrades of 23 logs. Although a t-test revealed no difference between total sample value recoveries of both systems, a test of value recovery per stem showed TL to have greater value recovery per stem than MTL. The small sample size (n=3) for each system for the total sample test could have masked significant differences. One possible explanation of the difference in average value recovery per stem is the degree of error of each system. TL had value recoveries of 60% or higher per stem while MTL had value recoveries that ranged from 30% to 100% (Figure 4.14). The extremely low value recoveries (<50%) were primarily from merchandizing CNS when the optimal solution made ST or poles. These low value recoveries likely reduced the mean value recovery per stem of MTL compared to TL.

Average value recovery was 80% for 39 operations worldwide; MTL and TL systems averaged slightly below this worldwide average (Murphy 2003). Value recoveries of CTL systems in the southeastern US ranged from 90% to 94%, although one CTL system recovered only 58% of optimum value from poor measurement (Boston and Murphy 2003; Conradie et al. 2004). While TL and MTL systems in this study had similar value recoveries to each other, they are well below the 90-94% reported for CTL systems on similar sites. A shovel operation in Washington that used a harvester with a bucking computer as a stationary processor recovered

83% of optimal value while a CTL operation in Oregon recovered 92% (Marshall and Murphy 2004). Value recovery for a contractor in New Zealand *Pinus radiata* plantations with a Waratah HTH 626 processor on a Caterpillar 330 CL excavator base that processed stems extracted in tree-length form to a landing was 89.8% for one site and 90.4% for another site (Murphy et al. 2005). The highest value recovery of the MTL system studied here was 78% of optimum and is below reported value recoveries in Washington (83%) and New Zealand (90%).

The harvester operator of the MTL system did not use a bucking optimization model to aid his decision-making. Although researchers detected no effect of operating speed in the range of 430 to 610 cubic meters per day on value recovery in New Zealand, operators in a Swedish study indicated that they had difficulties seeing defects in logs at the current feeding speed of 4 m/s (Gellerstedt 2002; Murphy et al. 2005). Perhaps the operator in this study sacrificed value for production speed. The lowest value recovery of MTL on the Bryan Tract of 67% was largely attributed to a failure to merchandize poles. MTL had recently acquired pole quota when they moved to the Bryan Tract and the operator was somewhat hesitant to merchandize poles. Perhaps this shift in market demand had some effect on the operator's ability to merchandize poles on that site.

CONCLUSIONS

The small sample size and uneven market conditions between MTL and TL crews were limitations to this study. Although not statistically significant, MTL did recover slightly more residual timber value per acre than TL on two of the three sites despite estimated \$2/ton higher logging costs. MTL had very limited pole quota on the third site. The modeled \$1/ton difference in harvesting cost between MTL and TL would still produce a lower value per acre on

Belote Tract from MTL by $26, but the value per acre difference on Wood and Bryan Tracts would increase to $120 and $401 respectively although not statistically significant. MTL also showed consistent increases (not statistically significant) over percent cruised value compared to TL: 14% on Belote, 15% on Wood, and 15% on Bryan Tracts. This gives encouraging evidence to suggest that MTL can recover more value than its system cost compared to TL under similar market conditions.

Sensitivity analyses showed that MTL can recover more value than TL with current markets or a 5% increase in precut product price considering only value recovery potential, not harvesting cost differences. Increases in precut product prices of 5%,10%, and 20% did not provide enough value to offset the additional cost of $2/ton for MTL. Again, the small sample size could have been a limitation in these analyses.

The individual stem analysis with AVIS showed MTL and TL to have similar value recoveries ranging from 67% to 78% for MTL and 73% to 78% for TL. The MTL harvester operator did not use a bucking optimization program to aid his decision-making. Future work could examine a MTL system that did utilize a bucking program to determine if the bucking program could improve value recovery. It appears there is room for value recovery improvement for these systems as they were below the 90% to 94% value recoveries reported for CTL systems in the southeastern US (Boston and Murphy 2003; Conradie et al. 2004).

Table 4.1. Mill specifications for harvested products, prices adjusted TMS 2007 GA Avg.

Product	Mill	Mill Specifications	Residual Timber Value TL ($/ton)	Residual Timber Value MTL ($/ton)
Pole	A	7-8" top, 11" DBH, lengths 32’ to 77’ in 5’ increments	$58.32	$56.26
ST1	B	Min 8" top in lengths of 25', 29', or 33' and greater	$40.00	$37.94
ST Precut1	B	Min 8" top in lengths of 12'6" and 16'6" only	$40.00	$37.94
ST2	C	Min 8" top, min 12" butt, min 25' length	$37.00	$34.94
ST Precut2	C	Min 10" top, min 12" butt; length 12'6",14'6", or 16'6"	$40.00	$37.94
CNS A	D	5.0" top, minimum length 29'	$18.62	$16.56
CNS B	D	5.0" top, minimum length 21'	$16.62	$14.56
CNS Precut1	D	6" top, 16'6" in length	$18.62	$16.56
CNS	E	9" butt, 5" top, minimum length 29'	$21.62	$19.56
CNS Precut2	E	16.5" length	$21.62	$19.56
PSP	F	7-9" butt; 5" top; minimum length 25'	$12.87	$10.81
PPW	G	3.0 " top, min length 20' TL, min length 12' DB**, max DOB 26"	$6.62	$4.56
HPW	H	6.0-22.0" butt; 3" top; minimum length 21'	$7.47	$5.41
Post	I	6-10" butt; 2.5-3" top; min 24' length	N/A	$4.16*

*Product market only available to MTL
**DB = double bunk

Table 4.2. Residual timber values used to value cruise volumes.

Product	Residual Timber Value TL ($/ton)	Residual Timber Value MTL ($/ton)
PST	$40.00	$37.94
PCNS	$18.62	$16.56
PPW	$6.62	$4.56
HPW	$7.47	$5.41

Table 4.3. Peterson height coefficients and associated statistics.

Tract	Parameter	Estimate	Std Error	n	p-value	Adj. r-squared
Belote	hb1	0.308244	0.00667	50	<0.0001	0.0508
	hb2	0.318839	0.16650	50	0.0614	
Wood	hb1	0.292583	0.00942	47	<0.0001	0.1092
	hb2	0.642223	0.25220	47	0.0144	
Bryan	hb1	0.270605	0.00612	44	<.0001	0.2561
	hb2	0.733170	0.18700	44	0.0003	
Thompson	hb1	0.280331	0.00887	49	<.0001	0.34
	hb2	1.155190	0.23620	49	<.0001	

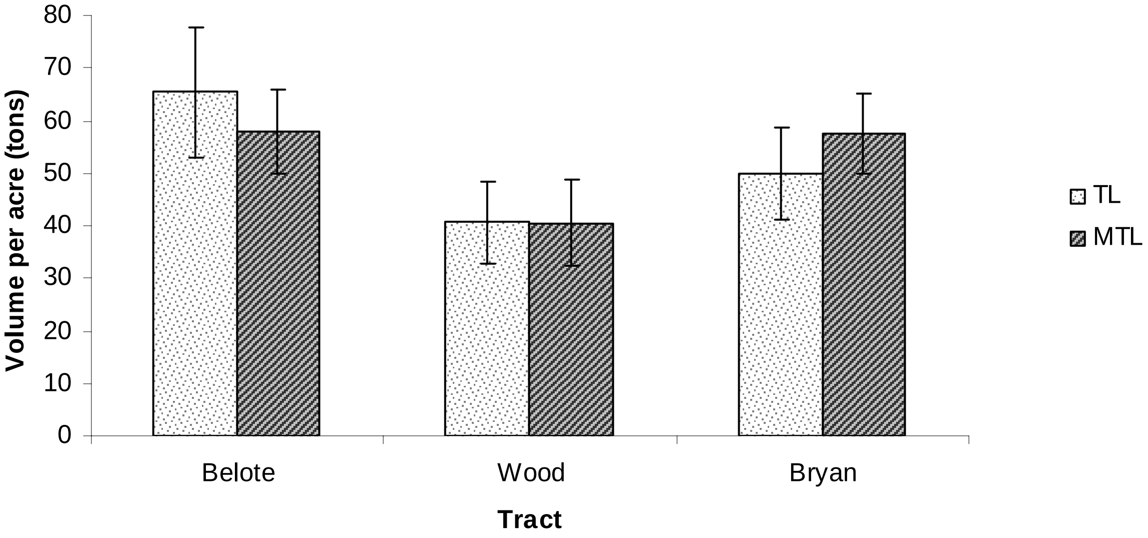

Figure 4.1. Cruised volumes on study sites with bars showing 95% confidence intervals.

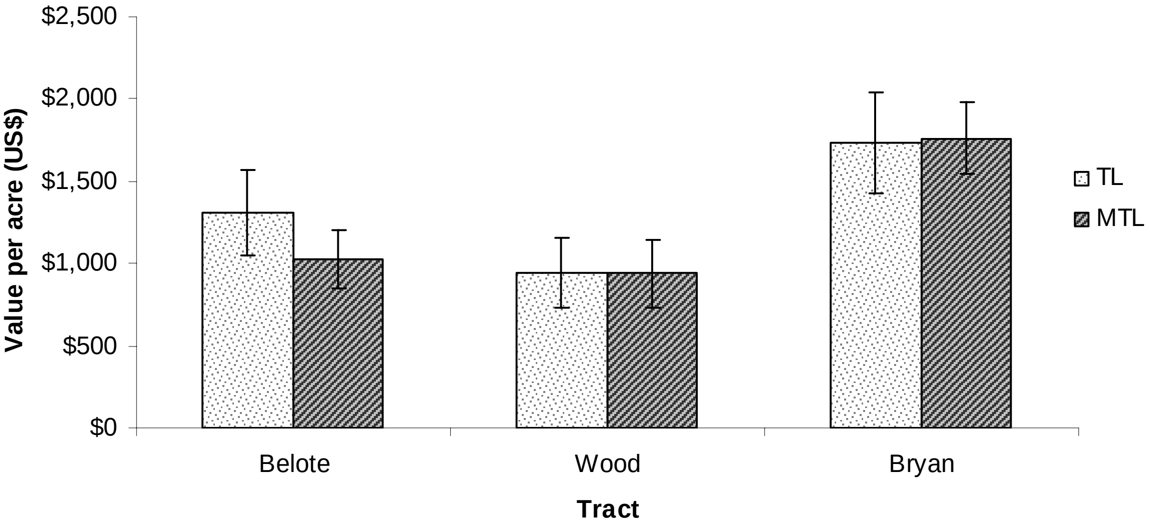

Figure 4.2. Cruised values on study tracts with bars showing 95% confidence intervals.

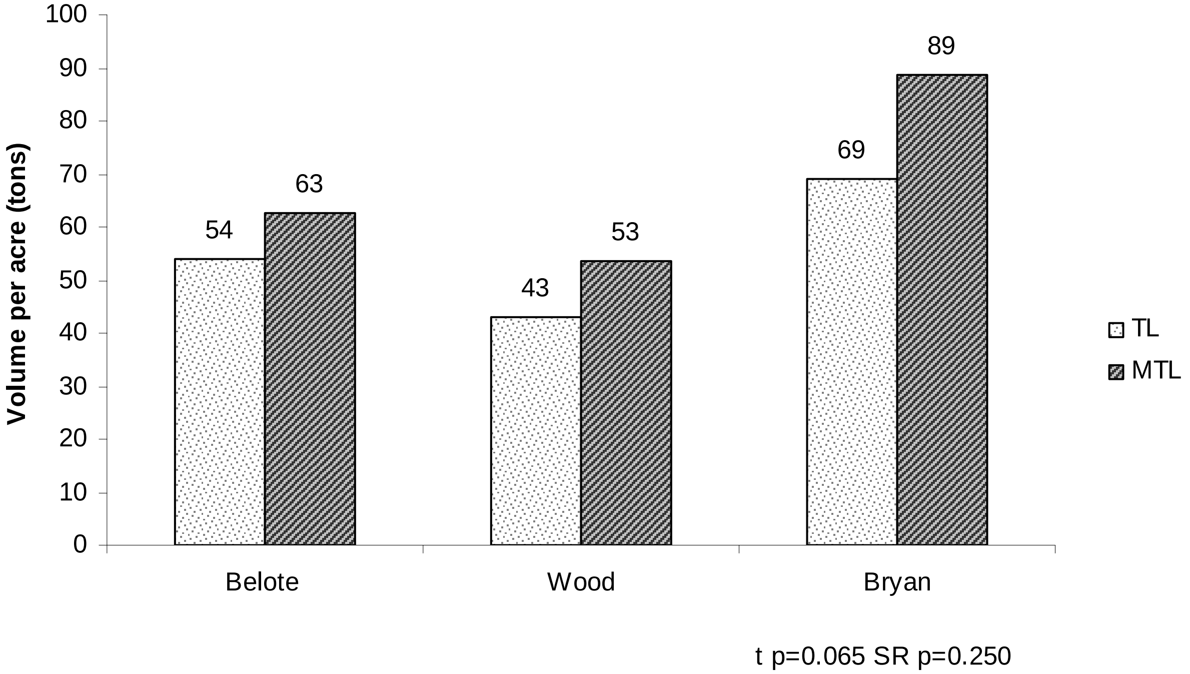

Figure 4.3. Volume per acre harvested on each tract by each system.

Figure 4.4. Total residual timber value per acre harvested on each tract by each system.

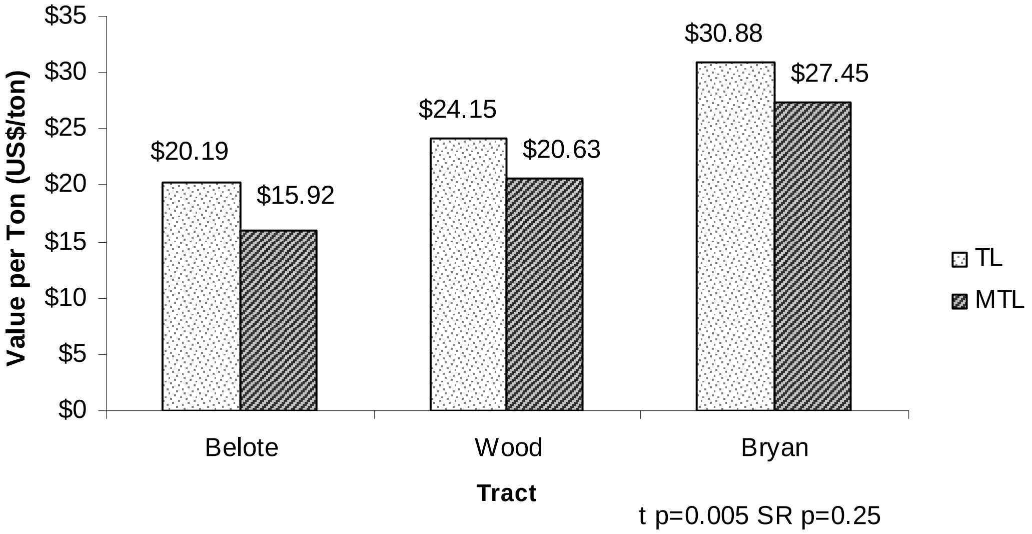

Figure 4.5. Average residual timber value per ton harvested by each system.

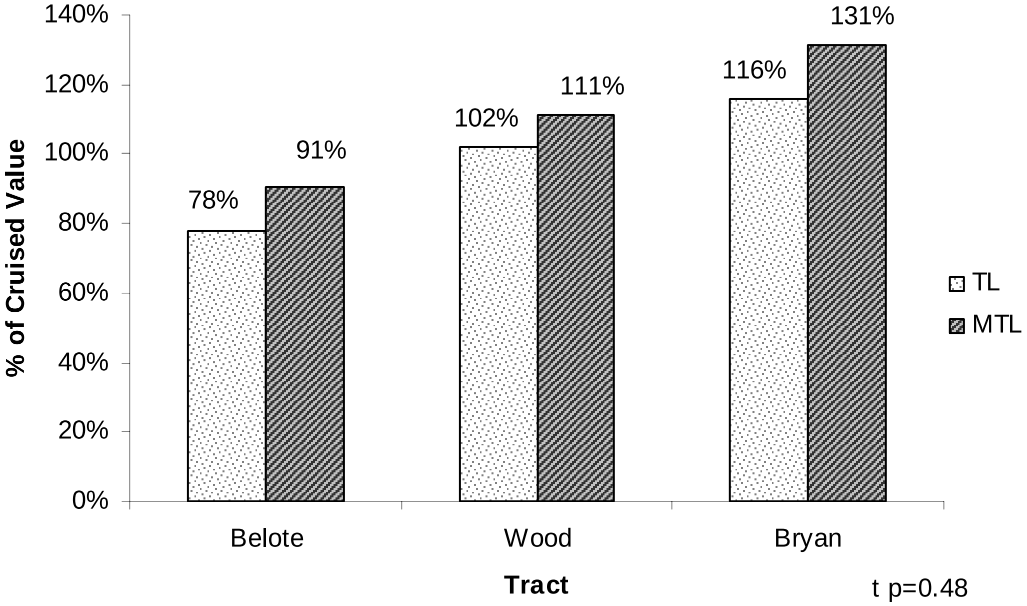

Figure 4.6. Percent of cruised value that each system recovered on each tract.

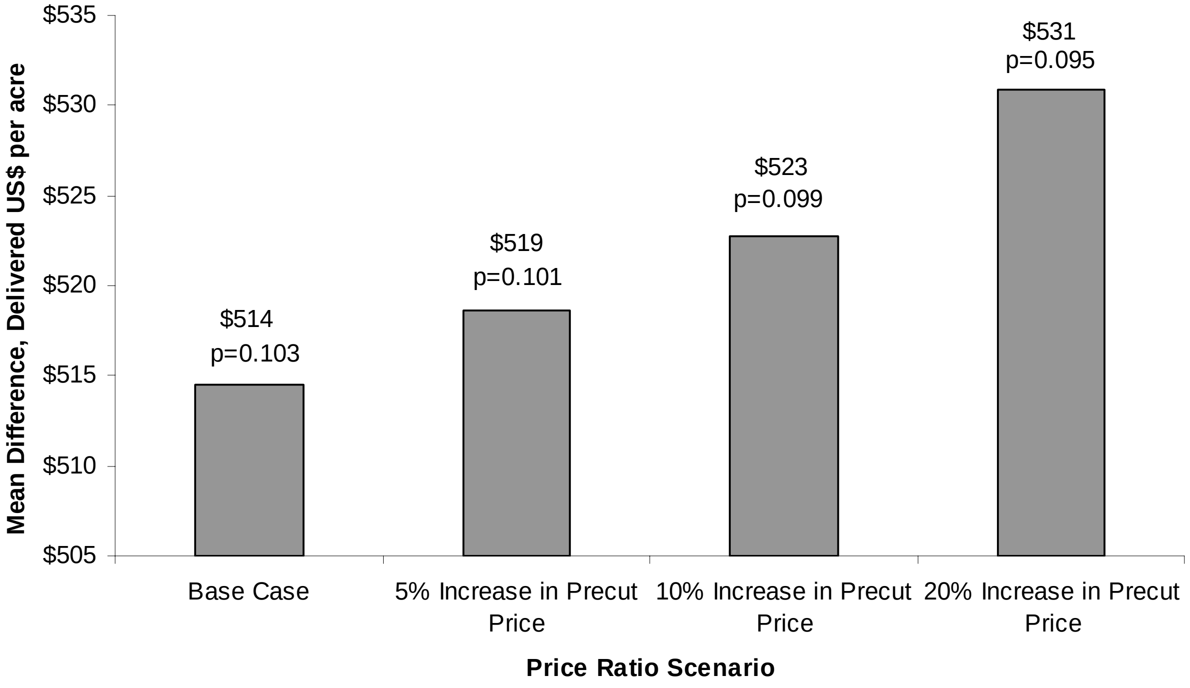

Figure 4.7. Mean difference in delivered value per acre, MTL – TL, with different price ratio scenarios and associated p-values.

Table 4.4 . Price ratio scenarios used to compare mean difference in delivered value per acre between MTL and TL systems.

	Delivered	Delivered Price Ratio Scenarios (Product Price ÷ PPW price)			
Product	$/ton	Base Case	Precut 5%	Precut 10%	Precut 20%
Pole	$76.82	3.20	3.20	3.20	3.20
ST	$57.00	2.37	2.37	2.37	2.37
ST Precut	$57.00	2.37	2.49	2.61	2.85
CNS	$35.00	1.46	1.46	1.46	1.46
CNS Precut	$35.00	1.46	1.53	1.60	1.75
PPW	$24.02	1.00	1.00	1.00	1.00
HPW	$23.62	0.98	0.98	0.98	0.98

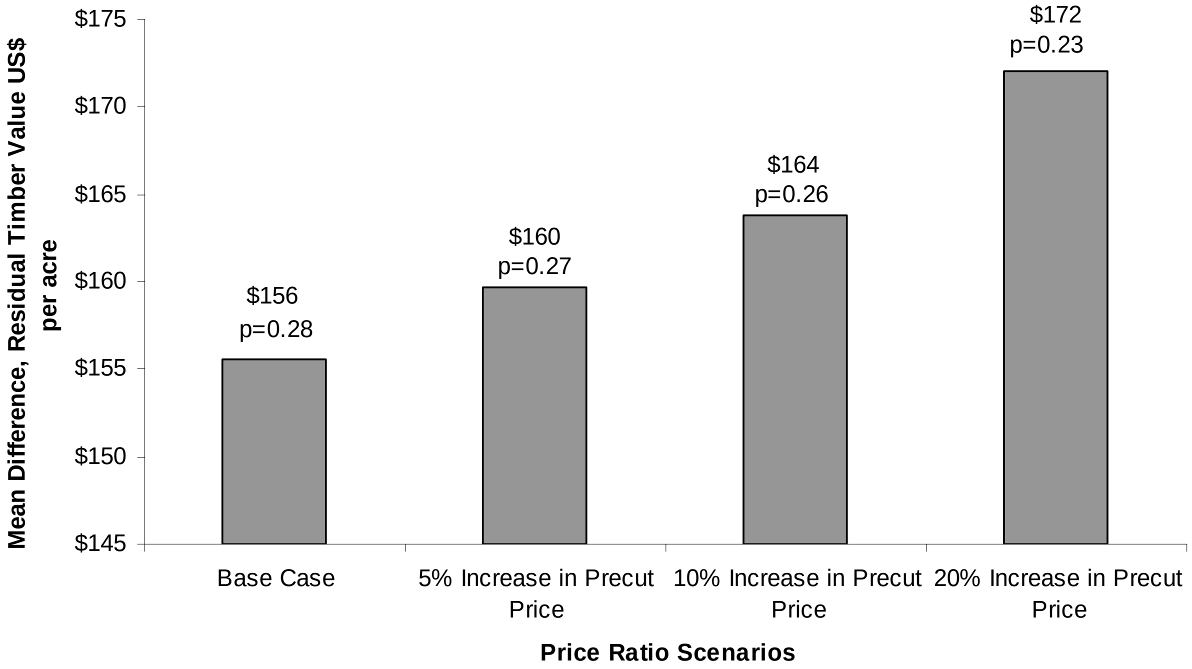

Figure 4.8. Mean difference in residual timber value per acre, MTL – TL, with different price ratio scenarios and associated p-values.

Table 4.5. Price ratio scenarios used to compare mean residual timber value per acre difference between MTL and TL systems.

	Delivered	Residual Timber Value		Residual Timber Value Ratio Scenarios (Product value ÷ PPW value)			
Product	$/ton	TL ($/ton)	MTL ($/ton)	Base Case	Precut 5%	Precut 10%	Precut 20%
Pole	$76.82	$58.32	$56.26	3.20	3.20	3.20	3.20
ST	$57.00	$40.00	$37.94	2.37	2.37	2.37	2.37
ST Precut	$57.00	$40.00	$37.94	2.37	2.49	2.61	2.85
CNS	$35.00	$18.62	$16.56	1.46	1.46	1.46	1.46
CNS Precut	$35.00	$18.62	$16.56	1.46	1.53	1.60	1.75
PPW	$24.02	$6.62	$4.56	1.00	1.00	1.00	1.00
HPW	$23.62	$7.47	$5.41	0.98	0.98	0.98	0.98

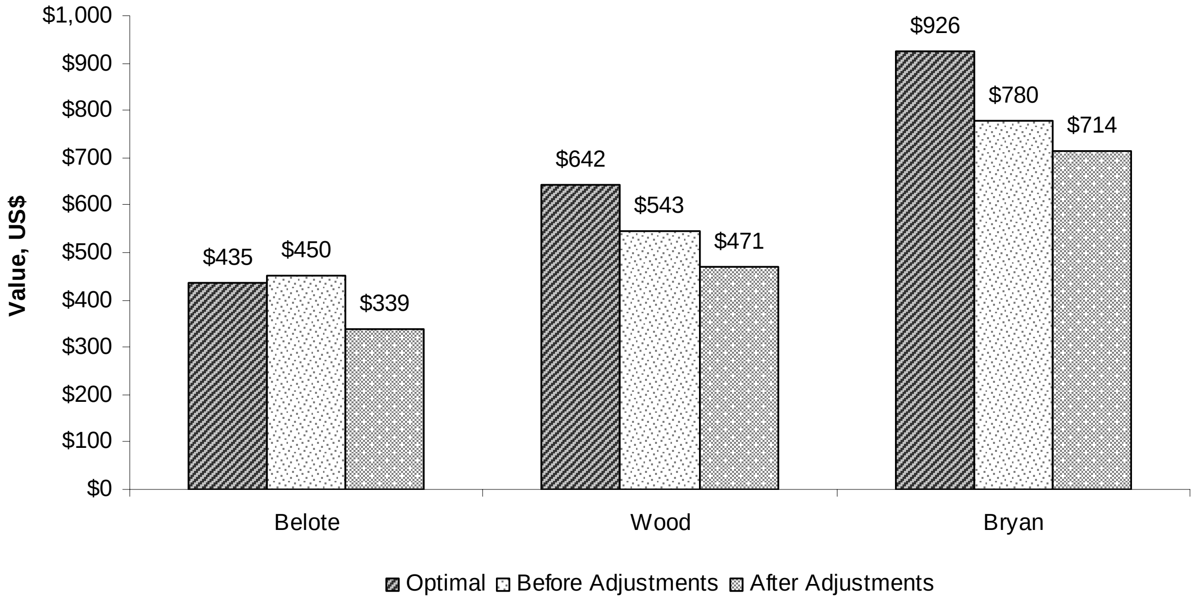

Figure 4.9. Total value recovered by TL from a sample of individual stems on all sites.

Table 4.6. Value recovery results for TL on Belote Tract for a sample of individual stems. Adapted from Conradie, I. P. Cut-to-length harvesting systems in the southeastern USA: Value recovery and adoption by potential users. Master of Science Thesis, University of Georgia, 2003.

Before adjustments for out-of-specification logs									
	Pole	ST	ST Precut	CNS	CNS Precut	PPW	PSP	Waste	Total
# logs optimal	9	4	4	6	5	21	0	22	71
# logs actual	8	11	0	5	0	2	0	23	50
Actual - Optimal	-1	7	-4	-1	-5	-19	0	1	-21
% Difference	-11%	175%	-100%	-17%	-100%	-90%	0%	5%	-30%
Volume (m3) optimal	4.70	1.59	0.85	1.68	0.68	1.90	0.00	0.26	11.66
Volume (m3) actual	3.14	6.39	0.00	1.40	0.00	0.08	0.00	0.63	11.64
Actual - Optimal	-1.56	4.80	-0.85	-0.28	-0.68	-1.82	0.00	0.37	-0.02
% Difference	-33%	302%	-100%	-17%	-100%	-96%	0%	142%	0%
Value (US$) optimal	$272	$64	$34	$37	$15	$13	$0	$0	$435
Value (US$) actual	$183	$236	$0	$30	$0	$1	$0	$0	$450
Actual - Optimal	-$90	$172	-$34	-$7	-$15	-$13	$0	$0	$15
% Difference	-33%	270%	-100%	-18%	-100%	-96%	0%	0%	3%
After adjustments for out-of-specification logs									
# logs optimal	9	4	4	6	5	21	0	22	71
# logs actual	2	10	4	8	6	9	0	32	71
Actual - Optimal	-7	6	0	2	1	-12	0	10	0
% Difference	-78%	150%	0%	33%	20%	-57%	0%	45%	0%
Volume (m3) optimal	4.70	1.59	0.85	1.68	0.68	1.90	0.00	0.26	11.66
Volume (m3) actual	0.86	4.74	0.95	2.37	0.86	0.87	0	0.99	11.64
Actual - Optimal	-3.84	3.15	0.10	0.69	0.18	-1.03	0.00	0.73	-0.02
% Difference	-82%	198%	12%	41%	26%	-54%	0%	281%	0%
Value (US$) optimal	$272	$64	$34	$37	$15	$13	$0	$0	$435
Value (US$) actual	$50	$10	$4	$8	$6	$9	$0	$0	$339
Actual - Optimal	-$223	-$54	-$30	-$29	-$9	-$4	$0	$0	-$96
% Difference	-82%	-84%	-88%	-78%	-60%	-32%	0%	0%	-22%

Table 4.7. Value recovery results for TL on Wood Tract for a sample of individual stems. Adapted from Conradie, I. P. Cut-to-length harvesting systems in the southeastern USA: Value recovery and adoption by potential users. Master of Science Thesis, University of Georgia, 2003.

	Pole	ST	ST Precut	CNS	CNS Precut	PPW	PSP	Waste	Total
Before adjustments for out-of-specification logs									
# logs optimal	16	0	6	4	5	23	0	21	75
# logs actual	7	14	0	4	0	12	0	21	58
Actual - Optimal	-9	14	-6	0	-5	-11	0	0	-17
% Difference	-56%		-100%	0%	-100%	-48%	0%	0%	-23%
Volume (m3) optimal	9.28	0.00	1.30	1.12	0.70	1.78	0.00	0.26	14.44
Volume (m3) actual	3.49	8.10	0.00	1.29	0.00	1.06	0.00	0.44	14.38
Actual - Optimal	-5.79	8.10	-1.30	0.17	-0.70	-0.72	0.00	0.18	-0.06
% Difference	-62%		-100%	15%	-100%	-40%	0%	69%	0%
Value (US$) optimal	$538	$0	$52	$24	$15	$12	$0	$0	$642
Value (US$) actual	$203	$305	$0	$28	$0	$7	$0	$0	$543
Actual - Optimal	-$336	$305	-$52	$4	-$15	-$5	$0	$0	-$99
% Difference	-62%		-100%	16%	-100%	-39%	0%	0%	-15%
After adjustments for out-of-specification logs									
# logs optimal	16	0	6	4	5	23	0	21	75
# logs actual	5	11	3	7	1	16	0	31	74
Actual - Optimal	-11	11	-3	3	-4	-7	0	10	-1
% Difference	-69%		-50%	75%	-80%	-30%	0%	48%	-1%
Volume (m3) optimal	9.28	0.00	1.30	1.12	0.70	1.78	0.00	0.26	14.44
Volume (m3) actual	2.58	6.19	0.66	2.32	0.13	1.62	0	0.9	14.4
Actual - Optimal	-6.70	6.19	-0.64	1.20	-0.57	-0.16	0.00	0.64	-0.04
% Difference	-72%		-49%	107%	-81%	-9%	0%	246%	0%
Value (US$) optimal	$538	$0	$52	$24	$15	$12	$0	$0	$642
Value (US$) actual	$149	$232	$26	$50	$3	$9	$0	$0	$471
Actual - Optimal	-$389	$232	-$26	$26	-$13	-$3	$0	$0	-$171
% Difference	-72%		-49%	105%	-81%	-26%	0%	0%	-27%

Table 4.8. Value recovery results for TL on Bryan Tract for a sample of individual stems. Adapted from Conradie, I. P. Cut-to-length harvesting systems in the southeastern USA: Value recovery and adoption by potential users. Master of Science Thesis, University of Georgia, 2003.

Before adjustments for out-of-specification logs									
	Pole	ST	ST Precut	CNS	CNS Precut	PPW	PSP	Waste	Total
# logs optimal	12	5	10	6	7	10	0	20	70
# logs actual	5	11	6	7	2	10	0	27	68
Actual - Optimal	-7	6	-4	1	-5	0	0	7	-2
% Difference	-58%	120%	-40%	17%	-71%	0%	0%	35%	-3%
Volume (m3) optimal	10.71	2.76	3.02	1.52	1.24	2.00	0.00	0.95	22.2
Volume (m3) actual	3.72	10.16	2.12	3.05	0.51	1.45	0.00	1.17	22.18
Actual - Optimal	-6.99	7.40	-0.90	1.53	-0.73	-0.55	0.00	0.22	-0.02
% Difference	-65%	268%	-30%	101%	-59%	-28%	0%	23%	0%
Value (US$) optimal	$620	$111	$120	$33	$27	$14	$0	$0	$926
Value (US$) actual	$217	$391	$85	$66	$11	$10	$0	$0	$780
Actual - Optimal	-$404	$280	-$35	$33	-$16	-$4	$0	$0	-$146
% Difference	-65%	254%	-29%	98%	-59%	-27%	0%	0%	-16%
After adjustments for out-of-specification logs									
# logs optimal	12	5	10	6	7	10	0	20	70
# logs actual	5	9	7	5	4	15	0	36	81
Actual - Optimal	-7	4	-3	-1	-3	5	0	16	11
% Difference	-58%	80%	-30%	-17%	-43%	50%	0%	80%	16%
Volume (m3) optimal	10.71	2.76	3.02	1.52	1.24	2.00	0.00	0.95	22.20
Volume (m3) actual	3.72	7.72	2.72	2.28	0.83	3.01	0	1.89	22.17
Actual - Optimal	-6.99	4.96	-0.30	0.76	-0.41	1.01	0.00	0.94	-0.03
% Difference	-65%	180%	-10%	50%	-33%	51%	0%	99%	0%
Value (US$) optimal	$620	$111	$120	$33	$27	$14	$0	$0	$926
Value (US$) actual	$216	$299	$109	$50	$18	$21	$0	$0	$714
Actual - Optimal	-$404	$189	-$12	$17	-$9	$7	$0	$0	-$212
% Difference	-65%	171%	-10%	50%	-33%	52%	0%	0%	-23%

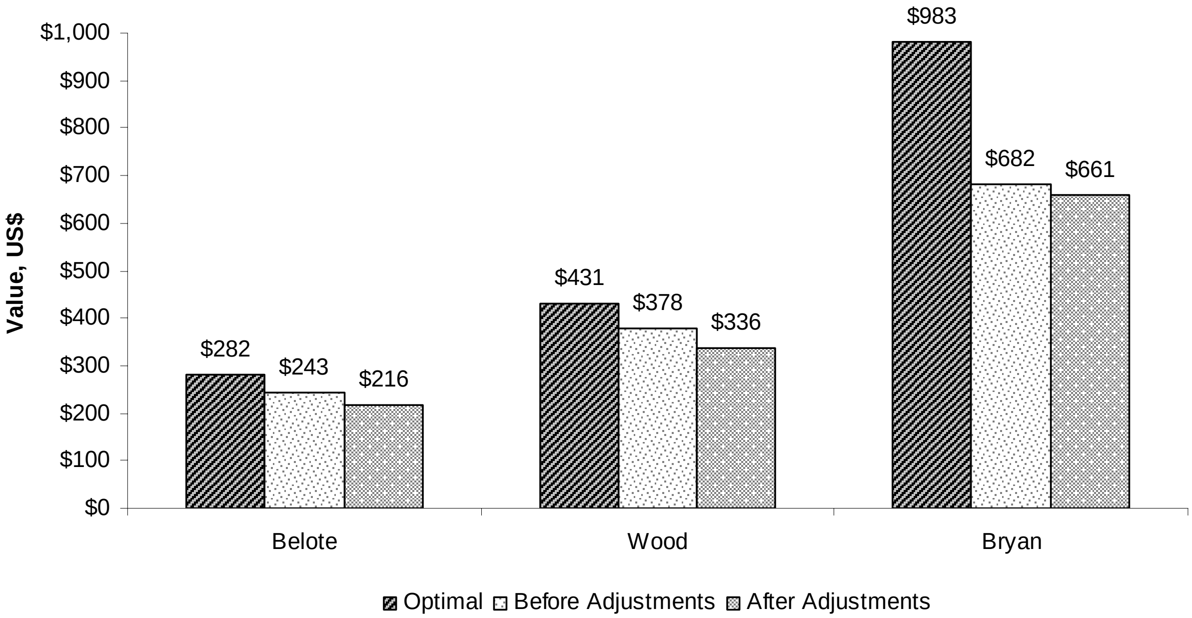

Figure 4.10. Total value recovered by MTL from a sample of individual stems on all sites.

Table 4.9. Value recovery results for MTL on Belote Tract for a sample of individual stems. Adapted from Conradie, I. P. Cut-to-length harvesting systems in the southeastern USA: Value recovery and adoption by potential users. Master of Science Thesis, University of Georgia, 2003.

Before adjustments for out-of-specification logs									
	Pole	ST	ST Precut	CNS	CNS Precut	PPW	Post	Waste	Total
# logs optimal	0	11	5	6	6	24	0	22	74
# logs actual	0	4	4	13	8	23	2	26	80
Actual - Optimal	0	-7	-1	7	2	-1	2	4	6
% Difference	0%	-64%	-20%	117%	33%	-4%	0%	18%	8%
Volume (m3) optimal	0.00	4.48	1.17	1.57	0.96	3.60	0.00	0.23	12.01
Volume (m3) actual	0.00	2.24	0.98	4.59	1.34	2.26	0.27	0.22	11.9
Actual - Optimal	0.00	-2.24	-0.19	3.02	0.38	-1.34	0.27	-0.01	-0.11
% Difference	0%		-16%	192%	40%	-37%		-4%	-1%
Value (US$) optimal	$0	$170	$45	$30	$19	$18	$0	$0	$282
Value (US$) actual	$0	$85	$37	$86	$23	$11	$1	$0	$243
Actual - Optimal	$0	-$85	-$7	$55	$4	-$7	$1	$0	-$40
% Difference	0%		-16%	182%	18%	-37%		0%	-14%
After adjustments for out-of-specification logs									
# logs optimal	0	11	5	6	6	24	0	22	74
# logs actual	0	3	5	12	6	28	0	31	85
Actual - Optimal	0	-8	0	6	0	4	0	9	11
% Difference	0%	-73%	0%	100%	0%	17%	0%	41%	15%
Volume (m3) optimal	0.00	4.48	1.17	1.57	0.96	3.60	0.00	0.23	12.01
Volume (m3) actual	0	1.32	1.33	1.81	0.98	3.61	0	0.39	11.9
Actual - Optimal	0.00	-3.16	0.16	0.24	0.02	0.01	0.00	0.16	-0.11
% Difference	0%	-71%	14%	15%	2%	0%	0%	70%	-1%
Value (US$) optimal	$0	$170	$45	$30	$19	$18	$0	$0	$282
Value (US$) actual	$0	$50	$51	$80	$17	$18	$0	$0	$216
Actual - Optimal	$0	-$120	$6	$50	-$3	$0	$0	$0	-$67
% Difference	0%	-71%	14%	164%	-13%	0%	0%	0%	-24%

Table 4.10. Value recovery of MTL on Wood Tract for a sample of individual stems. Adapted from Conradie, I. P. Cut-to-length harvesting systems in the southeastern USA: Value recovery and adoption by potential users. Master of Science Thesis, University of Georgia, 2003.

	Pole	ST	ST Precut	CNS	CNS Precut	PPW	PSP	Waste	Total
Before adjustments for out-of-specification logs									
# logs optimal	4	8	12	2	10	23	0	24	83
# logs actual	3	5	10	8	7	24	0	27	84
Actual - Optimal	-7	-13	-22	-10	-17	-47	0	-51	-167
% Difference	-175%	-163%	-183%	-500%	-170%	-204%	0%	-213%	-201%
Volume (m3) optimal	2.21	3.60	3.11	0.55	1.49	2.30	0.00	0.22	13.48
Volume (m3) actual	1.70	2.57	2.71	2.64	1.27	2.22	0.00	0.33	13.44
Actual - Optimal	-0.51	-1.03	-0.40	2.09	-0.22	-0.08	0.00	0.11	-0.04
% Difference	-23%	-29%	-13%	380%	-15%	-3%	0%	50%	0%
Value (US$) optimal	$124	$137	$118	$11	$30	$11	$0	$0	$431
Value (US$) actual	$95	$98	$103	$49	$22	$11	$0	$0	$378
Actual - Optimal	-$29	-$39	-$15	$38	-$8	$0	$0	$0	-$53
% Difference	-23%	-29%	-13%	351%	-27%	-3%	0%	0%	-12%
After adjustments for out-of-specification logs									
# logs optimal	4	8	12	2	10	23	0	24	83
# logs actual	1	6	10	8	7	25	0	31	88
Actual - Optimal	-3	-2	-2	6	-3	2	0	7	5
% Difference	-75%	-25%	-17%	300%	-30%	9%	0%	29%	6%
Volume (m3) optimal	2.21	3.60	3.11	0.55	1.49	2.30	0.00	0.22	13.48
Volume (m3) actual	0.64	22.02	20.16	2.64	1.27	2.65	0	0.57	13.44
Actual - Optimal	-1.57	18.42	17.05	2.09	-0.22	0.35	0.00	0.35	-0.04
% Difference	-71%	512%	548%	380%	-15%	15%	0%	159%	0%
Value (US$) optimal	$124	$137	$118	$11	$30	$11	$0	$0	$431
Value (US$) actual	$36	$113	$103	$49	$22	$13	$0	$0	$336
Actual - Optimal	-$88	-$25	-$15	$38	-$8	$2	$0	$0	-$96
% Difference	-71%	-18%	-13%	351%	-27%	16%	0%	0%	-22%

Table 4.11. Value recovery results for MTL on Bryan Tract for a sample of individual stems. Adapted from Conradie, I. P. Cut-to-length harvesting systems in the southeastern USA: Value recovery and adoption by potential users. Master of Science Thesis, University of Georgia, 2003.

Before adjustments for out-of-specification logs									
	Pole	ST	ST Precut	CNS	CNS Precut	PPW	PSP	Waste	Total
# logs optimal	19	3	4	0	6	21	0	31	84
# logs actual	4	15	3	5	8	25	0	38	98
Actual - Optimal	-15	12	-1	5	2	4	0	7	14
% Difference	-79%	400%	-25%		33%	19%	0%	23%	17%
Volume (m3) optimal	14.83	1.69	1.43	0.00	1.03	2.53	0.00	0.87	22.38
Volume (m3) actual	3.39	10.19	1.10	2.03	1.43	3.37	0.00	0.87	22.38
Actual - Optimal	-11.44	8.50	-0.33	2.03	0.40	0.84	0.00	0.00	0.00
% Difference	-77%	503%	-23%		39%	33%	0%	0%	0%
Value (US$) optimal	$831	$64	$54	$0	$21	$13	$0	$0	$983
Value (US$) actual	$189	$375	$42	$34	$25	$17	$0	$0	$682
Actual - Optimal	-$642	$311	-$12	$34	$4	$4	$0	$0	-$301
% Difference	-77%	482%	-23%		19%	33%	0%	0%	-31%
After adjustments for out-of-specification logs									
# logs optimal	19	3	4	0	6	21	0	31	84
# logs actual	4	14	4	4	8	26	0	43	103
Actual - Optimal	-15	11	0	4	2	5	0	12	19
% Difference	0%	367%	0%		33%	24%	0%	39%	23%
Volume (m3) optimal	14.83	1.69	1.43	0.00	1.03	2.53	0.00	0.87	22.38
Volume (m3) actual	3.39	9.44	1.41	1.69	1.48	3.55	0	1.43	22.39
Actual - Optimal	-11.44	7.75	-0.02	1.69	0.45	1.02	0.00	0.56	0.01
% Difference	0%	459%	-1%		44%	40%	0%	64%	0%
Value (US$) optimal	$831	$64	$54	$0	$21	$13	$0	$0	$983
Value (US$) actual	$189	$346	$54	$29	$25	$18	$0	$0	$661
Actual - Optimal	-$642	$282	-$1	$29	$5	$5	$0	$0	-$322
% Difference	0%	437%	-1%		23%	40%	0%	0%	-33%

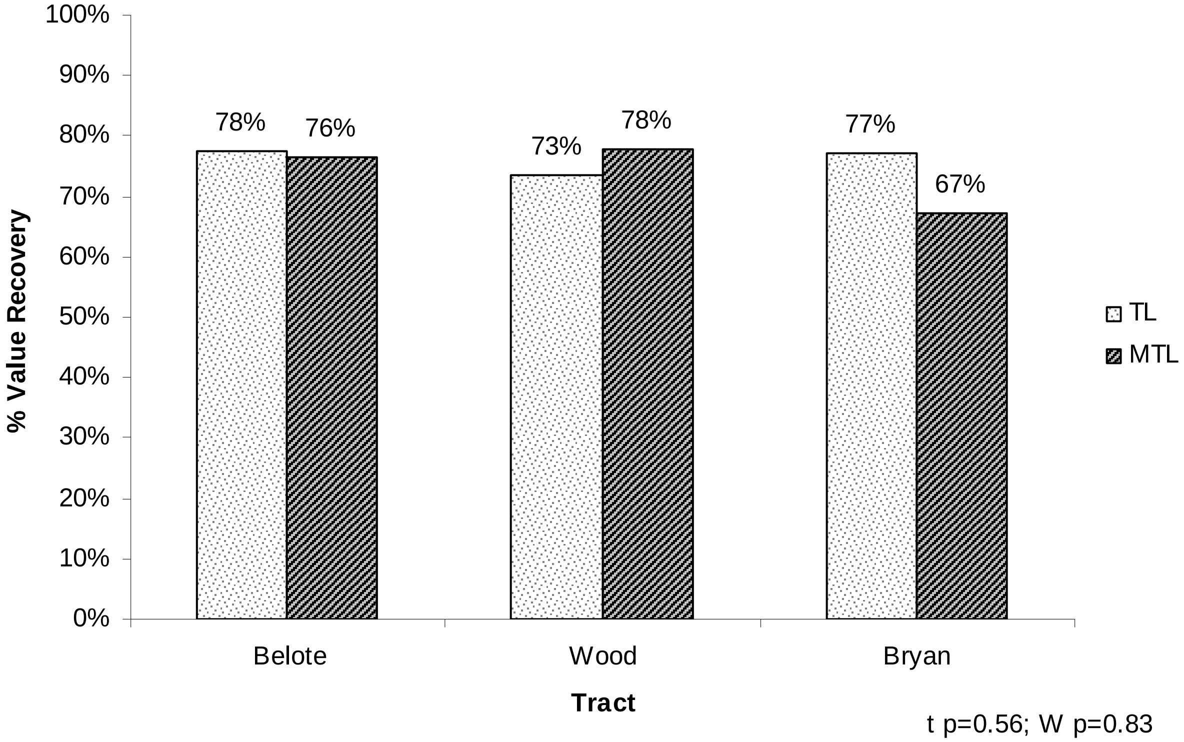

Figure 4.11. Total value recovery by tract for a sample of individual stems.

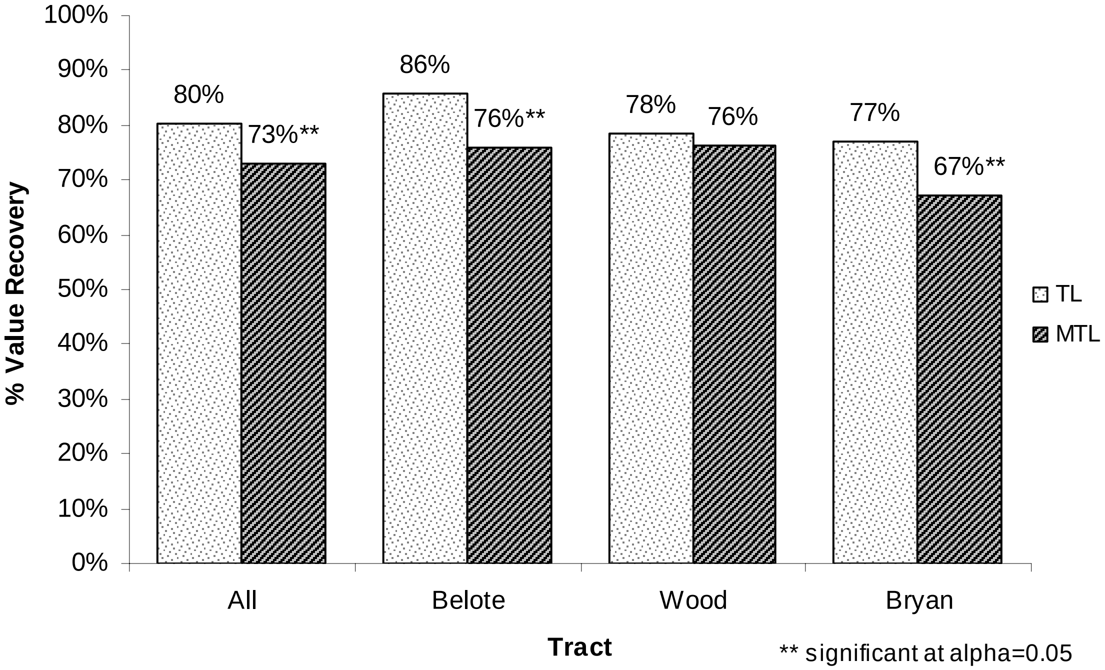

Figure 4.12. Average value recovery for individual stems.

Table 4.12 Market conditions during the study.

	Harvesting System	
Tract	TL	MTL
Belote	4/30/07-5/4/07: Griffin closed 1 week; Focus on CNS.	5/28/07-6/29/07: Griffin did not take precuts for 2 weeks; No pole or Tolleson quota for 3 weeks.
Wood	5/14/07-5/25/07	7/23/07-8/10/07: No pole quota for 1 week; no Tolleson quota.
Bryan	4/2/07-4/27/07: ST quota restrictive at Tolleson and Griffin; Griffin did not take wood for a week and a half; ATL did not take poles for 1 week.	8/20/07-9/21/07: Griffin quota restrictive; No Tolleson quota for 1 week.

Table 4.13. Value per acre harvested by product.

	Value per acre (US$)								
	Belote			Wood			Bryan		
Product	TL	MTL	Diff	TL	MTL	Diff	TL	MTL	Diff
PPOLE	$109	$0	-$109	$33	$146	$113	$246	$675	$429
PST	$87	$326	$238	$439	$529	$89	$1,353	$1,419	$66
PST P	$0	$0	$0	$0	$0	$0	$77	$17	-$60
PCNS	$806	$507	-$299	$515	$310	-$205	$390	$138	-$253
PCNS P	$0	$58	$58	$0	$34	$34	$0	$65	$65
PSP	$26	$4	-$22	$13	$0	-$13	$0	$0	$0
PPW	$59	$100	$41	$38	$80	$42	$62	$111	$48
HPW	$4	$5	$0	$0	$3	$3	$0	$12	$12
	$1,092	$1,000	-$92	$1,039	$1,102	$63	$2,129	$2,436	$307

Table 4.14. Volume per acre harvested by product.

	Volume per acre (tons)								
	Belote			Wood			Bryan		
Product	TL	MTL	Diff	TL	MTL	Diff	TL	MTL	Diff
PPOLE	1.9		-1.9	0.6	2.6	2.0	4.2	12.0	7.8
PST	2.4	8.6	6.2	11.4	13.9	2.5	35.2	38.3	3.1
PST P							1.9	0.5	-1.5
PCNS	38.3	27.5	-10.9	24.3	16.7	-7.6	18.2	7.6	-10.6
PCNS P		3.5	3.5		2.0	2.0		3.9	3.9
PSP	2.0	0.4	-1.6	1.0		-1.0			
PPW	8.9	22.0	13.1	5.7	17.5	11.9	9.4	24.3	14.9
HPW	0.6	0.9	0.3		0.6	0.6		2.2	2.2
	54.1	62.8	8.8	43.0	53.4	10.4	68.9	88.8	19.8

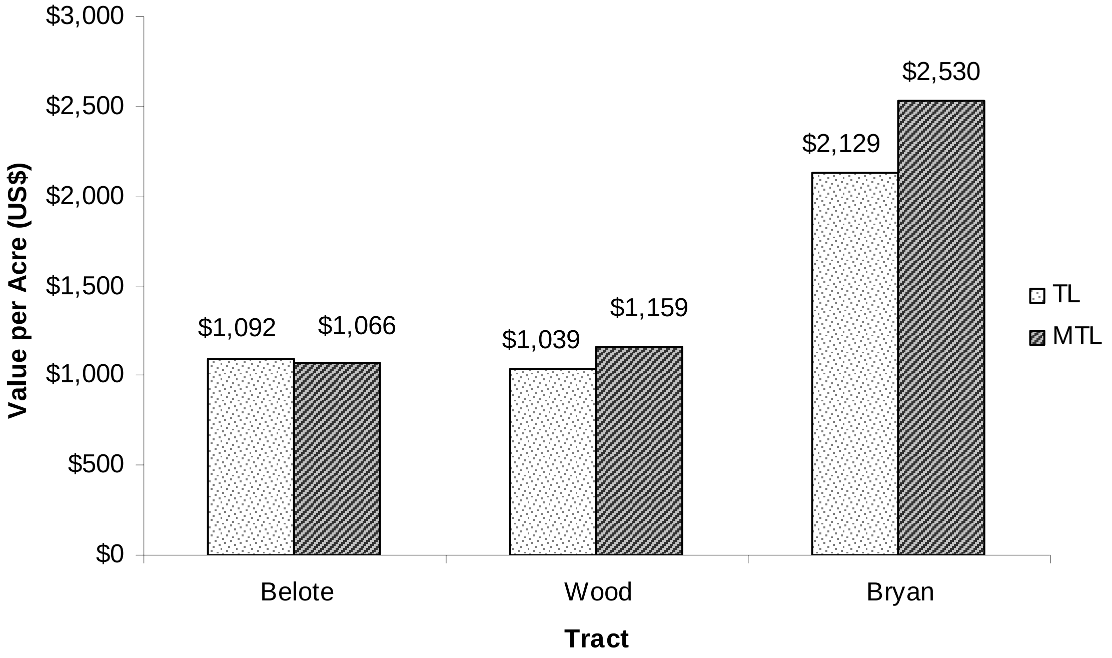

Figure 4.13. Total residual timber value per acre harvested on each tract by each system with harvesting cost differential of $1/ton.

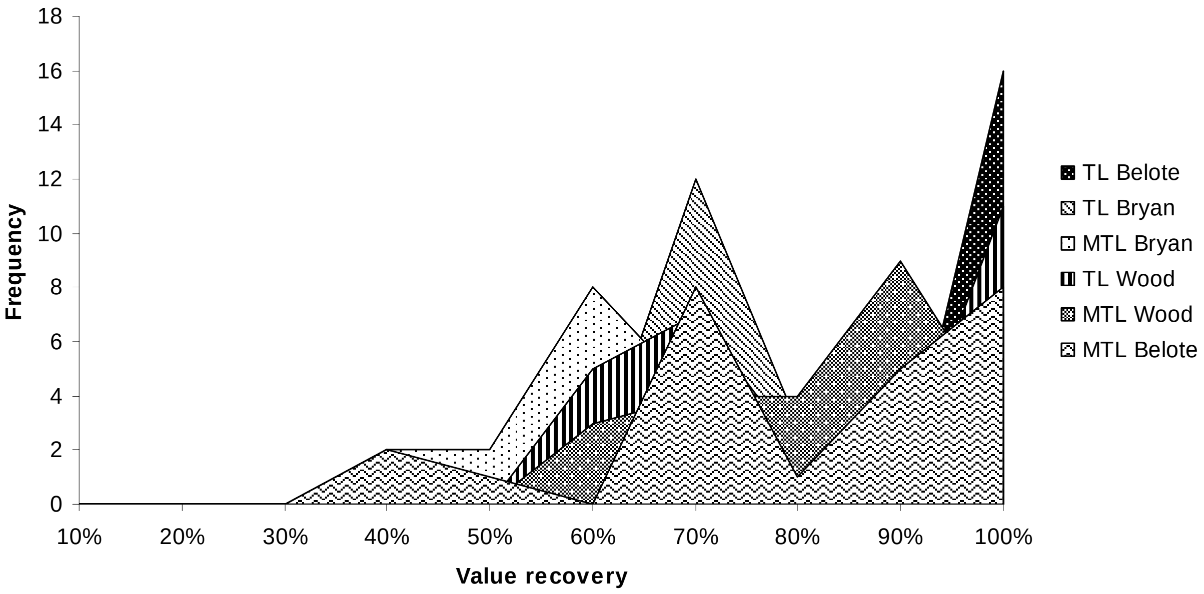

Figure 4.14. Frequency distribution of value recovery per stem for each system on each site.

CHAPTER 5

SUMMARY AND CONCLUSIONS

We saw from a survey that most Georgia logging contractors buck logs using chainsaws or sawbucks, and that most loggers have up to six product sorts in a week. There was almost an even split between estimating and measuring product dimensions with the highest percentage of respondents estimating dimensions with some measurement. Most loggers reported that they are not compensated for additional sorts.

Processing TL loads of PPW and PCNS with a Waratah processor did not increase load value in our study. Because of issues with non-random load selection, thinnings as a source of wood, numerous out-of-spec stems, prices, and weight losses we recommend making few operational decisions based on this study. Future studies of this type should ensure random selection of loads and use wood from clearcuts or later thinnings if possible. Greater attention to labeling and load separation in future studies could reduce error in weight data. This could slow down the study, increase costs, or force a small sample size.

The small sample size and uneven market conditions between MTL and TL crews were limitations to this study. Although not statistically significant, MTL did recover slightly more residual timber value per acre than TL on two of the three sites despite estimated \$2/ton higher logging costs that reduced per ton residual timber values. MTL also had very limited pole quota on the third site. The modeled \$1/ton difference in harvesting cost between MTL and TL would still produce a lower value per acre on one tract from MTL by \$26, but the value per acre difference on two other tracts would increase to $120 and $401 respectively. MTL also showed consistent increases (not statistically significant) over percent cruised value compared to TL: 14%, 15%, and 15%. This gives encouraging evidence to suggest that MTL can recover more value than its system cost compared to TL under similar market conditions.

Sensitivity analyses showed that MTL can recover more value than TL with current markets or with a 5% increase in precut product price considering only value recovery potential, not harvesting cost differences. Increases in precut product prices of 5%,10%, and 20% did not provide enough value to offset the additional cost of $2/ton for MTL. Again, the small sample size could have been a limitation in these analyses.

The individual stem analysis with AVIS showed MTL and TL to have similar value recoveries ranging from 67% to 78% for MTL and 73% to 78% for TL. The MTL harvester operator did not use a bucking optimization program to aid his decision-making. Future work could examine a MTL system that did utilize a bucking program to determine if the bucking program could improve value recovery. It appears there is room for value recovery improvement for these systems as they were below the 90% to 94% value recoveries reported for CTL systems in the southeastern US (Boston and Murphy 2003; Conradie et al. 2004).

There are several costs and benefits of processing with a harvester on the landing that this study did not evaluate. We did not examine the difference in cost of the logger processing raw forest products at the harvesting site compared to the mill processing raw material. Mills that accept tree-length products do incur an additional processing cost to trim products to size. One benefit of processing to length in the woods is that it shifts processing costs from the mill to the logger. Mills in the southeastern US do not pay a premium for precut products and therefore do not appear to reward the additional processing cost in the woods. Another benefit of processing with a harvester is bark removal. Pulling stems individually through the harvesting head removes branches and bark that a delimbing gate may miss. As a result, a logger could load more wood onto a trailer if it had less bark; this could potentially reduce transport costs as more wood on a trailer would require less truckloads to deliver the same volume of wood. One cost of processing to length compared to delivering tree-length relates to out-of-spec products. We had several out-of-spec stems delivered to the yard study. If the mills are willing to accept stems that do not meet specifications, then it is very difficult for the MTL system to recover more value as its primary benefit is measuring dimensions.

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APPENDIX A

TYPE FILE DATA FOR TL ON ALL SITES

Product	Min Length (m)	Max Length (m)	Step Length (m)	Min SED (cm)	Max SED (cm)	Max LED (cm)	Sale Price $(\$/m^3)$	Rel. Value $(\$/m^3)$	Sweep Code	Allowable Qualities
Pole	9.8	23.5	0.1	18	56	56	58.32	58.32	1	A
ST Mill B	7.6	24.4	1.2	20	71	71	40	40	1	ABC
ST P Mill B	3.8	5.0	1.2	20	71	71	40	40	1	ABC
ST Mill C	7.6	25.5	0.1	20	91	91	37	37	1	AB
ST P Mill C	5.0	5.0	1.2	25	91	91	40	40	1	AB
CNS A Mill D	8.8	25.5	0.1	13	51	999	18.62	18.62	1	ABCD
CNS B Mill D	6.4	25.5	0.1	13	51	999	16.62	16.62	1	ABCD
CNS C Mill D	5.0	5.0	0.1	15	51	999	18.62	18.62	1	ABCD
CNS Mill E	8.8	25.5	0.1	13	64	64	21.62	21.62	1	ABCD
CNS P Mill E	5.0	5.0	0.1	15	64	64	21.62	21.62	1	ABCD
PW TL	6.1	25.5	0.1	8	66	66	6.62	6.62	8	ABCDE
PW DB	3.7	6.1	0.1	8	66	66	6.62	6.62	8	ABCDE
Super pulp	7.6	25.5	0.1	13	23	23	12.87	12.87	8	ABCDE
Post	7.3	25.5	0.1	6	8	25			1	ABCD
Waste	0.1	25.5	0.1	0	999	999	0	0	9	ABCDE

Quality Code Key:

A	No knots above 3", no sweep, no ring knots, no cankers
B	No ring knots, no excessive knots, < 50% stem in knots, no cankers > 24" long and > 2" deep, no excessive sweep
C	Knots no larger than 4", no more than 3 knots per 4' section, no ring knots, no disease > 2" deep, no excessive sweep
D	No canker 1st 16', no excessive crook, no forked wood, no "knotty" trees
E	No limit on knots, no limit on sweep, no limit on cankers

Column Definitions:

Min Length	minimum length in meters
Max Length	maximum length in meters
Step Length	incremental lengths between minimum and maximum that are allowed
Min SED	minimum small end diameter in cm
Max LED	maximum large end diameter in cm
Sale Price	$/cubic meter price of wood (same as $/ton price)
Rel. Value	indicates a production priority not shown in the sale price (same as sale price here)
Sweep Code	numerical code to indicate sweep; 9 is highly swept and 1 is slightly swept (sweep is included in quality code for this study)

APPENDIX B

TYPE FILE DATA FOR MTL ON ALL SITES

Product	Min Length (m)	Max Length (m)	Step Length (m)	Min SED (cm)	Max SED (cm)	Max LED (cm)	Sale Price ($\$/\text{m}^3$)	Rel. Value ($\$/\text{m}^3$)	Sweep Code	Allowable Qualities
Pole	9.8	23.5	0.1	18	56	56	56.26	56.26	1	A
ST Mill B	7.6	24.4	1.2	20	71	71	37.94	37.94	1	ABC
ST P Mill B	3.8	5.0	1.2	20	71	71	37.94	37.94	1	ABC
ST Mill C	7.6	25.5	0.1	20	91	91	34.94	34.94	1	AB
ST P Mill C	3.8	5.0	1.2	25	91	91	37.94	37.94	1	AB
CNS A Mill D	8.8	25.5	0.1	13	51	998	16.56	16.56	1	ABCD
CNS B Mill D	6.4	25.5	0.1	13	51	998	14.56	14.56	1	ABCD
CNS C Mill D	5.0	5.0	0.1	15	51	998	16.56	16.56	1	ABCD
CNS Mill E	8.8	25.5	0.1	13	64	64	19.56	19.56	1	ABCD
CNS P Mill E	5.0	5.0	0.1	15	64	64	19.56	19.56	1	ABCD
PW TL	6.1	25.5	0.1	8	66	66	4.56	4.56	8	ABCDE
PW DB	3.7	6.1	0.1	8	66	66	4.56	4.56	8	ABCDE
Super pulp	7.6	25.5	0.1	13	23	23	10.81	10.81	8	ABCDE
Post	7.3	25.5	0.1	6	8	25	4.16	4.16	1	ABCD
Waste	0.1	25.5	0.1	0	998	998	0	0	9	ABCDE

Quality Code Key:

A	No knots above 3", no sweep, no ring knots, no cankers
B	No ring knots, no excessive knots, < 50% stem in knots, no cankers > 24" long and > 2" deep, no excessive sweep
C	Knots no larger than 4", no more than 3 knots per 4' section, no ring knots, no disease > 2" deep, no excessive sweep
D	No canker 1st 16', no excessive crook, no forked wood, no "knotty" trees
E	No limit on knots, no limit on sweep, no limit on cankers

Column Definitions:

Min Length	minimum length in meters
Max Length	maximum length in meters
Step Length	incremental lengths between minimum and maximum that are allowed
Min SED	minimum small end diameter in cm
Max LED	maximum large end diameter in cm
Sale Price	$/cubic meter price of wood (same as $/ton price)
Rel. Value	indicates a production priority not shown in the sale price (same as sale price here)
Sweep Code	numerical code to indicate sweep; 9 is highly swept and 1 is slightly swept (sweep is included in quality code for this study)

APPENDIX C

CONFIGURATION FILES FOR TL AND MTL ON ALL SITES

	TL Belote	TL Wood	TL Bryan	MTL Belote	MTL Wood	MTL Bryan
Peterson height coefficient						
hb1	3.08E-01	2.93E-01	2.71E-01	3.08E-01	2.93E-01	2.71E-01
hb2	3.19E-01	6.42E-01	7.33E-01	3.19E-01	6.42E-01	7.33E-01
Avg stump height, m	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02
Max log volume, m3	3.00E+00	3.00E+00	3.00E+00	3.00E+00	3.00E+00	3.00E+00
Max step between over bark diameters, m	6	6	6	6	6	6
Under bark regression coefficients						
b0	-13.82	-13.82	-13.82	-13.82	-13.82	-13.82
b1	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
b2	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
b3	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
b4	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
b5	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
b6	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
Skid length tolerance, m	1	1	1	1	1	1
Allowable diameter error, cm	2.5	2.5	2.5	2.5	2.5	2.5
Out-of-spec diameter penalty	0	0	0	0	0	0
Allowable length error, cm	7.6	7.6	7.6	7.6	7.6	7.6
Out-of-spec length penalty	0	0	0	0	0	0
Out-of-spec quality penalty	0	0	0	0	0	0
Out-of-spec sweep penalty	0	0	0	0	0	0
Multiple out-of-spec penalty	0	0	0	0	0	0

APPENDIX D

EXAMPLE DATA IN STEM FILE

```
==============================================================
  Stem_no:  130   Data_set     9[1]   2[2]   0
    0.0      0.3      3.0      6.1      9.1    12.2    15.2    16.7    17.8[3]
   24.9    24.9    18.3    16.8    14.7    11.9      7.6      5.3      0.3[4]
    A        D[5]
   11.2   17.8

  Cut    3
     DA[6]     PT      W
   9.00     5.80     3.00

==============================================================
```

---

[1] Number of height-diameter pairs
[2] Number of quality codes
[3] Height, m
[4] Diameter at the specified height, cm
[5] Quality code and height (m) where it changes
[6] Log type and length (m) that logging contractor cut

APPENDIX E

EXAMPLE DATA IN REPORT FILE

```
Stem number: 130
Optimal solution:
 CUT  SED   LEN  CUM.LEN  No  LOG TYPE   VOLUME   VALUE$
  1   130  11.0   11.0      7    CNS Mi     0.28      5.53
  2    80   3.9   14.9     10    PW DB      0.04      0.18
 RE     3   2.9   17.8     11     Waste     0.01      0.00
                                  TOTAL     0.32      5.71
Skid solution:
 CUT  SED   LEN  CUM.LEN  No  LOG TYPE   VOLUME   VALUE$
  1   148  9.00    9.0      4     CNS A     0.25      4.18
  2    82  5.80   14.8     10     PW DB     0.07      0.33
 RE     3  3.00   17.8     11     Waste     0.01      0.00
                                  TOTAL     0.32      4.51
                                                 DIFFERENCE $   1.20
                                                  VALUE LOSS    21 %
```

APPENDIX F1

MACHINE RATE ASSUMPTIONS FOR MTL SYSTEM

Interest	10%	Labor	$13.00
Insurance	1%	Fringe	40%
Taxes	4%	Fuel	$2.75

Machine: Feller-Buncher

Purchase Price	$194,000	Fuel	6	gal/PMH @
Salvage Value	25%	Lube	40	% Fuel
Economic Life (yr)	5	Maint. & Repair		100%
Utilization	65%			

Machine: Skidder

Purchase Price	$165,000	Fuel	5.2	gal/PMH @
Salvage Value	20%	Lube	40	% Fuel
Economic Life (yr)	5	Maint. & Repair		100%
Utilization	60%			

Machine: Loader

Purchase Price	$112,000	Fuel	3.6	gal/PMH @
Salvage Value	20%	Lube	40	% Fuel
Economic Life (yr)	10	Maint. & Repair		100%
Utilization	65%			

Machine: Processor

Purchase Price	$388,000	Fuel	6	gal/PMH @
Salvage Value	25%	Lube	40	% Fuel
Economic Life (yr)	6	Maint. & Repair		100%
Utilization	65%			

APPENDIX F2

MACHINE RATE ASSUMPTIONS FOR TL SYSTEM

Interest	10%	Labor		$13.00
Insurance	1%	Fringe		40%
Taxes	4%	Fuel		$2.75

Machine: Feller-Buncher

Purchase Price	$194,000	Fuel	6	gal/PMH @
Salvage Value	25%	Lube	40	% Fuel
Economic Life (yr)	5	Maint. & Repair		100%
Utilization	65%			

Machine: Skidder

Purchase Price	$165,000	Fuel	5.2	gal/PMH @
Salvage Value	20%	Lube	40	% Fuel
Economic Life (yr)	5	Maint. & Repair		100%
Utilization	60%			

Machine: Loader

Purchase Price	$112,000	Fuel	3.6	gal/PMH @
Salvage Value	20%	Lube	40	% Fuel
Economic Life (yr)	10	Maint. & Repair		100%
Utilization	65%			

APPENDIX G1

VALUE RECOVERY OF INDIVIDUAL STEMS FOR TL ON BELOTE TRACT BEFORE DOWNGRADES FOR OUT-OF-SPEC STEMS

Stem No.	Length	Volume	Optimum Value$	Skid Value$	Diff.$	% Loss	% Value Recovery
51	17	0.31	6.13	15.92	-9.79	-160%	260%
52	17.9	0.5	25.33	27.82	-2.49	-10%	110%
53	18.6	0.47	13.93	26.76	-12.83	-92%	192%
54	18.7	0.46	13.39	25.04	-11.65	-87%	187%
55	15.9	0.55	18.07	19.17	-1.1	-6%	106%
56	16.9	0.58	30.49	20.7	9.79	32%	68%
57	18.1	0.36	7.24	19.32	-12.08	-167%	267%
58	19.4	0.69	34.52	24.52	10	29%	71%
60	15.8	0.41	11.96	21.69	-9.73	-81%	181%
61	18.1	0.39	7.96	7.87	0.09	1%	99%
62	14.2	0.51	25.54	28.13	-2.59	-10%	110%
63	16.9	0.25	3.81	5.28	-1.47	-39%	139%
64	20.2	0.53	25.74	18.6	7.14	28%	72%
65	19.1	0.24	4.25	3.96	0.29	7%	93%
66	19.5	0.53	26.45	18.53	7.92	30%	70%
67	19	0.47	13.44	15.76	-2.32	-17%	117%
68	18.7	0.8	41.62	29.58	12.04	29%	71%
69	17.9	0.64	31.25	22.53	8.72	28%	72%
70	17.4	0.36	7.26	7.26	0	0%	100%
71	16.1	0.62	18.64	21.97	-3.33	-18%	118%
73	20.2	0.56	17.21	18.79	-1.58	-9%	109%
273	7.1	0.1	0.69	1.67	-0.98	-142%	242%
74	16	0.73	36.97	26.27	10.7	29%	71%
75	17.2	0.36	9.68	18.37	-8.69	-90%	190%
		Total	$431.57	$445.51	-$13.94	-3%	103%

APPENDIX G2

VALUE RECOVERY OF INDIVIDUAL STEMS FOR TL ON BELOTE TRACT AFTER DOWNGRADES FOR OUT-OF-SPEC STEMS

Stem No.	Length	Volume	Optimum Value$	Skid Value$	Diff.$	% Loss	% Value Recovery
51	17	0.31	6.13	6.11	0.02	0%	100%
52	17.9	0.5	25.33	24.85	0.48	2%	98%
53	18.6	0.47	13.93	13.91	0.02	0%	100%
54	18.7	0.46	13.39	12.95	0.44	3%	97%
55	15.9	0.55	18.07	16.62	1.45	8%	92%
56	16.9	0.58	30.49	18.35	12.14	40%	60%
57	18.1	0.36	7.24	7.24	0	0%	100%
58	19.4	0.69	34.52	21.89	12.63	37%	63%
60	15.8	0.41	11.96	11.59	0.37	3%	97%
61	18.1	0.39	7.96	7.87	0.09	1%	99%
62	14.2	0.51	25.54	25.01	0.53	2%	98%
63	16.9	0.25	3.81	3.8	0.01	0%	100%
64	20.2	0.53	25.74	14.9	10.84	42%	58%
65	19.1	0.24	4.25	3.96	0.29	7%	93%
66	19.5	0.53	26.45	15.8	10.65	40%	60%
67	19	0.47	13.44	9.37	4.07	30%	70%
68	18.7	0.8	41.62	26.14	15.48	37%	63%
69	17.9	0.64	31.25	20.17	11.08	35%	65%
70	17.4	0.36	7.26	7.26	0	0%	100%
71	16.1	0.62	18.64	17.36	1.28	7%	93%
73	20.2	0.56	17.21	15.76	1.45	8%	92%
273	7.1	0.1	0.69	0.69	0	0%	100%
74	16	0.73	36.97	23.7	13.27	36%	64%
75	17.2	0.36	9.68	9.29	0.39	4%	96%
		Total	$431.57	$334.59	$96.98	22%	78%

APPENDIX H1

VALUE RECOVERY OF INDIVIDUAL STEMS FOR TL ON WOOD TRACT BEFORE DOWNGRADES FOR OUT-OF-SPEC STEMS

Stem No.	Length	Volume	Optimum Value$	Skid Value$	Diff.$	% Loss	% Value Recovery
101	20.2	0.88	45.12	28.93	16.19	36%	64%
102	15.2	0.62	12.45	21.51	-9.06	-73%	173%
103	19.3	0.81	43.66	27.95	15.71	36%	64%
104	19.5	0.7	36.33	23.87	12.46	34%	66%
105	18	0.54	26.7	29.48	-2.78	-10%	110%
106	15.2	0.43	12.25	8.61	3.64	30%	70%
107	18.3	0.69	36.09	24.12	11.97	33%	67%
108	17.5	0.49	14.44	16.7	-2.26	-16%	116%
109	17.2	0.7	37.05	32.25	4.8	13%	87%
110	15.6	0.76	39.46	24.68	14.78	37%	63%
210	4.5	0.05	0.37	0.37	0	0%	100%
111	18.3	0.83	43.47	25.27	18.2	42%	58%
112	17.8	0.41	11.72	21.35	-9.63	-82%	182%
113	16.4	0.44	12.83	15.13	-2.3	-18%	118%
114	14.8	0.57	29.91	32.61	-2.7	-9%	109%
115	14.8	0.34	6.81	6.71	0.1	1%	99%
116	16.3	0.73	39.32	38.72	0.6	2%	98%
117	18.3	0.33	6.55	6.29	0.26	4%	96%
118	11.6	0.31	6.75	6.65	0.1	1%	99%
119	15.7	0.47	23.45	26.21	-2.76	-12%	112%
120	19.6	0.76	38.21	26.78	11.43	30%	70%
121	18.1	0.5	25.4	17.37	8.03	32%	68%
122	18.4	0.53	26.28	18.44	7.84	30%	70%
123	19.2	0.44	12.41	23.27	-10.86	-88%	188%
124	15.2	0.53	26.68	20.1	6.58	25%	75%
125	15.5	0.57	28.49	19.94	8.55	30%	70%
		Total	$642.2	$543.31	$98.89	15%	85%

APPENDIX H2

VALUE RECOVERY OF INDIVIDUAL STEMS FOR TL ON WOOD TRACT AFTER DOWNGRADES FOR OUT-OF-SPEC STEMS

Stem No.	Length	Volume	Optimum Value$	Skid Value$	Diff.$	% Loss	% Value Recovery
101	20.2	0.88	45.12	28.93	16.19	36%	64%
102	15.2	0.62	12.45	11.49	0.96	8%	92%
103	19.3	0.81	43.66	27.92	15.74	36%	64%
104	19.5	0.7	36.33	23.27	13.06	36%	64%
105	18	0.54	26.7	26.33	0.37	1%	99%
106	15.2	0.43	12.25	8.61	3.64	30%	70%
107	18.3	0.69	36.09	21.82	14.27	40%	60%
108	17.5	0.49	14.44	10.06	4.38	30%	70%
109	17.2	0.7	37.05	32.25	4.8	13%	87%
110	15.6	0.76	39.46	24.68	14.78	37%	63%
210	4.5	0.05	0.37	0.37	0	0%	100%
111	18.3	0.83	43.47	25.27	18.2	42%	58%
112	17.8	0.41	11.72	11.27	0.45	4%	96%
113	16.4	0.44	12.83	9	3.83	30%	70%
114	14.8	0.57	29.91	29.91	0	0%	100%
115	14.8	0.34	6.81	6.71	0.1	1%	99%
116	16.3	0.73	39.32	38.72	0.6	2%	98%
117	18.3	0.33	6.55	6.29	0.26	4%	96%
118	11.6	0.31	6.75	6.65	0.1	1%	99%
119	15.7	0.47	23.45	22.92	0.53	2%	98%
120	19.6	0.76	38.21	23.64	14.57	38%	62%
121	18.1	0.5	25.4	15	10.4	41%	59%
122	18.4	0.53	26.28	15.36	10.92	42%	58%
123	19.2	0.44	12.41	11.9	0.51	4%	96%
124	15.2	0.53	26.68	15.98	10.7	40%	60%
125	15.5	0.57	28.49	16.76	11.73	41%	59%
		Total	$642.2	$471.11	$171.09	27%	73%

APPENDIX I1

VALUE RECOVERY OF INDIVIDUAL STEMS FOR TL ON BRYAN TRACT BEFORE DOWNGRADES FOR OUT-OF-SPEC STEMS

Stem No.	Length	Volume	Optimum Value$	Skid Value$	Diff.$	% Loss	% Value Recovery
26	20.6	0.83	43.81	24.82	18.99	43%	57%
27	17.1	1.13	13.87	38.37	-24.5	-177%	277%
28	17.7	0.95	31.33	31.02	0.31	1%	99%
29	24.6	1.64	86.68	56.89	29.79	34%	66%
30	19.8	1.09	59.02	39.92	19.1	32%	68%
31	14.9	0.74	25.81	20	5.81	23%	77%
32	16.4	0.68	34.77	32.34	2.43	7%	93%
33	15.7	0.81	45.68	41.95	3.73	8%	92%
34	19.8	1.14	59.57	36.29	23.28	39%	61%
35	18.5	1.19	63.46	63.43	0.03	0%	100%
36	15.9	1.01	55.01	39.09	15.92	29%	71%
37	15.4	1.13	35.84	37.18	-1.34	-4%	104%
38	16.9	0.78	19.98	27.42	-7.44	-37%	137%
39	21.9	1.02	29.41	25.42	3.99	14%	86%
40	17.9	0.98	51.98	49.85	2.13	4%	96%
41	15.8	0.96	52.58	36.12	16.46	31%	69%
42	15.1	0.93	45.05	33.11	11.94	27%	73%
43	15.5	0.58	19.47	12.66	6.81	35%	65%
44	15.6	0.48	14.58	9.87	4.71	32%	68%
45	15.9	0.5	13.5	10.65	2.85	21%	79%
46	20.8	0.7	33.47	32.1	1.37	4%	96%
47	21.6	1.48	51.5	51.92	-0.42	-1%	101%
48	14.8	0.52	16.42	11.4	5.02	31%	69%
49	15.1	0.41	11.58	8.32	3.26	28%	72%
50	16.7	0.48	11.6	9.81	1.79	15%	85%
		Total	$925.97	$779.95	$146.02	16%	84%

APPENDIX I2

VALUE RECOVERY OF INDIVIDUAL STEMS FOR TL ON BRYAN TRACT AFTER DOWNGRADES FOR OUT-OF-SPEC STEMS

Stem No.	Length	Volume	Optimum Value$	Skid Value$	Diff.$	% Loss	% Value Recovery
26	20.6	0.83	43.81	24.82	18.99	43%	57%
27	17.1	1.13	13.87	11.06	2.81	20%	80%
28	17.7	0.95	31.33	29.14	2.19	7%	93%
29	24.6	1.64	86.68	55.38	31.3	36%	64%
30	19.8	1.09	59.02	39.49	19.53	33%	67%
31	14.9	0.74	25.81	20	5.81	23%	77%
32	16.4	0.68	34.77	32.34	2.43	7%	93%
33	15.7	0.81	45.68	41.95	3.73	8%	92%
34	19.8	1.14	59.57	36.29	23.28	39%	61%
35	18.5	1.19	63.46	63.18	0.28	0%	100%
36	15.9	1.01	55.01	37.3	17.71	32%	68%
37	15.4	1.13	35.84	32.14	3.7	10%	90%
38	16.9	0.78	19.98	19.95	0.03	0%	100%
39	21.9	1.02	29.41	19.07	10.34	35%	65%
40	17.9	0.98	51.98	49.85	2.13	4%	96%
41	15.8	0.96	52.58	35.55	17.03	32%	68%
42	15.1	0.93	45.05	29.62	15.43	34%	66%
43	15.5	0.58	19.47	12.66	6.81	35%	65%
44	15.6	0.48	14.58	9.87	4.71	32%	68%
45	15.9	0.5	13.5	8.44	5.06	37%	63%
46	20.8	0.7	33.47	32.1	1.37	4%	96%
47	21.6	1.48	51.5	46.2	5.3	10%	90%
48	14.8	0.52	16.42	11.4	5.02	31%	69%
49	15.1	0.41	11.58	8.32	3.26	28%	72%
50	16.7	0.48	11.6	7.71	3.89	34%	66%
		Total	$925.97	$713.83	$212.14	23%	77%

APPENDIX J1

VALUE RECOVERY OF INDIVIDUAL STEMS FOR MTL ON BELOTE TRACT BEFORE DOWNGRADES FOR OUT-OF-SPEC STEMS

Stem No.	Length	Volume	Optimum Value$	Skid Value$	Diff.$	% Loss	% Value Recovery
76	17.7	0.32	5.73	4.64	1.09	19%	81%
77	17.9	0.39	9.76	5.91	3.85	39%	61%
78	18.3	0.56	17.02	14.47	2.55	15%	85%
79	18.3	0.4	7.32	5.88	1.44	20%	80%
80	16	0.29	5.19	4.31	0.88	17%	83%
81	18.2	0.33	5.92	4.85	1.07	18%	82%
82	19.5	0.22	2.52	2.39	0.13	5%	95%
83	19	0.39	1.9	5.78	-3.88	-204%	304%
84	19.5	0.6	18.77	18.17	0.6	3%	97%
85	13.9	0.27	4.7	2.94	1.76	37%	63%
86	16.8	0.46	15.14	6.98	8.16	54%	46%
87	18.1	0.48	13.65	8.75	4.9	36%	64%
88	17.9	0.52	14.98	14.96	0.02	0%	100%
89	19.1	0.69	3.43	21.77	-18.34	-535%	635%
90	17.4	0.53	15.97	9.72	6.25	39%	61%
91	17.6	0.38	9.69	4.23	5.46	56%	44%
92	19.9	0.69	3.4	5.51	-2.11	-62%	162%
93	14.1	0.48	13.56	8.39	5.17	38%	62%
94	19.1	0.64	20.34	16.06	4.28	21%	79%
95	20.5	0.87	29.56	29.67	-0.11	0%	100%
96	18.6	0.48	14.18	8.53	5.65	40%	60%
97	11.9	0.47	6.31	4.11	2.2	35%	65%
98	14.7	0.41	11.39	7.23	4.16	37%	63%
99	18.1	0.48	12.89	8.49	4.4	34%	66%
100	18.3	0.61	19.13	19.2	-0.07	0%	100%
		Total	$282.45	$242.94	$39.51	14%	86%

APPENDIX J2

VALUE RECOVERY OF INDIVIDUAL STEMS FOR MTL ON BELOTE TRACT AFTER DOWNGRADES FOR OUT-OF-SPEC STEMS

Stem No.	Length	Volume	Optimum Value$	Skid Value$	Diff.$	% Loss	% Value Recovery
76	17.7	0.32	5.73	4.64	1.09	19%	81%
77	17.9	0.39	9.76	5.88	3.88	40%	60%
78	18.3	0.56	17.02	14.47	2.55	15%	85%
79	18.3	0.4	7.32	5.88	1.44	20%	80%
80	16	0.29	5.19	4.31	0.88	17%	83%
81	18.2	0.33	5.92	4.85	1.07	18%	82%
82	19.5	0.22	2.52	2.39	0.13	5%	95%
83	19	0.39	1.9	1.91	-0.01	-1%	101%
84	19.5	0.6	18.77	18.05	0.72	4%	96%
85	13.9	0.27	4.7	3.05	1.65	35%	65%
86	16.8	0.46	15.14	6.98	8.16	54%	46%
87	18.1	0.48	13.65	8.75	4.9	36%	64%
88	17.9	0.52	14.98	14.96	0.02	0%	100%
89	19.1	0.69	3.43	3.44	-0.01	0%	100%
90	17.4	0.53	15.97	9.72	6.25	39%	61%
91	17.6	0.38	9.69	3.6	6.09	63%	37%
92	19.9	0.69	3.4	3.16	0.24	7%	93%
93	14.1	0.48	13.56	8.39	5.17	38%	62%
94	19.1	0.64	20.34	16.06	4.28	21%	79%
95	20.5	0.87	29.56	29.54	0.02	0%	100%
96	18.6	0.48	14.18	8.53	5.65	40%	60%
97	11.9	0.47	6.31	2.18	4.13	65%	35%
98	14.7	0.41	11.39	7.23	4.16	37%	63%
99	18.1	0.48	12.89	8.47	4.42	34%	66%
100	18.3	0.61	19.13	19.2	-0.07	0%	100%
		Total	$282.45	$215.64	$66.81	24%	76%

APPENDIX K1

VALUE RECOVERY OF INDIVIDUAL STEMS FOR MTL ON WOOD TRACT BEFORE DOWNGRADES FOR OUT-OF-SPEC STEMS

Stem No.	Length	Volume	Optimum Value$	Skid Value$	Diff.$	% Loss	% Value Recovery
126	17.2	0.3	5.39	4.35	1.04	19%	81%
127	16.9	0.42	10.78	6.31	4.47	41%	59%
128	17.2	0.59	8.7	17.13	-8.43	-97%	197%
129	18.9	0.49	13.45	11.49	1.96	15%	85%
130	17.8	0.32	5.71	4.51	1.2	21%	79%
131	18.1	0.5	14.45	11.6	2.85	20%	80%
132	18.9	0.68	32.5	32.11	0.39	1%	99%
133	18.2	0.41	9.91	7.04	2.87	29%	71%
134	19	0.43	11.11	7.52	3.59	32%	68%
135	18	0.5	13.75	13.18	0.57	4%	96%
136	17.2	0.68	21.67	21.54	0.13	1%	99%
137	18	0.62	18.19	15.74	2.45	13%	87%
138	18.6	0.49	13.55	11.62	1.93	14%	86%
139	18.1	0.55	15.87	14.28	1.59	10%	90%
140	17.5	0.41	11.26	7.29	3.97	35%	65%
141	19.4	0.5	23.81	16.45	7.36	31%	69%
142	15.2	0.51	15.13	12.22	2.91	19%	81%
143	18	0.87	25.67	27.61	-1.94	-8%	108%
144	19.7	0.6	28.6	18.24	10.36	36%	64%
145	18	0.64	19.72	28.78	-9.06	-46%	146%
146	15.2	0.75	40.41	36.31	4.1	10%	90%
148	19.9	1.06	37.26	28.89	8.37	22%	78%
149	20.8	0.72	23.3	18.03	5.27	23%	77%
150	16.7	0.41	11.04	6.13	4.91	44%	56%
		Total	$431.23	$378.37	$52.86	12%	88%

APPENDIX K2

VALUE RECOVERY OF INDIVIDUAL STEMS FOR MTL ON WOOD TRACT AFTER DOWNGRADES FOR OUT-OF-SPEC STEMS

Stem No.	Length	Volume	Optimum Value$	Skid Value$	Diff.$	% Loss	% Value Recovery
126	17.2	0.3	5.39	4.35	1.04	19%	81%
127	16.9	0.42	10.78	6.31	4.47	41%	59%
128	17.2	0.59	8.7	2.9	5.8	67%	33%
129	18.9	0.49	13.45	11.49	1.96	15%	85%
130	17.8	0.32	5.71	4.51	1.2	21%	79%
131	18.1	0.5	14.45	11.6	2.85	20%	80%
132	18.9	0.68	32.5	20.69	11.81	36%	64%
133	18.2	0.41	9.91	7.04	2.87	29%	71%
134	19	0.43	11.11	7.52	3.59	32%	68%
135	18	0.5	13.75	13.18	0.57	4%	96%
136	17.2	0.68	21.67	21.54	0.13	1%	99%
137	18	0.62	18.19	15.74	2.45	13%	87%
138	18.6	0.49	13.55	11.62	1.93	14%	86%
139	18.1	0.55	15.87	14.28	1.59	10%	90%
140	17.5	0.41	11.26	7.29	3.97	35%	65%
141	19.4	0.5	23.81	13.38	10.43	44%	56%
142	15.2	0.51	15.13	12.22	2.91	19%	81%
143	18	0.87	25.67	25.33	0.34	1%	99%
144	19.7	0.6	28.6	18.24	10.36	36%	64%
145	18	0.64	19.72	17.06	2.66	13%	87%
146	15.2	0.75	40.41	36.31	4.1	10%	90%
148	19.9	1.06	37.26	28.89	8.37	22%	78%
149	20.8	0.72	23.3	18.03	5.27	23%	77%
150	16.7	0.41	11.04	6.13	4.91	44%	56%
		Total	$431.23	$335.65	$95.58	22%	78%

APPENDIX L1

VALUE RECOVERY OF INDIVIDUAL STEMS FOR MTL ON BRYAN TRACT BEFORE DOWNGRADES FOR OUT-OF-SPEC STEMS

Stem No.	Length	Volume	Optimum Value$	Skid Value$	Diff.$	% Loss	% Value Recovery
1	17.8	1.35	69.86	41.58	28.28	40%	60%
2	23.2	1	42.11	24.99	17.12	41%	59%
3	23.3	1.38	43.74	40.42	3.32	8%	92%
4	22.6	0.93	42.72	26.31	16.41	38%	62%
5	21.7	0.85	28.58	24.15	4.43	16%	84%
6	23.5	1	44.88	40.71	4.17	9%	91%
7	22.2	1.29	65.68	61.02	4.66	7%	93%
8	22.7	0.89	38.62	26.53	12.09	31%	69%
9	23	1.19	54.36	51.73	2.63	5%	95%
10	19.2	0.81	38.01	23.42	14.59	38%	62%
11	21.1	0.72	35.85	21.94	13.91	39%	61%
12	22.1	0.86	42.56	25.04	17.52	41%	59%
13	16.7	1.2	41.95	40.95	1	2%	98%
14	19.8	0.72	36.34	20.87	15.47	43%	57%
15	22.5	0.87	41.7	39.46	2.24	5%	95%
16	21.5	0.66	32.11	14.94	17.17	53%	47%
17	23.1	0.91	46.36	28.01	18.35	40%	60%
18	22.5	1.08	53.55	29.35	24.2	45%	55%
19	19.9	0.35	1.7	3.85	-2.15	-126%	226%
20	21.8	0.56	16.25	7.51	8.74	54%	46%
21	19.1	0.56	26.21	8.4	17.81	68%	32%
22	22.4	0.56	23.63	8.22	15.41	65%	35%
23	20.5	0.49	4.77	6.19	-1.42	-30%	130%
24	22.7	1.55	82.1	48.46	33.64	41%	59%
25	20.3	0.61	29.26	18.01	11.25	38%	62%
		Total	$982.90	$682.06	$300.84	31%	69%

APPENDIX L2

VALUE RECOVERY OF INDIVIDUAL STEMS FOR MTL ON BRYAN TRACT AFTER DOWNGRADES FOR OUT-OF-SPEC STEMS

Stem No.	Length	Volume	Optimum Value$	Skid Value$	Diff.$	% Loss	% Value Recovery
1	17.8	1.35	69.86	41.58	28.28	40%	60%
2	23.2	1	42.11	24.99	17.12	41%	59%
3	23.3	1.38	43.74	40.42	3.32	8%	92%
4	22.6	0.93	42.72	26.31	16.41	38%	62%
5	21.7	0.85	28.58	24.15	4.43	16%	84%
6	23.5	1	44.88	40.71	4.17	9%	91%
7	22.2	1.29	65.68	61.02	4.66	7%	93%
8	22.7	0.89	38.62	22.61	16.01	41%	59%
9	23	1.19	54.36	51.73	2.63	5%	95%
10	19.2	0.81	38.01	23.42	14.59	38%	62%
11	21.1	0.72	35.85	21.94	13.91	39%	61%
12	22.1	0.86	42.56	25.04	17.52	41%	59%
13	16.7	1.2	41.95	29.53	12.42	30%	70%
14	19.8	0.72	36.34	20.87	15.47	43%	57%
15	22.5	0.87	41.7	39.46	2.24	5%	95%
16	21.5	0.66	32.11	14.94	17.17	53%	47%
17	23.1	0.91	46.36	26.33	20.03	43%	57%
18	22.5	1.08	53.55	29.35	24.2	45%	55%
19	19.9	0.35	1.7	1.67	0.03	2%	98%
20	21.8	0.56	16.25	7.51	8.74	54%	46%
21	19.1	0.56	26.21	8.4	17.81	68%	32%
22	22.4	0.56	23.63	8.22	15.41	65%	35%
23	20.5	0.49	4.77	4.34	0.43	9%	91%
24	22.7	1.55	82.1	48.46	33.64	41%	59%
25	20.3	0.61	29.26	18.01	11.25	38%	62%
		Total	$982.90	$661.01	$321.89	33%	67%