AN ABSTRACT OF THE DISSERTATION OF

Stephen J. Pilkerton for the degree of Doctor of Philosophy in Forest Engineering presented on June 12, 2009.

Title: Thinning Aged Douglas-Fir: An Analysis Of Mobilization Costs And A Log Bucking Strategy For Revenue Improvement

Abstract approved:

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Loren D. Kellogg

Contract harvest operations have become the preferred approach to reducing the largest cost component of timber production through free market competition amongst logging contractors bidding or negotiating for work. The goal of this research was to investigate economic components of harvesting operations not previously studied for steep slope thinning harvests in Douglas-fir (Pseudotsuga menziesii) stands. This research explored three important issues affecting Pacific Northwest costs and revenues. On the expense side, mobilization costs associated with wildlife protections restricting harvest operating seasons were modeled for nine Siuslaw National Forest timber sales. Mobilization costs resulting from seasonal restrictions imposed for nesting of northern spotted owl (Strix occidentalis) and marbled murrelet (Brachyramphus marmoratus) were \$1.48 to \$2.60 per 100 cubic feet (1 Ccf) for an array of sale volumes, cut tree sizes, and one-way mobilization distances. Total sale costs ranged from \$7000 to \$43000, depending on the number of mobilizations required. With respect to income, two studies were performed to evaluate revenue improvement through bucking-to-value strategies. The first evaluated a reduced set of log lengths that approach computer-generated optimal values and the potential for development of a bucking decision tool. The second sought value optimization with a log allocation constraint through the application of a combinatorial heuristic approach for the reduced set of log lengths to create the bucking pattern cutting card. A reduced set of five log lengths, two mill-length logs and three woods-lengths resulting from combinations of the mill-lengths, was evaluated for value recovery. Resulting values obtained 96 to 98 percent of full set optimal values for 45 and 65 year old stands, respectively. Value recovery exceeded current unaided bucking practices. A modified Simulated Annealing heuristic achieved 99.93 to 100 percent of known maximum for the unconstrained optimization. The SA generated bucking solutions improved value recovery by $2.61 to $2.73 per Ccf while meeting the preferred log allocation. The resulting bucking patterns were easily incorporated into a cutting card based on length to merchantable top. This approach reduced the number of logs handled, increased mill preferred long logs, decreased pattern count, and increased recovered value. Improved revenues exceeded estimated mobilization costs.

Thinning Aged Douglas-Fir: An Analysis Of Mobilization Costs And A Log Bucking Strategy For Revenue Improvement

by
Stephen J. Pilkerton

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

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Stephen J. Pilkerton, Author

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CONTRIBUTION OF AUTHORS

Dr. John Sessions guided the formulation of the mathematical model and was involved with the writing of Chapter 4.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (continued)

DEDICATION

To all the intellects, from time initial, which never reached, or never will reach, their potential due to the inhumanities humanity inflicts upon human beings (Lucy Gimpel, World War II era Polish Jew, being one); and to those intellects which will not have the opportunities I have been afforded.

THINNING AGED DOUGLAS-FIR: AN ANALYSIS OF MOBILIZATION COSTS AND A LOG BUCKING STRATEGY FOR REVENUE IMPROVEMENT

CHAPTER 1: INTRODUCTION

In today's global economy, specifically wood product commodity markets, price competition drives producers to identify ways to maintain or improve their market share while maintaining or improving net revenues. Thus producers seek to reduce costs and increase values. Contract harvest operations have become the preferred approach to reducing the largest cost component of timber production through free market competition amongst logging contractors bidding or negotiating for work. This transfers the cost control, production, and risk concerns to the contractor. This operating model has historically worked.

Contractor experience and costing knowledge in regeneration harvests do not necessarily translate to thinning harvests. Likewise harvest planners lack current production and cost estimates for thinning harvests. Past thinning harvest research has provided guidance during the expansion of thinning operations: searching for the appropriate piece size (Putnam et al., 1984); evaluating operations in lower valued species and techniques to minimize damage (Kellogg et al., 1986); choice of yarding system (Hochrien and Kellogg, 1988); alternative thinning prescriptions (Kellogg et al., 1996); thinning for young stand management (Kellogg et al., 1999); and thinning planning and layout costs (Kellogg et al., 1998).

However, three important issues affecting costs and revenues for thinning harvests on steep slopes in the Pacific Northwest have not been evaluated and reported before: 1) Operating season restrictions and resulting mobilization costs; and 2) Improving revenues through value recovery for bucking strategies using a reduced set of log lengths that approach values of computer-generated solutions; and 3) achieving the log allocation requirement while seeking the optimal value with the application of a combinatorial heuristic approach for a reduced set of log lengths.

Increasingly restrictive harvest operating seasons, particularly on public lands to accommodate reproductive periods for sensitive wildlife species, result in higher total costs. These restrictions typically require cessation of operations at that site. This results in mobilizations of operations (equipment move-in, set-up; take-down, and move-out) to non-restricted locations. These mobilizations increase costs and should be included in appraisal and bidding formulation. These costs may lack a historic basis with the transition to thinning harvests on smaller acreage units. These costs are not as easily quantified as other costs such as equipment insurance and taxes. Additionally, awareness of mobilization costs in forest operations is likely lower than for large construction projects where mobilization costs are accounted for in bid line items and possibly reimbursed up front (Edgerton and MacDermott, 1997). Helicopter harvesting operations may be the exception due to their high expense and large logistical support system (Sloan and Sherar, 1997).

This research work consists of three manuscripts. Manuscript 1 first addresses the mobilization costs associated with harvest season closures. Three bird nesting related harvest restriction scenarios were modeled for nine thinning harvest timber sales comprising the Siuslaw National Forests Fiscal Year 2008 (FY08) Timber Sale program. The study evaluated the mobilization costs associated with seasonal restrictions imposed for nesting of northern spotted owl (Strix occidentalis) and marbled murrelet (Brachyramphus marmoratus) near thinning harvests in publicly managed young Douglas-fir (Pseudotsuga menziesii) stands. This economic evaluation summarized total cost and cost per 100 cubic feet volume ($ / Ccf) for a cable logging operation under three closure scenarios. This research will improve the awareness and knowledge of mobilization costs for public land managers, logging contractors, and producers who hire them for planned thinning harvests. Awareness of the costs associated with environmental restrictions allows the participants to make informed operational planning and costing decisions. Understanding of this cost and its magnitude should impart a desire on timber owners and producers to seek revenues to offset the expected cost increase.

Manuscript 2 then addresses the potential for revenue improvements through improved tree bucking (log manufacturing) strategies. Steep slope thinning harvests generally preclude the use of mechanized harvesting systems or whole tree yarding, requiring log length bucking to minimize residual stand damage. Bucking optimization research has shown 4-7 percent increase in net revenues compared with a bucker's choice of log lengths (Sessions et al., 1989a). These are achievable but require the use of handheld computers during log making, thus limiting practical field implementation (Olsen et al., 1997). Additionally, these optimizations on individual trees may fail to meet log purchase order constraints (Sessions, et al., 1989b).

This research addresses improving the bucking strategy by evaluating a new strategy of using a reduced set of log lengths to approach the optimal value while still producing woods-lengths logs and improving the percentage of mill preferred lengths. Sample trees from two Douglas-fir stands were analyzed. Stand 1 was 45 years old and stand 2 was 65 years old. The reduced set of five log lengths includes two mill-length logs and three woods-length logs created from the combination of the two mill-lengths. The results summarize the effect on total value and volume recovery with the use of the strategy. Values were summarized per 100 cubic feet volume for comparison to modeled mobilization costs. Additionally, the development of a tree bucking decision tool using a simple cutting card incorporating the reduced set of lengths is introduced. Optimization of this reduced set of lengths was still performed by a single-stem optimizer, OSU-BUCK (Sessions et al., 1993). As previously mentioned, the optimizer does not necessarily achieve optimization with an objective of delivering a minimum percent of preferred long logs when the pricing structure does not sufficiently represent the true value associated with the preferred lengths.

Finally, the third manuscript addresses the bucking-to-value with a log allocation constraint: specifically, to seek the optimal value with the purchase order constraint for the reduced set of log lengths with the use of a combinatorial heuristic technique. A Simulated Annealing heuristic was developed and evaluated for achievement of the long log constraint while optimizing value. Resulting values were compared with the single-stem optimizer and the unaided field bucking solutions. The resulting set of log bucking patterns for the constrained optimal solution was then used to develop a cutting card based on merchantable tree height to implement the reduced set of log lengths in the field. The reduced set of log lengths, together with the heuristic approach for determining patterns that achieve an order constraint, should provide a logging manager with bucking instructions to improve value recovery in thinnings.

Forest harvesting professionals – planners, producers, and contractors – informed of the magnitude of mobilization costs associated with environmental restrictions can seek alternatives to reduce or eliminate the economic impact through planning and scheduling of harvest activities. Additionally, value improvement and increased revenues through improved log bucking strategies and allocations are proposed to maintain or improve economic competitiveness.

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CHAPTER 2: HARVEST MOBILIZATION COSTS ASSOCIATED WITH WILDLIFE SEASONAL CLOSURE REGULATIONS

Introduction

In the past, thinning harvests in young Douglas-fir (Pseudotsuga menziesii) stands in western Oregon and Washington have been year round activities. With rocked roads, adequate drainage structures, and cable logging systems, harvesting activities proceeded even in wet weather. However, periods of work stoppage did occur, giving logging contractors historical experience with cessation of harvesting activities and with cost accounting for these periods. Some examples follow:

- Safety concerns prevent timber falling in high winds,
- Yarding might cease under rarer extreme events (wind, driving rains, and extreme cold),
- Seasonal shut downs of harvesting activities were limited to planned mill closures (i.e., two week winter holiday / maintenance shutdown), or
- Fire season "hoot owl" – 1:00 PM daily stop work, or
- Fire season closures (no logging during extreme fire hazard conditions).

More recent accommodations for bird nesting seasons and other environmental concerns have imposed additional harvesting closures. These closures alter the historic practices and expense structure. Wildlife breeding and nesting seasons, most notably the northern spotted owl (SO) (Strix occidentalis) and marbled murrelet (MM) (Brachyramphus marmoratus), have imposed harvest closures to avoid "harassment" (activities within 100 yards) during these critical periods (Miller, 2008):

Spotted owl: 1 March to 7 July

Marbled murrelet: 1 April to 5 August

During these critical habitat periods, harvesting activities must cease, idling crews and equipment at that location with resulting mobilization to another harvest setting.

Another seasonal restriction associated with thinning harvests on public lands is the “sap flow” season, a period when tree bark is most susceptible to removal with resulting damage to the cambial layer. Sap flow is a biological response to environmental site conditions, and variability can occur year to year on a given site and regionally within a management area. Unlike MM and SO nesting closures, sap flow season does not have defined start and end dates, although it typically starts around mid-April and carries into mid-June. Sap flow closure is an administrative decision. Logging practices, techniques, and contractor care and commitment can minimize log-tree impacts and resulting stem damage, which allows a diligent contractor to avoid a work stoppage.

Although these environmental closures are most common on publicly managed forests, the habitat rules apply to private lands as well. However, because private forests typically do not have the stand structure associated with Nesting – Roosting – Foraging (NeRF) habitat many contractors move harvest operations to private lands when faced with a closure season. The operation will stay on the new site until it is finished unless there is a pending contract time limit with the previous job, resulting in an additional mobilization for on-time completion. Contractors may not move back to the previously closed harvest operation immediately after the closure is lifted, resulting in an additional reduction of the operating season at the original public land management site.

The combined effect of these closures may result in a continuous period from early spring to summer when harvests may not occur. Permitted operational periods between closure periods may not be beneficial as they may be so short as to be impractical to return. The result is a need to move the operation's equipment to another harvest location, an activity that does not produce revenue for the contractor. The contractor incurs expenses with this activity.

Objectives

The objectives of this research were to quantify the costs associated with operational shutdown and relocation to accommodate seasonal closures for wildlife and environmental concerns, specifically:

1) Identify the additional mobilizations required to accommodate seasonal closures for two bird species with known closure seasons;
2) Identify the mobilization costs on a total sale basis (dollars) and unit volume basis ($ / Ccf) resulting from imposed seasonal closures for thinning sales comprising one fiscal year's sale program on the Siuslaw National Forest of Oregon's Coast Range;
3) Evaluate the sensitivity of using sale aggregate values versus sale unit specific values of a timber sale for inputs to STHARVEST (Fight, et al., 2003) and resulting estimate of yarding cost.

Methods

Our study evaluated the mobilization costs associated with seasonal restrictions imposed for nesting of SO and MM near thinning harvests in publicly managed young Douglas-fir stands. This economic evaluation will be useful to both logging contractors and public land managers for cost appraisals of planned thinning harvests. This economic evaluation summarized total cost and cost per unit volume, $ / Ccf,[1] for a cable logging operation under three closure scenarios:

1) SO restriction

2) MM restriction

3) SO and MM restrictions

We initially considered sap flow restrictions for modeling in addition to the wildlife restrictions. However, the sap flow season, typically mid-April to mid-June, coincides with both SO and MM seasons and did not impose additional restrictions. Fire season closures were not analyzed for this project (equipment idled but not moved off site unless fire is proximate). Additionally, we assumed wet weather yarding was independent of wet weather hauling restrictions (log decks at site provide production buffers).

The three bird related harvest restriction scenarios were modeled for nine thinning harvest timber sales comprising the Siuslaw National Forests Fiscal Year 2008 (FY08) Timber Sale schedule. Table 2.1 summarizes mean DBH, average cut trees per acre, average cut tree volume, total sale acreage, harvest volume per acre, and total sale volume. The modeled seasonal restrictions were fictional for these

[1] 1 Ccf = 1 cunit, 100 cubic feet

specific timber sales, but represent conditions feasible for publicly managed Coast Range forests.

Table 2.1. Descriptive data for nine timber sales for Siuslaw National Forest FY2008.

Timber Sale Number	Mean DBH (inch)	Average Cut Tree (cubic feet)	Cut Trees Per Acre	Total Acres	Harvest Volume (cf/acre)	Sale Volume (Ccf)
1	13.3	38	113	276	4310	11895
2	13.0	33	126	491	4195	20608
3	12.1	26	118	280	3109	8706
4	11.0	23	134	491	3113	15287
5	12.1	27	118	226	3225	7289
6	11.6	25	168	106	4173	4423
7	12.6	32	110	328	3471	11384
8	12.1	30	88	298	2621	7810
9	12.7	32	115	253	3656	9249

Harvest productivity (Ccf / hour) and harvesting cost ($ / Ccf) analysis were performed using STHARVEST (Hartsough, 2001; Fight, et al., 2003). Harvesting cost reflected total stump to truck costs to fell, limb / buck, yard, and load. Daily production was divided into total sales volume (Ccf) to predict total days required for completion of the timber sale. Total days exceeding available annual operating days require multiple years to complete the harvest and produce additional mobilizations (move-in/out) to accommodate seasonal closures. Resulting multiple year scenarios were determined by dividing total sale volume by the STHARVEST determined daily production to obtain days needed to complete the sale. Comparing the days to complete the sale with the allowable operating season – days per year – quantified the total number of years and resulting entries required to complete the sale. Allowable operating days per year were 161, 162, and 140 for the 3 scenarios, respectively.

Allowable days reflect working five days per week, less major holidays, during the period restrictions were not in effect. The daily scheduled work period was nine hours. For comparisons, a “normal” unrestricted operating year consists of 251 days.

Our study modeled commercial thinning (partial harvest) on steep slopes in western Oregon. Stump to truck harvest costs derived using STHARVEST required several inputs for the harvest system modeled - hand felled, log length, cable yarding:

- Average yarding distance (feet)
- Average slope (percent)
- Area harvested (acres) (optional)
- Number of cut trees per acre
- Cut tree volume (cubic feet)

Average yarding distance was determined from sale planning maps (Table 2.2). A constant 40 percent slope applied to all sales. The acres harvested data value for each sale was not used within STHARVEST, but was used for the spreadsheet based mobilization cost analysis. Harvested trees per acre and cut tree size were the primary factors influencing unit costs ($/Ccf). The timber sales data provided these values for each different unit (stands) within a timber sale. Five sales were evaluated with the unit level values to determine resulting cost per cunit. The unit level results were weighted by unit volume for sensitivity analysis to determine if using a single, representative value for cut trees per acre and cut tree volume over the entire sale (multiple units) was adequate.

Machinery owning and operating costs (machine rate) and labor costs within STHARVEST are based on 1998 values. Costs were adjusted by the Consumers Price

Index to 2008 values (Sahr, 2007). A fuel rate of $4.00 per gallon reflected 2008 market values.

Total mobilization costs for each sale were determined for a yarder and loader. Lowboy transport times were based on one-way highway and forest road (gravel surface) miles from Corvallis, Oregon to the midpoint of the timber sale location. Table 2.2 summarizes one-way road miles for each timber sale. Travel rates of 40 and 15 miles per hour (mph), highway and forest roads respectively, were used to calculate travel time for both loaded and unloaded travel. Four and two hours load and unload time were assumed for the yarder and loader, respectively. A lowboy cost of $142.00 per hour was applied to travel and load/unload time[2]. STHARVEST determined machine rates (per hour, with crews) of $220.00 and $95.00 for yarder and loader costs, respectively. The machine rates were adjusted to reflect transport only (non-operating) costs.

Calculated total mobilization costs for each scenario were divided by the total sale volume to arrive at a total unit cost ($/Ccf). Mobilization costs for one-way transport, annual (two one-way transports) and total sale on a total dollar basis were calculated. The resulting mobilization costs are the “opportunity costs” associated with the additional equipment move-in and move-outs required to accommodate seasonal closures. One mobilization cycle (move-in and move-out) was considered the baseline; any additional mobilizations become the opportunity cost.

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[2] Personal Communication. 29 AUG 2008. Robert Bateman, Harvesting Contractor, Monroe, OR.

Table 2.2. Data inputs for STHARVEST analysis and mobilization cost determination for nine timber sales.

Timber Sale Number	Harvest Type	System Type	Average Yarding Distance (feet)	Slope (percent)	Move In Distance One way Highway (miles)	Move In Distance One way Resource (miles)
1	Partial	Cable - Manual Fell	650	40	38	3
2	Partial	Cable - Manual Fell	500	40	66	4
3	Partial	Cable - Manual Fell	590	40	81	2
4	Partial	Cable - Manual Fell	500	40	36	6
5	Partial	Cable - Manual Fell	350	40	72	5
6	Partial	Cable - Manual Fell	475	40	71	2
7	Partial	Cable - Manual Fell	350	40	57	1
8	Partial	Cable - Manual Fell	610	40	36	5
9	Partial	Cable - Manual Fell	475	40	71	7

The mobilization cost analysis methodology is straightforward and can be conducted with the STHARVEST software, a spreadsheet, and public domain input data. This data consists of Forest Service cruise reports and sale area planning maps, both of which are available to timber sale planners and prospective purchasers. Appendix A outlines the method's general steps and includes a numerical example.

Results / Discussion

STHARVEST total stump to truck harvest costs ranged from \$109.00 to \$123.00 per Ccf for the nine sales evaluated (Table 2.3). Total stump to truck harvest costs consist of felling, yarding, and loading costs. The yarding cost ranged from \$74.33 to \$85.03 per Ccf. Resulting daily production was 19.8 to 23.0 Ccf. Yarding production is usually the limiting production activity of the stump to truck processes and thus the resulting daily yarding production was used for mobilization cost analysis.

Sensitivity analysis performed on five of the sales evaluated the “goodness” of using single sale-level values for cut tree volume and cut trees per acre rather than performing the STHARVEST analysis for each unit of a sale with their respective tree volume and cut trees per acre values. The five sales evaluated had 3 to 11 units. The four sales not evaluated had 11 to 19 units. These four were not evaluated because the sale-level value was expected to be less sensitive with more units (samples) under the principles of statistical central tendency and normalcy. Table 2.4 summarizes the singular sale value and sale unit weighted average value results. The closeness of the results indicate the simplified approach of using singular values for the entire sale is acceptable for developing a daily production value. The resulting daily production value differed by 0.1 Ccf, or one-half of one percent, for Sale #8, which had the largest discrepancy in resulting cost per Ccf between the sale aggregate and sale unit weighted approach.

Table 2.3. Results from STHARVEST analysis for the nine timber sales.

Timber Sale Number	Total Harvest Costs ($/Ccf)	Yarding Costs ($/Ccf)	Daily Yarding Production (Ccf / day)
1	112.31	79.50	21.7
2	111.86	77.99	22.0
3	121.57	84.98	19.9
4	123.23	85.03	19.8
5	113.47	77.37	21.9
6	119.35	82.55	20.5
7	108.60	74.33	23.0
8	117.80	82.67	20.6
9	112.07	77.85	22.0

Table 2.4. Harvesting cost sensitivity analysis on use of single sale values of cut trees per acre and cut tree volume versus unit weighted average values for stratified stands.

Timber Sale Number	Total Harvest cost (stump to truck)	
	Sale Average ($/Ccf)	Weighted Average ($/Ccf)
1	112.31	112.13
3	121.57	121.03
6	119.35	119.47
8	117.80	119.05
9	112.07	112.27

The resultant daily yarding production applied to each sale's total volume determined the number of days required to complete the harvest. Dividing these days by the allowable number of operating days under the three scenarios determined the number of years required to complete yarding (Figure 2.1). As the SO and MM scenarios only differed by one allowable day per year, the results were very similar. The results are presented on an individual species basis for clarity, applicability, and recognition of the difference in calendar seasonality. Sale contract length (time for purchaser to complete harvest) and "normal" unrestricted operating time to completion are provided for comparison with the scenario results (Table 2.5). On two sales (# 2, 4), for the most restrictive case (SO & MM), the modeled time to completion exceeded the contract allotted length by a fractional year.[3]

[3] The reader should note this analysis was for units which do not actually have seasonal restriction and the result in excess of contract time limit is not a shortcoming of sale planners.

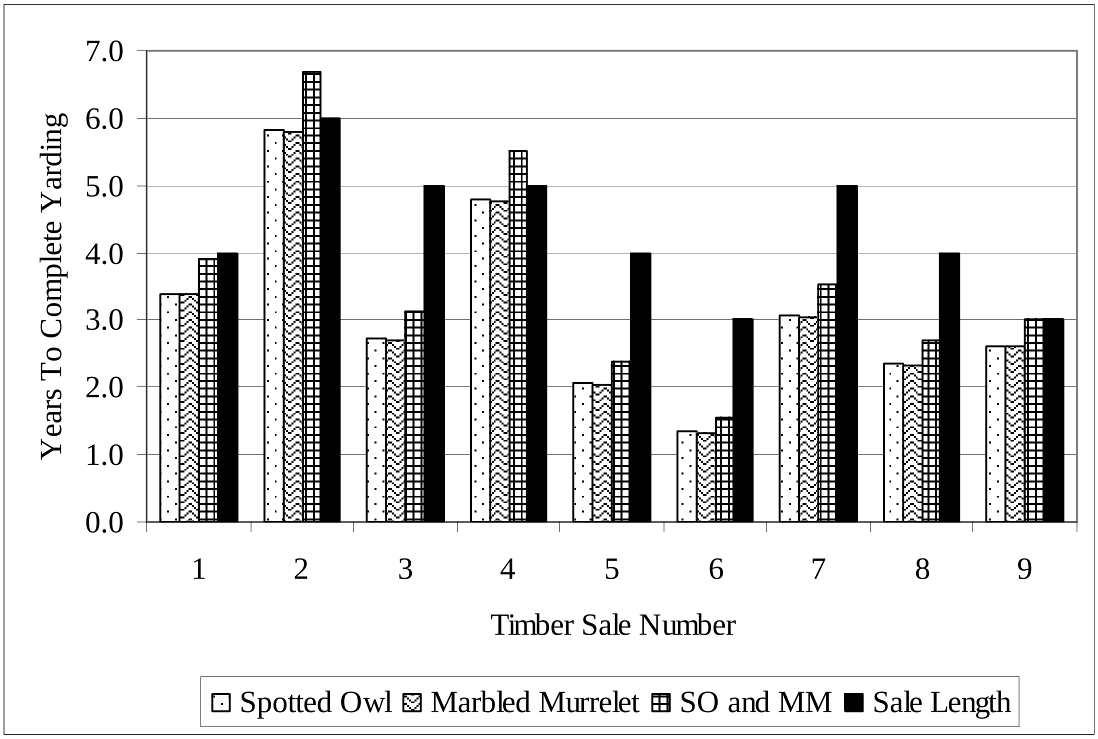

Figure 2.1. Years to complete yarding for nine timber sales and three seasonal restrictions.

Table 2.5. Projection of years to complete yarding under operating restriction scenario.

Timber Sale Number	Yarding Days Required	Years to complete harvest under Operating Restriction Scenario:			Normal Time to Complete	Sale Contract Length (years)
		Spotted Owl	Marbled Murrelet	SO and MM		
1	547	3.4	3.4	3.9	2.2	4
2	937	5.8	5.8	6.7	3.7	6
3	437	2.7	2.7	3.1	1.7	5
4	771	4.8	4.8	5.5	3.1	5
5	332	2.1	2.1	2.4	1.3	4
6	216	1.3	1.3	1.5	0.9	3
7	494	3.1	3.1	3.5	2.0	5
8	378	2.4	2.3	2.7	1.5	4
9	421	2.6	2.6	3.0	1.7	3

Subtraction of one mobilization cycle (initial “normal” move-in and move-out) for the sale resulted in the additional mobilization cycles required to accommodate the seasonal restrictions. Table 2.6 presents the results for the nine sales and three scenarios. The most restrictive season (SO and MM) resulted in an additional mobilization cycle (beyond the single species restriction) on three of the nine sales. The one-way mobilization cost ($/Ccf), calculated as previously described, was applied to these entry cycles and resulted in an additional life of sale mobilization cost of $1.48 to $2.64 per Ccf for the nine sales modeled. The low value $1.48 per Ccf, was for sale 1, across all three scenarios. The high value, $2.64 per Ccf, showed the effect of a reduced operating season from 160 plus days to 140 days, requiring an additional mobilization cycle. Figure 2.2 presents the total life of sale mobilization costs for a “normal” and the restricted scenarios for the nine sales. These values reflect the initial and any additional mobilizations.

Table 2.6. Additional mobilizations (move-in and move-out) and cost per Ccf to accommodate seasonal restrictions.

Timber Sale Number	Normal Two-way Mobilizat. Cost ($/Ccf)	Additional Two-way mobilizations required to accommodate restriction:			Life of Sale, Additional Mobilization costs ($/Ccf) to accommodate restriction:		
		Spotted Owl	Marbled Murrelet	SO and MM	Spotted Owl	Marbled Murrelet	SO & MM
1	0.49	3	3	3	1.48	1.48	1.48
2	0.35	5	5	6	1.75	1.75	2.10
3	0.88	2	2	3	1.76	1.76	2.64
4	0.40	4	4	5	1.61	1.61	2.01
5	1.04	2	2	2	2.09	2.09	2.09
6	1.63	1	1	1	1.63	1.63	1.63
7	0.57	3	3	3	1.71	1.71	1.71
8	0.77	2	2	2	1.54	1.54	1.54
9	0.84	2	2	2	1.69	1.69	1.69

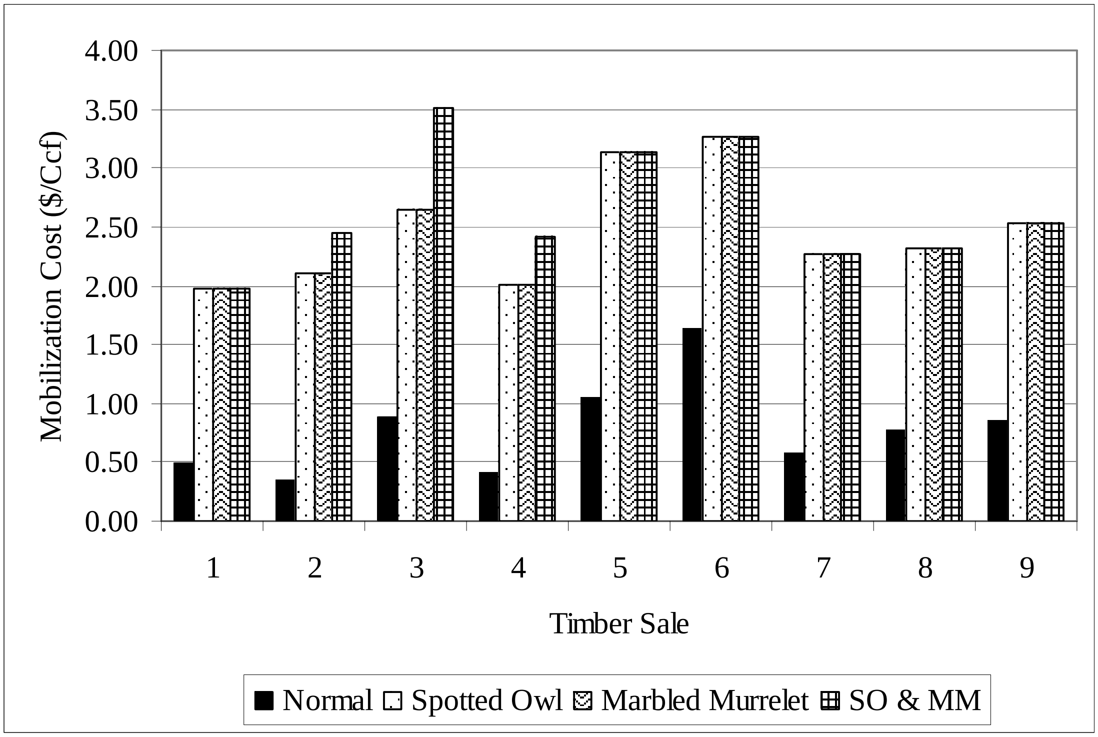

Figure 2.2. Total mobilization costs ($/ Ccf) to accommodate yarding seasonal restrictions.

The additional opportunity cost for mobilization of $1.50 to $ 2.60 per Ccf can seem insignificant with total harvest costs exceeding $120.00 per Ccf. Table 2.7 presents the results for the nine sales on a total dollar basis for one-way mobilizations, an annual mobilization cycle, and the total timber sale. Viewed this way, a single one-way move may cost $3000 to $4000. Over the life of the timber sale, the resulting costs range from $7000 to $43000, depending on the number of moves involved. Under competitive bidding, $1.50 to $2.60 per Ccf may determine the winning bidder, or if the winning bidder makes a profit.

As seen in Table 2.7, a low mobilization cost ($/Ccf) is not an indicator of a low total mobilization cost. The relationship is a complex association of move-in distance, total sale volume, yarding productivity, and operating season length.

Table 2.7. Mobilizations costs (move in and move out) to accommodate seasonal restrictions.

Timber Sale Number	One-Way Total Mobilizat. Cost ($/Ccf)	One-Way Total Mobilizat. Cost ($)	Two-Way Annual Mobilizat. Cost ($)	Life of Sale -- Additional Mobilization costs ($) to accommodate restriction:		
				Spotted Owl	Marbled Murrelet	SO and MM
1	0.25	2937	5875	17625	17625	17625
2	0.18	3614	7229	36144	36144	43373
3	0.44	3828	7656	15311	15311	22967
4	0.20	3070	6140	24559	24559	30699
5	0.52	3806	7611	15223	15223	15223
6	0.82	3607	7214	7214	7214	7214
7	0.28	3239	6478	19435	19435	19435
8	0.39	3011	6022	12044	12044	12044
9	0.42	3901	7803	15606	15606	15606

Three Example Applications

Logging contractors and sale planners may use mobilization cost results to develop bids and appraisals. These appraisals would allow planners to evaluate proposed thinning harvests next to Nesting, Roosting, and Foraging (NeRF) stands for economic viability by comparing logging costs with timber values. For example, a very young stand next to a NeRF stand may not be a viable candidate for entry. Low volumes per tree and harvest volumes per acre lower production rates and result in higher logging costs. If log market values drop below total cost of production (including transport, profit, and risk), the proposed timber sale could go “no bid”. The result is time, effort, and money expended without producing income for the landowner, thus the need to include multiple mobilization costs where appropriate.

A second potential application of this approach is to plan timber sale size to approach the upper limit of an entry cycle, that is, keep required number of yarding days within an integer number of years. A table similar to Table 2.5 would guide a sale planner. Evaluating timber Sale #5 would indicate the total sale volume should be reduced to bring the required yarding time under 2.0 years in order to avoid an additional entry cycle when constrained by either SO or MM seasonal restrictions. This would reduce the total mobilization cost from $2.09 to $1.04 per Ccf. Alternatively, Sale #3's 2.7 years for both the SO and MM scenarios seems to be ideal by providing 0.3 years buffer to complete the yarding within the final mobilization cycle.

The timing of the initial move-in can influence the resulting number of mobilization cycles and thus total costs. The presented results reflect an initial move-in at the end of the seasonal closure, i.e., July and August. This created a continuous operating season prior to the March / April seasonal closure. An initial January move-in results in an additional one-way mobilization the first operational year and two total additional moves compared to an initial July move-in for a required time to harvest.

Thirdly, this use of STHARVEST and our approach may provide others with a method to quantify mobilization costs in general. Production studies typically do not include mobilization costs in the results (Becker, et al; 2006; Sloan and Sherar, 1997). One could use our methodology to include mobilization costs. Ground-based and cable-based mobilization costs are not as large a component as aerial-based system costs (MacDonald, 1999) and can be overlooked. Management of mobilization costs can be addressed and should be for successful operations (Edgerton and MacDermott, 1997).

Summary

Increasing operational restrictions on timber harvest operations to accommodate critical habitat seasons for wildlife decrease the number of available operational days. If a timber sale cannot be completed prior to a seasonal closure, a mobilization cycle (move-out / move-in) must be conducted, with a return after the closure is lifted. The results of this study, modeled on nine USDA Forest Service timber sales, suggest multiple mobilization cycles are possible prior to completion of the timber sale. The additional costs of these mobilizations ranged from $1.48 per Ccf to over $2.60 per Ccf for an array of sale volumes, cut tree sizes, cut trees per acre, one-way mobilization distance, and calculated production rates. The relationship is complex. STHARVEST provides an analyst with a tool, coupled with a spreadsheet, to evaluate a given set of inputs for expected mobilization costs. Knowledge of these costs allows a planner, timber sale purchaser, or harvesting contractor to budget accordingly beyond the expected stump to truck harvest cost.

Connection to other Manuscripts:

This manuscript identifies opportunity costs associated with harvesting public timber sales. These costs ($/Ccf) indicate the need for cost savings or revenue improvements to offset reduction in net revenues to the logging contractor or timber purchaser. Manuscript 2 evaluates log bucking and log lengths in order to seek revenue improvements. Manuscript 3 (heuristic) is an extension of Manuscript 2 to consider mill purchase order constraints on values determined and seek a more efficient evaluation technique. These two manuscripts focus on capturing value from logs with bucking strategies that could help offset the increased costs due to seasonal operating constraints.

Targeted Journal: Western Journal of Applied Forestry

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CHAPTER 3: AN EVALUATION OF LOG LENGTH ON TIMBER VALUES

Introduction

Bucking, or cross-cutting, is the process of sawing a felled tree length bole into shorter log segments. This initial process can create woods-length or mill-length (sawn-lumber length) logs. Woods-length logs are typically bucked into mill-length logs prior to entering the mill's headrig. Resulting log lengths influence revenues and logging costs important to forest managers, logging contractors, and mill managers.

The economic importance of optimizing the value of log lengths from a tree has attracted mathematical programming solutions and applications of linear programming (Pearse and Sydneysmith, 1966), dynamic programming (Pnevmaticos and Mann, 1972; Pickens et al., 1993), and network algorithms (Sessions, 1988). The introduction of handheld computers allowed for in-woods real time solutions (Garland et al., 1989). The importance of log lengths expanded optimal analysis to incorporate sawmill finished products (Faaland and Briggs, 1984; Mendoza and Bare, 1986; Maness and Adams, 1991; Nordmark, 2005). Value improvement through bucking practices is a global activity (Evanson, 1996; Herajarvi and Verkasalo, 2002; Wang et al., 2004).

Interest in value optimization (net revenue) of Pacific Northwest timber has been focused on two fronts: 1) tree length optimization in the woods based on revenues and costs of mill delivered logs, of which OSU-BUCK (Sessions et al., 1993) is an example; and 2) log length milling optimization based on finished veneer, lumber, and pulp product values, of which TREEVAL (Fight et al., 2001) is an example.

The in-woods efforts have focused on creating a set of logs from an individual stem which maximizes net revenues from log values based on quality premiums associated with log grades, diameters, and lengths; less stumpage, harvesting, and trucking costs. Smaller trees generally have lower values and higher production costs, reducing the opportunity to generate significant revenue gains associated with optimal bucking (Olsen et al., 1991). Recent in-woods optimization research on log bucking strategies and log allocations has focused on mechanized harvesting (Murphy et al., 2004; Kivinen, 2007). However, these automated cut-to-length systems produce shorter log lengths (typically <= 20 feet) that western Oregon mills consider less desirable. Length measuring devices, diameter encoders, and computers on cut-to-length systems, coupled with mill price lists for length-diameter combinations, enable operational improvements towards achievement of optimum stand values (Malinen and Palander, 2004). Several combinatorial approaches show feasibility and positive returns for cut-to-length mechanized harvesting operations (Marshall et al., 2006). However, the machinery involved in these cut-to-length systems is generally restricted to relatively level topography.

The in-mill efforts have focused on generating finished product values from a given log based on product dimensions and quality.

This study evaluates log bucking strategies for long log harvesting common in the Pacific Northwest to determine if a simplified, reduced set of bucking lengths produces near optimal returns to the timber owner and simultaneously produces a distribution of acceptable log lengths to the mill purchaser. It will be useful to landowners and mill managers interested in improved information about their thinning harvest operations. A positive outcome (favorable comparison with conventional bucking prescription) would allow a bucking supervisor to create a cutting instruction card (log lengths by tree length) that would approach computer-aided single stem value optimization. Harvest planners and managers could use the resulting log set for developing a stand level analysis or multiple stand analysis for log allocation decisions similar to those achievable with cut-to-length systems, but on steep terrain and for long log lengths not achievable with cut-to-length systems in the Pacific Northwest.

Research questions arose about the significance of log length in value optimization within tree length and log length optimizers. All previous research efforts involving OSU-BUCK have utilized the Scribner board foot basis for optimization. TREEVAL uses a cubic foot basis, for 16- or 20-foot mill length logs. Based on the preponderance of 16- and 20-foot lengths in the literature (Fahey and Martin, 1974; Hallock et al., 1979; Willits and Fahey, 1988; Middleton and Munro, 1989; Haynes and Fight, 1992; Patterson et al., 1993; Nagubadi et al., 2003; Random Lengths, 2008) it was decided to evaluate cubic foot based value optimization for mill-length logs of 16 and 20 feet and woods-length logs of 32, 36, and 40 feet.

Objectives

Using the log valuation / stem optimization capabilities of the OSU-BUCK software program, the objectives of this analysis were:

1) Evaluate the value and volume differences for stems optimally bucked with a complete set of allowable log lengths and a reduced set of lengths for two sample sets of second-growth Douglas-fir (Pseudotsuga menziesii) trees to determine if a reduced set is economically viable for pursuing development of a simplified bucking decision tool.

2) Evaluate the validity of using a board foot per cubic foot (BF/CF) ratio to convert log prices in dollars per one-thousand board feet ($/Mbf) to dollars per one-hundred cubic feet ($/Ccf) as an approach to developing cubic based pricing in the absence of mill provided values.

Methods

The study evaluates the effect of log length on value and volume recovery of two sample sets of Douglas-fir trees. Stand 1 is a 45-year old stand and Stand 2 is a 65-year old stand. Stand 1 trees were located in the Oregon Cascade Range foothills, on the Oakridge Ranger District (Kellogg et al., 1998). Stand 2 trees were located on Starker Forest land east of Alsea, Oregon.

Fifty sample trees were measured after felling/bucking and prior to yarding in each stand. Inside bark diameters at the butt and bucked log faces were measured to the nearest 0.1 inch. Lengths were measured (nearest 0.1 foot) at bucking cuts and to the total top.

Average inside bark butt diameter for Stand 1 sample trees was 9.9 inches (SD = 2.1 inches). Average stem length was 73.4 feet (SD = 9.7 feet) to a top diameter averaging 2.1 inches. These values compare favorably with stand DBH and height values of 9.8 inches and 71 feet (Kellogg et al., 1999). Average tree merchantable volume was 23 cubic feet (cf).

Stand 2 average inside bark butt diameter for the sample trees was 18.4 inches (SD = 5.0 inches). Average recovered stem length was 101.8 feet (SD = 19.6 feet) to a top diameter averaging 8.6 inches. Stand 2 top diameter was the resulting merchantable top, primarily a function of falling breakage on the steeper and broken terrain. Average recovered merchantable volume was 123 cubic feet per tree. Figure 3.1 shows the frequency distribution of the butt diameters and Figure 3.2 is the frequency distribution of the stem lengths for each stand. Total length of the 50 sample stems was 3,670 feet and 5,092 feet in stands 1 and 2, respectively. These values were used to verify full allocation of each stem in the sample set.

The board foot log prices ($/Mbf) used were obtained from a western Willamette Valley mill, Summer 2006. For Stand 1, an average board foot / cubic foot ratio value of 3.64 was generated from Cahill's (1984) Table 1 for scaling diameters 6 to 11 inches. This value was applied to the board foot basis log values to calculate cubic foot basis log values. For Stand 2, a BF/CF ratio of 4.85 (6 to 22 inch scaling diameters) was used to generate cubic volume based log prices. Fiber prices ($/ton) were calculated for both BF and CF basis using the appropriate BF/CF ratio and a conversion factor of 7 tons per Mbf. This results in a value of 51 pounds per cubic foot, within accepted ranges of 38-55 pounds/CF (Briggs, 1994). Table 3.1 indicates the log values used in our study.

Table 3.1. Log prices used in OSU-BUCK board foot and cubic foot based analysis. Sawlogs (to 5-inch diameter inside bark).

		Stand 1	Stand 2
Scaling Length	$ per Mbf	$ per Ccf	$ per Ccf
38 – 40	650.00	236.60	315.25
30 – 36	620.00	225.70	300.70
24 – 28	575.00	209.30	278.88
16 – 22	500.00	182.00	242.50
12 – 14	400.00	145.60	194.00
8	200.00	72.80	97.00
Fiber logs			
12 - 40	150.00	54.60	72.75

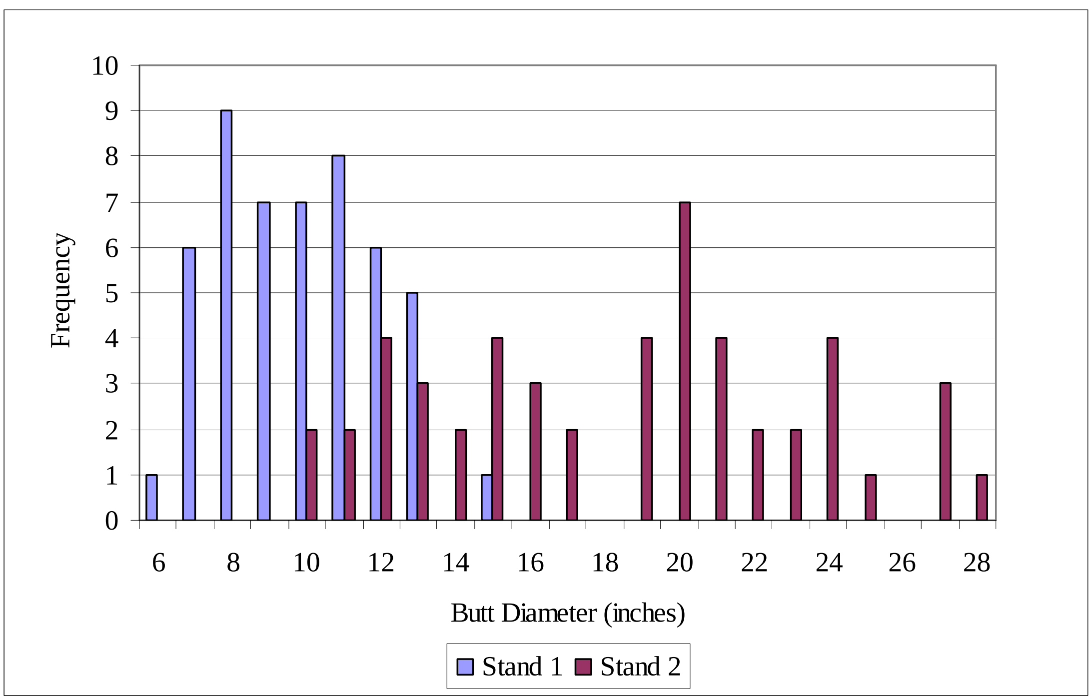

Figure 3.1. Frequency distribution for butt diameters of the 50 sample trees, Stands 1 and 2.

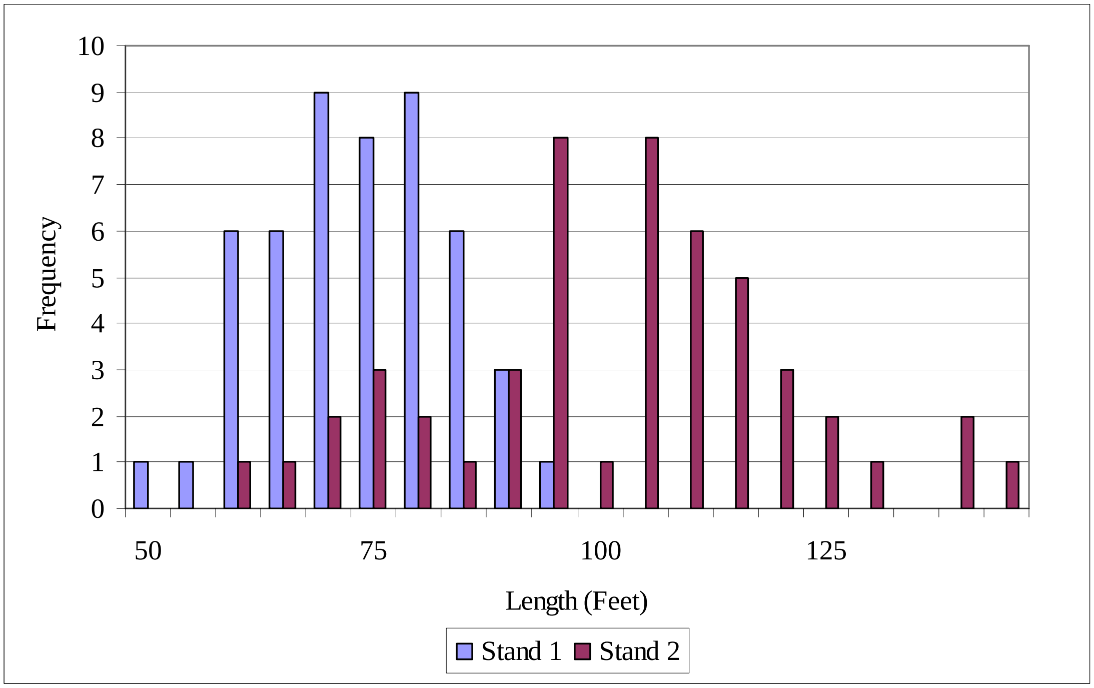

Figure 3.2. Frequency distribution of stem lengths of the 50 sample trees, Stands 1 and 2.

Logging and hauling costs were set at zero to focus the analysis on log values. As OSU-BUCK optimizes on gross length and gross diameter, stem defects were ignored. OSU-BUCK provides the flexibility to analyze the longer 32, 36, and 40-foot woods-length combinations that convert into 16- and 20-foot mill-lengths.

Nine bucking scenarios were initially evaluated in OSU-BUCK for Stand 1 sawlogs to a five-inch small end scaling diameter (inside bark). The scenarios were:

1) AS-BUCKED. As-Bucked[4] log lengths (12 to 40 feet) for butt logs and bucking of subsequent logs to the merchantable top.

2) BF OPTIMAL. Optimally bucked log lengths, 12 to 40 feet, 2 foot multiples, 1 foot of trim, Scribner Board Foot volume, 40-foot scaling segment basis.

[4] Actual field bucking without the aid of optimization tools.

3) CF OPTIMAL. Optimally bucked log lengths, 12 to 40 feet, 2 foot multiples, 1 foot of trim, Smalian's cubic foot volume basis, modified per (NLRAG, 1995), 40-foot maximum scaling segment.

4) COMBO. Optimally bucked, log lengths limited to 16, 20, 32, 36, and 40 feet, 1 foot of trim, 40-foot cubic foot basis.

5) (16). Optimally bucked, 16-foot log length only, 0.5 ft. trim, 40-foot cubic

6) (20). Optimally bucked, 20-foot log length only, 0.5 ft. trim, 40-foot cubic

7) (16&20). Optimally bucked, 16 and 20-foot log lengths only, 0.5 foot of trim, 40-foot cubic foot basis.

8) (16&40). Optimally bucked, 16 and 40-foot log lengths only, 40-foot cubic

9) (16, 20, 40). Optimally bucked, 16, 20 and 40-foot log lengths only, 40-foot cubic foot basis.

Stand 2 trees were evaluated for only four of the bucking strategies based on the experience with Stand 1 analysis:

1) AS-BUCKED

2) BF OPTIMAL

3) CF OPTIMAL

4) COMBO

The resulting sawlog data were imported into a spreadsheet and summarized, including total value of the sawlogs, BF volume, CF volume, mean BF/CF ratio, number of sawlogs, and total length of sawlogs. Total length and cubic foot volume of the fiber logs were also summarized. Fiber log value was not summarized.

Results

Stand One

The AS-BUCKED logs were analyzed using both the board foot and cubic foot basis to test the appropriateness of the BF/CF ratio used to develop the $/Ccf log prices. For Stand 1, under the board foot values, the 50 stems were valued at $ 2228. Using the 3.64 BF/CF ratio, the cubic foot based value for the same logs was $ 2214, a difference of $ -14 or -0.63 percent. The mean BF/CF ratio for the 76 sawlogs was 3.73 (Table 3.2). This compares favorably with the Cahill based initial estimate of 3.64. The closeness of these values indicates an acceptable log price conversion strategy for this stand.

The AS-BUCKED (scenario 1) achieved 90.4 percent of the optimal $ 2466.00 under the board foot basis. Interestingly, the same log lengths achieved 94.4 percent of the optimal $ 2,346 under the cubic foot volume basis. The bucker bucked approximately 55 percent of all logs in 32-, 36-, or 40-foot lengths. Over 80 percent of the AS-BUCKED butt logs were in these three lengths.

The BF-OPTIMAL solution created over 55 percent of its logs in 16-, 24-, and 32-foot lengths. Most of the 16- and 24-foot logs were second logs. The optimizer cut a short butt log to capture scale on only four stems. Excessive taper in the lower bole created the short butt logs in the optimal solution. The taper was 1 inch in 8 feet for three of the stems (16-foot butt logs) and 1 inch in 5 feet for the fourth stem (12-foot butt log). Scribner scale rules provide for a taper of 1 inch in 10 feet.

Table 3.2. Summary of sawlog values and volumes bucked from 50 sample trees for nine scenarios in Stand 1.

	SCENARIOS								
	1	2	3	4	5	6	7	8	9
	AS-BUCKEI	BF OPTIMAL	CF OPTIMAL	CF (COMBOS)	CF (16)	CF (20)	CF (16&20)	CF (16&40)	CF (16,20,40)
TOTAL SAWLOG VALUE * BF basis *	$2,214 *2228*	$2,466 *2466*	$2,346	$2,262	$1,681	$1,631	$1,776	$2,155	$2,188
BOARD FOOT VOLUME	3610	4170	3710	3520	4000	3340	4000	3400	3390
CUBIC FOOT VOLUME	986	1005	1023	994	911	894	965	945	964
AVG. BF/CF RATIO	3.73	4.24	3.71	3.65	4.41	3.66	4.15	3.86	3.69
TOTAL # OF SAWLOGS	76	92	73	71	129	100	124	73	73
TOTAL LENGTH OF SAWLOGS (FT)	2328	2384	2411	2319	2129	2050	2262	2184	2244
NO. OF FIBER LOGS	50	50	50	50	50	50	50	50	50
TOTAL LENGTH OF FIBER LOGS (FT)	1342	1286	1259	1351	1541	1620	1408	1486	1426
FIBER CF VOLUME	159	135	144	161	195	218	174	185	175
TOTAL CF VOLUME	1144	1140	1167	1155	1107	1113	1139	1130	1139
$ TOTAL / CF TOTAL	1.95	2.16	2.01	1.96	1.52	1.47	1.56	1.91	1.92
CF FIBER/CF TOTAL (%)	13.9	11.8	12.4	14.0	17.7	19.6	15.3	16.4	15.4
$ TOTAL / CF SAWLOG	2.25	2.45	2.29	2.28	1.84	1.82	1.84	2.28	2.27
BF / LINEAR FOOT	1.55	1.75	1.54	1.52	1.88	1.63	1.77	1.56	1.51
CF / LF of SAWLOG	0.42	0.42	0.42	0.43	0.43	0.44	0.43	0.43	0.43

The CF-OPTIMAL solution bucked over 30 percent of all logs in 40-foot lengths. The trend is greater in butt logs. This trend resulted in 17 of the 50 bucker's solutions matching the CF-OPTIMAL solution. The BF optimal solutions only matched the CF solution on 15 of the 50 trees. Only one stem had a short log bucked off the butt. It was one of the stems on which this occurred under the BF-OPTIMAL scenario. This suggests CF solutions are not as sensitive to excessive taper. It should be noted the BF/CF ratio calculated by dividing the total BF volume by the total CF volume for this scenario is 3.63. Recall our assumed ratio was 3.64. It is not clear if this is significant or a coincidence. The mean BF/CF ratio for these 73 sawlogs is 3.71 (Table 3.2). The CF bucking algorithm generated 18 – 37 more cubic feet of volume than was achieved under scenarios 1 and 2. It is not clear why this occurred. All scenarios had the required 3670 feet of total stem length. Scenario 3 (CF-OPTIMAL) did have the largest amount of recovered length in sawlogs (Figure 3.3).

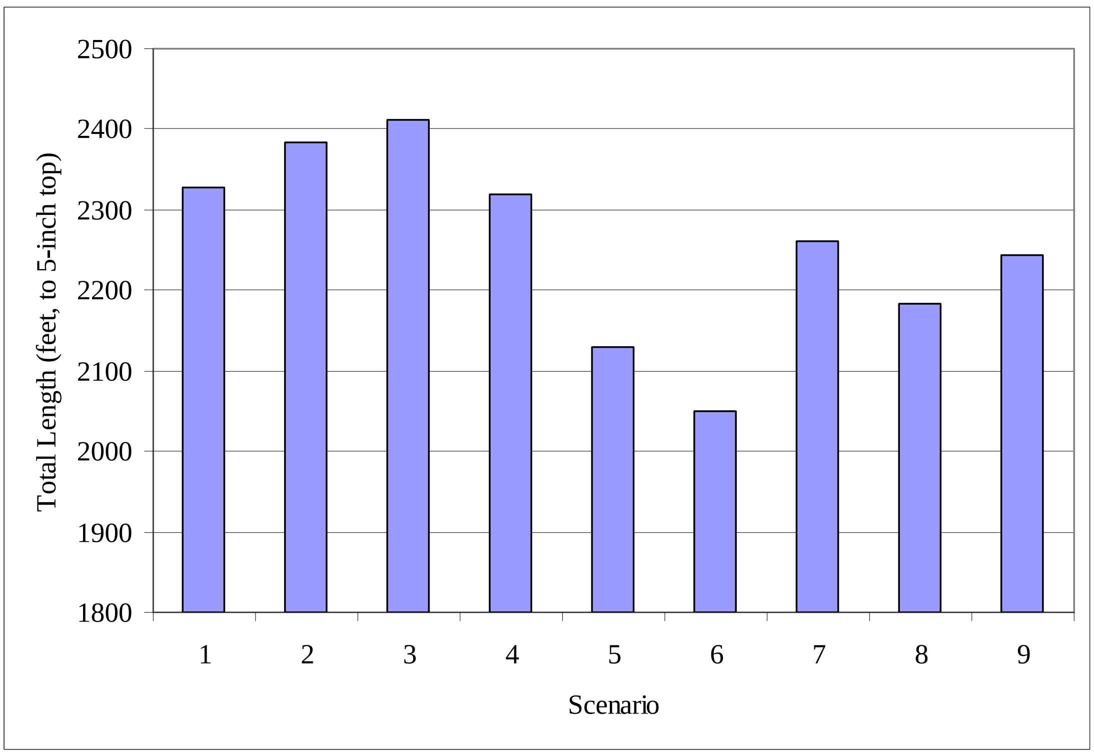

Figure 3.3. Total length of recovered sawlogs (5-inch top) for Stand 1's 50 sample trees.

One of the criticisms of the optimal bucking algorithm is its tendency to cut more logs than a bucker's traditional solution (Olsen et al., 1991). This is evident with the BF-OPTIMAL solution in scenario 2 (Figure 3.4). The CF-OPTIMAL (scenario 3) solution cut three fewer logs than the bucker (scenario 1) did.

Scenario 4 (COMBO) was hypothesized to be a solution acceptable to both logging managers and mill managers. Logging managers want to control costs by handling fewer logs and mill managers prefer long logs to maximize overrun[5] and cut long boards. The solution was constrained to cutting only 16-, 20-, 32-, 36-, and 40-foot log lengths. The longer woods-length logs can be bucked into preferred 16- and 20-foot mill-length logs while reducing the number of pieces handled in the woods and mill yard. In fact, this solution created the fewest number of sawlogs (Table 3.2, Figure 3.4). Still, this solution achieved 96.8 percent of the CF optimal solution value.

The mill-length scenarios 5, 6, and 7 represent the solutions for cutting only 16-foot, only 20-foot, and only 16- and 20-foot log lengths, respectively. Of course, cutting only 16-foot logs resulted in the greatest number of logs. However, this is only five more logs than the 16&20-foot scenario, which matched the 4000 BF of volume generated by the 16-foot scenario. Note both of these scenarios had BF/CF ratios over 4.1. Scenario 6, 20-foot lengths only, had the lowest BF volume of any scenario. This is likely due to the fact that for 5-, 6-, and 7-inch diameters, the 20-foot length sits in the middle of, or just before, a board foot step breakpoint (NLRAG, 1995).

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[5] Overrun: Ratio of mill tally lumber board foot volume to Scribner log scale volume. 100 percent overrun = 100 * (120 BF lumber – 60 BF log) / 60 BF log

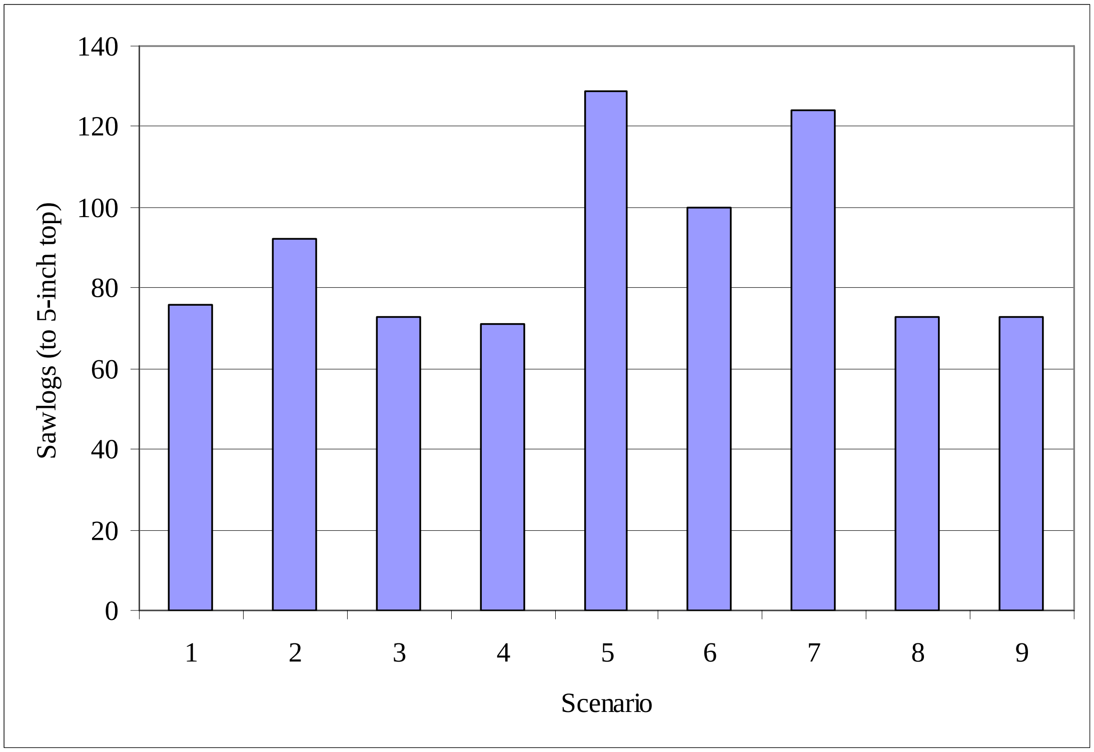

Figure 3.4. Number of sawlogs bucked from 50 sample trees by scenario for Stand 1.

For scenario 7, sixteen-foot log lengths are only slightly favored (56.5 percent) over 20-footers. This preference for 16-foot logs increases to 60 percent on a butt logs only basis. Total log values for scenarios 5, 6, and 7 are appropriate for the log pricing structure used. They achieve approximately 72 percent of the CF optimum scenario value. It should be recognized that the prices for 16- and 20-foot log lengths are approximately 80 percent of the longer log unit values. TREEVAL may be the more appropriate tool to address mill-length log values if the conversion from board foot prices does not reflect true market values for logs on a cubic foot basis. This may occur if long log pricing on a board foot basis is determined for an anticipated level of overrun realized. On a cubic foot basis, the volume paid for is much closer to the volume realized because cubic log scaling rules account for taper, unlike the Scribner board foot rules that do not.

The choice of log lengths is important. Analysis of the potential bucking points on an 80-foot stem shows only 5 and 4 locations with 16- or 20-foot lengths, respectively. Using multiples of 16- and 20-foot lengths doubles the number of potential bucking points to eight. Any combination of both 16- and 20-foot logs with any long log length (32-, 36-, 40-foot) provides potentially 14 bucking points to an 80-foot merchantable top. However, if the long log used is a 32-footer, mill recovery of lumber is limited to 8 through 24 feet if a minimum 8-foot mill length log is assumed. By comparison, logs 36- and 40-foot in length allow lumber recovery of 8 through 28 feet in length. This is a subtle distinction of how woods-length logs may influence mill-lengths and ultimately the mill's flexibility in meeting lumber orders.

Additional scenarios were evaluated to identify combinations of two or three logs consisting of at least one long log and a short log that may simplify analysis and actual bucking of stems while achieving a desired level of value or volume recovery. In addition to the previously identified five log length scenario (COMBO), the best three log length scenario consisted of 16-, 20-, and 40-foot lengths. The best two log length scenario consisted of 16- and 40-foot log lengths. Table 3.3 summarizes the results of these on total length and cubic volume of sawlog manufactured, number of sawlogs, percent fiber, and percent by volume of long logs (36-feet and longer). As the number of allowable log lengths in the scenario decreases, the less the scenario approximates the AS-BUCKED solution. The combination of 16, 20, 32, 36, and 40-foot log lengths best simulates the results a tree faller might produce. This is an important characteristic in modeling stand level recovery. If maximizing wood utilization for sawlogs is important, one must recognize that restricting allowable lengths limits recovery. With a camprun (single log price per unit volume, independent of length) scenario (all lengths 12 to 40 feet), length of recovered sawlogs is maximum at 2479 feet or 67.6 percent of the total stem length analyzed for the 50 stems. In contrast, the two log length solution only utilizes 60 percent of the stem length for sawlogs.

Table 3.3. Summary of 5, 3, and 2 log lengths scenarios compared with "as-bucked" solution for Stand 1.

	SCENARIOS			
	AS-BUCKED	CF (COMBOS)	CF (16,20,40)	CF (16&40)
# of LOG LENGTHS	15	5	3	2
TOTAL LENGTH OF SAWLOGS (Feet)	2328	2319	2244	2184
CF SAWLOG VOLUME	986	994	964	945
TOTAL # OF SAWLOGS	76	71	73	73
LONG LOGS (>=36 feet, % by volume)	60	67	80	82
PERCENT FIBER	13.9	14.0	15.4	16.4
# OF FIBER LOGS	50	50	50	50
TOTAL LENGTH OF FIBER LOGS (Feet)	1342	1351	1426	1486
FIBER CF VOLUME	159	161	175	185
TOTAL CF VOLUME	1144	1155	1139	1130

Fifty fiber logs were produced under each scenario. For the sample trees evaluated, no less than 12 percent of the CF volume would become fiber material with a 5-inch minimum diameter requirement for sawlogs. Sawlog and fiber CF volumes for the scenarios evaluated are presented in Figure 3.5.

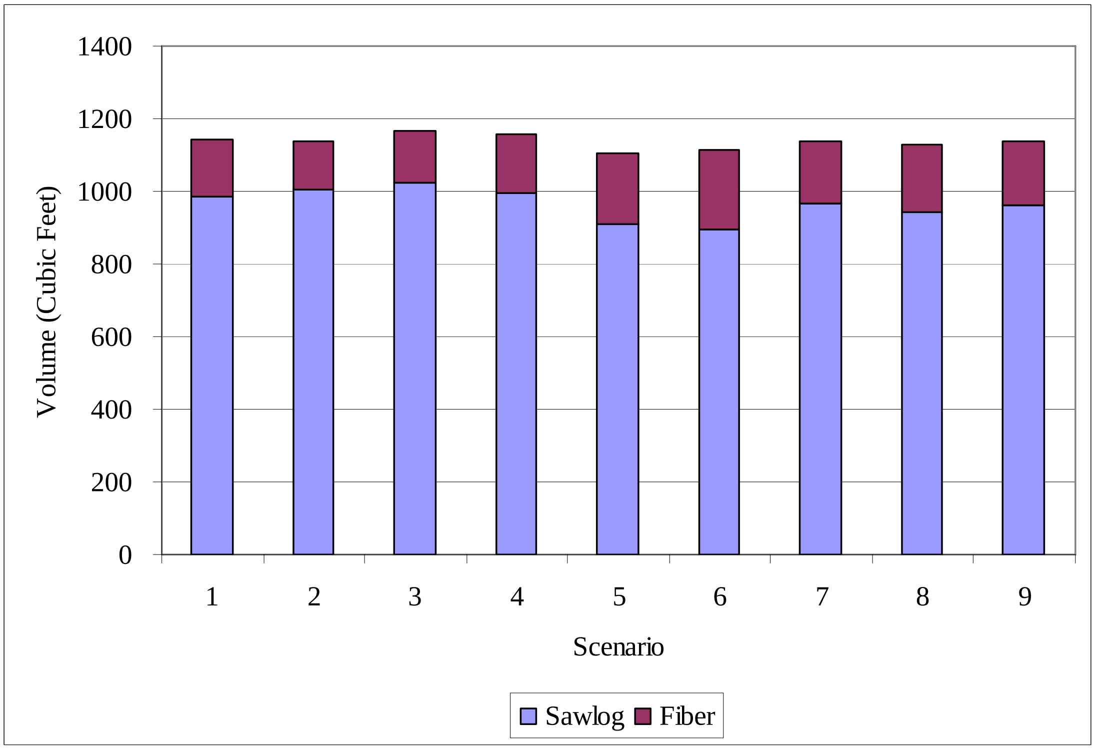

Figure 3.5. Cubic foot volume recovered for 50 sample trees by scenario, Stand 1.

Stand Two

The AS-BUCKED solution approach generated 94 percent of the OSU-BUCK optimal value on a BF basis. The COMBO approach generated 97 percent of the optimal value. The 50 trees created 158, 152, and 148 sawlogs for the BF-optimal, AS-BUCKED, and COMBO solutions; respectively. Two fiber logs were created under the BF-COMBO solution; however, the CF-COMBO solution did not create any fiber logs. The BF-COMBO solution also underutilized 40 feet more than the CF-COMBO solution. This is a result of the board foot scaling rules in small diameter long logs – i.e., a 36-foot by 6 inch log has 60 board feet compared to 40 board feet if that log was extended to 40 feet but resulted in a 5 inch scaling diameter.

As with Stand 1, the AS-BUCKED logs were analyzed in both the board foot and cubic foot basis to test the appropriateness of the BF/CF ratio used to develop the $/Ccf log prices. For Stand 2, under the board foot values, the 50 stems were valued at $17,645. Using the 4.85 BF/CF ratio, the cubic foot based value for the same logs was $ 18,594; a difference of $ 949, an increase of 5.4 percent. The resulting BF/CF ratio for the 152 sawlogs was 4.36 (Table 3.4). Recall the cubic foot prices for Stand 2 were based on a BF/CF ratio of 4.85. This disparity indicates the need for careful determination of the BF/CF ratio if converting to dollars per cubic foot from dollars per board foot in larger diameter stands. A BF/CF ratio of 4.60 is derived for pricing conversion using the resulting value ($17,645), and volumes (27970 BF, 6087 CF) for the sawlogs. This BF/CF value was not used, but shows an approach one may take to derive or improve a conversion factor.

The CF-COMBO approach resulted in the fewest number of sawlogs. The optimal CF-COMBO solution incorporated only one short log per tree, in order to utilize as much of the merchantable stem as possible within the allowable log lengths. This is an improvement over the BF optimal solution where short logs are incorporated more often due to Scribner scaling rules. Additionally, the percentages of long logs (lengths greater than or equal to 36 feet) were 49 and 69 percent for BF and CF optimal based solutions, respectively. The CF-COMBO approach generated 76 percent of the volume in long logs, 63 percent of which were in 40-foot lengths.

Many mill purchase orders have a minimum long log requirement of 70 percent.

The percent volume by log length distribution for the CF-COMBO solution was:

Log Length	Volume (percent)
36-40	76
32	17
16-20	7

The COMBO approach created a set of woods-length logs acceptable to the mill purchaser with minimal percent of short logs while creating the minimum number of pieces requiring handling during harvesting operations. The COMBO approach did underutilize total available stem length by 50 feet compared to the optimal and AS-BUCKED solutions for the 50 stems. The longest single non-utilized piece was 10 feet and the majority of pieces were less than 3 feet.

The CF based optimal solutions from OSU-BUCK improve on the criticisms of BF based optimal solutions: they minimize short logs; cut desirable percent of long logs without artificial price adjusters; and utilize more of the stem length.

Table 3.4. Summary of Stand 2 sawlog values and volumes bucked from 50 sample trees for four different scenarios.

	SCENARIOS			
	1	2	3	4
	AS-BUCKED	BF OPTIMAL	CF OPTIMAL	CF (COMBOS)
TOTAL SAWLOG VALUE	$18,594	$18,742	$19,042	$18,696
* BF basis *	*17,645*	*18,742*		
BOARD FOOT VOLUME	27970	30270	28900	28290
CUBIC FOOT VOLUME	6087	6196	6209	6119
AVG. BF/CF RATIO	4.36	4.59	4.39	4.42
TOTAL # OF SAWLOGS	152	158	150	148
TOTAL LENGTH OF SAWLOGS (FT)	5046	5013	5044	4980
LONG LOGS (>= 36') (PERCENT BY VOLUME)	80	49	69	75
$ TOTAL / CF VOLUME	3.05	3.02	3.07	3.06
BF / LINEAR FOOT	5.54	6.04	5.73	5.68
CF / LF of SAWLOG	1.21	1.24	1.23	1.23

Discussion

The single value average for the BF/CF ratio used in Stand 1 analysis created a difference of five percent between the BF and CF optimal values. The different log length solutions account for some of this difference. The optimal BF solutions were entered as User Solutions under the CF basis in anticipation of this possibility. The resulting CF based value of $2176 for the BF based bucking solution is 88.4 percent of the CF optimal. This shows that the apparent increase of $ 126 (2462-2336) for the 50 stems when bucked on a BF basis is related to the well-known step-function of Scribner scale for scaling diameters less than 11 inches. The increase of $ 126 is related to increased BF scale. Compare BF volumes of 4170 and 3710 in Table 3.2 for scenarios 2 and 3. Another point of evidence is the 4.24 BF/CF ratio resulting from scenario 2. The BF/CF ratio will maximize at the beginning of a step function for a given log diameter. Because CF volume increases with log length, and the BF scale stays the same, the BF/CF ratio decreases. These maximum breakpoints occur at 16, 24, and 34 feet scaling lengths for a 5-inch diameter log (Table 3.5). The BF based optimization thus will buck a 34-foot, 5-inch log and generally avoid a 40-foot, 5-inch log which results in an increase of the BF/CF ratio. A high BF/CF ratio interestingly occurs in six-inch diameter logs. This is even evident in Cahill's (1984) table, with a higher BF/CF ratio for 6-inch (3.32) diameter logs than 7-inch (3.25).

Table 3.5. Scribner board foot volume table by scaling diameter and length. Blanks denote identical volume within a column a breakpoint; e.g., a 5-inch diameter log has 20 board feet from 16-feet through 22-feet.

	DIAMETER, Small End, Inside Bark (inches)							
LENGTH (feet)	5	6	7	8	9	10	11	12
8	10	10	10	10	20	30	30	40
10				20			40	50
12			20		30	40		60
14		20					50	70
16	20		30	30	40	60	70	80
18							80	90
20				40	50	70		100
22		30	40			80	90	110
24	30				60	90	100	120
26				50			110	130
28			50		70	100	120	140
30		40		60		110	130	150
32		50	60	70	90	120	140	160
34	40				100	130	150	170
36		60		80		140	160	180
38			70		110		170	190
40				90	120	150	180	200

As seen in the BF and CF-based value analysis of Stand 2, one must exercise care in choosing a BF/CF ratio for converting prices from a $/Mbf to a $/Ccf basis. The use of a singular value may average out for a large set of possible lengths.

Singular values for each length and diameter combination would seem best, but difficult to apply in practice. Some mills purchase logs on a weight basis, $/ton. It is likely this is a conversion from analysis of proprietary known weights and board foot recovery. It is difficult to evaluate various BF to CF pricing conversion strategies without this information.

It is hypothesized that timberland owners have a need for pricing conversions. Cubic foot volume measurements more accurately reflect products (lumber, veneer, chips, flakes, etc) and product recovery. The USDA Forest Service timber sales, except in Alaska, are sold on a $/Ccf basis. International markets use cubic meters for volumes. Without an understanding of conversions, the log marketer will be handicapped in their ability to obtain the highest revenue for their timber, from the purchasers, if mills begin offering bids exclusively in $/Ccf.

The pricing conversion results for Stand 1 and 2 suggest Cahill's (1984) values can be used as a starting point for BF/CF ratio to convert $/Mbf pricing to $/Ccf. However, it is recommended this value be determined from a sample for each stand (or similar stands). The BF/CF ratio used in our study was an arithmetic average of the expected range of scaling diameters. Knowledge of log output and their scaling diameter frequency distribution would allow a forest manager to develop a weighted average value. Cahill's values were determined from a regression equation based on Scribner scaling diameter. OSU-BUCK data outputs may be used to create both the frequency distribution for a weighted average and a dataset for a regression equation based on length and diameter, providing optional approaches for producing BF/CF pricing ratios.

OSU-BUCK currently values sawlogs and pulpwood on the same scale basis, thus undervaluing fiber volume under Scribner (cylinder) scaling rules. Given a lack of open market sawlog pricing on a cubic basis, analysis is needed to see if log valuation based on the summation of cubic recovery of lumber and other products at their unit values is an appropriate technique.

With 16- and 20-foot logs being valued the same in our price table, one must not draw a definite conclusion that 16-foot log lengths are better (higher value) than 20-foot lengths. It may be more a function of recoverable log length in a given stem. For example, a stem that has 40 feet to a 5-inch top would be fully recovered with 20-foot logs (provided adequate trim is available) compared to only 32 feet of recovered saw length under a 16-foot scenario. Likewise, a stem 48 feet in length would be better suited to a solution of 16-foot log lengths than just 40 feet of recovery under a 20-foot log length solution.

Having more length options clearly increases value, volume, and recovery of sawlog length. It is interesting the COMBO scenario has such a high recovery percentage, given only five log length options. This strategy appears to meet the milling criteria of producing log lengths to the minimum length that meets the maximum length and quality of the end product produced while meeting the logger's criteria of minimizing the number of logs handled. Given the historical inventory system, scaling practices, and the preference of long log harvesting in the Pacific Northwest, it seems appropriate to evaluate stand values based on woods-length logs that will convert into 16 and 20-foot mill length logs; i.e., woods-lengths of 32, 36, and 40-feet. This holds for both thinning and final harvest aged stands.

The magnitude of gains, on a tree basis, may seem small with thinning sized stems (Stand 1). However, at the stand level this could be several hundred dollars per acre, depending on thinning intensity. Compared to the CF-OPTIMAL solution, the AS-BUCKED (bucker's choice) solution resulted in a decreased potential revenue of $ 2.44 per tree. The COMBO solution resulted in a decrease of $ 1.50 per tree. Evaluation of effort required to capture these gains is critical as falling/bucking costs can approach $ 0.50 per minute.

Obtaining the data to optimally evaluate the stem takes additional time. At breakeven revenue (increased value of logs less cost of obtaining data inputs), five minutes more could be spent by the bucker to optimally improve the bucking pattern. Olsen (1991) estimates four minutes per tree is required for second-growth Douglas-fir stems. For breakeven revenue, this would need to be reduced to two minutes if the optimal solution is constrained to five allowable log lengths. Viewed another way, constraining the optimal bucking pattern to achieve acceptable log lengths for the mill and logging contractor costs the timber owner $ 1.50 per tree. The simplified set of log lengths in the COMBO solution permits a value improvement of $0.94 per tree over current bucker practices. At 23 CF per tree, this translates to $4.09 per Ccf.

The magnitude of gains is larger for larger trees (Stand 2). Comparing AS-BUCKED and COMBO to the OPTIMAL solutions under BF pricing shows potential value improvements of $21.94 and $11.12 per tree respectively. The COMBO solution approach thus can improve average tree value by $10.82 per tree over current bucking practices. At 123 CF per tree, this translates to $8.80 per Ccf. The COMBO solution is computer based and thus input costs (time to enter tree diameter-length data for analysis) would reduce this amount. A comparison of a bucker's solution under the reduced set of lengths to the optimal solution was not possible with this dataset. This would require a field trial. A heuristic analysis approach may provide an alternative evaluation technique in lieu of additional field trials. The COMBO set of lengths, combined with length based price differentials, creates a more manageable set of potential bucking patterns for the bucker.

A simple cutting pattern card is envisioned where the bucker measures merchantable stem length and looks up the log length pattern (Table 3.6). The COMBO optimal solution did not cut any extra short logs to maximize value. A short log was cut to utilize stem length once one or more long logs were in the solution. Occasionally the optimal solution cut a short log from the butt end, pushing the long logs up the stem. Mill purchase orders generally require a minimum percentage of the volume in long logs. This requirement generally results in cutting long logs in the lower portion of the bole.

Table 3.6. Log bucking pattern as a function of merchantable length (trim requirement = 0, for example clarity).

Total Merchantable Length	Preferred Cutting Pattern (butt to top)			
72	32-40,	40-32,	36-36	
76	36-40,	40-36		
80	40-40,	32-32-16		
84	32-32-20,	32-20-32,	20-32-32	
88	32-40-16,	40-32-16,	36-36-16,	16-36-36

TREEVAL

Log evaluation within TREEVAL is limited to the existing data set based on 16- and 20-foot log lengths. The preponderance of 16 and 20-foot lengths in the literature, as mill length logs in recovery studies, as finished lumber output, and as reflected in price premiums for these lengths suggest they are an appropriate basis for analysis models such as TREEVAL and FEEMA (Financial Evaluation of Ecosystem Management Activities, Fight and Chmelik, 1998).

TREEVAL may be the more appropriate to evaluate cutting solutions which OSU-BUCK considers an "alternate optimal" based on log scale based valuations. The occurrence of “alternate optima” increased in Stand 2 cubic volume based solutions. For example, a tree (Stand 1, sample #48) had two equivalent dollar-value solutions. One cutting pattern had a 40-foot log, the other a 32- and a 12-foot log. Clearly, the second pattern recovers more sawn length within the scaling cylinder. This raises the question: Are two 20-foot logs and resulting sub length (16-, 14-, 12-foot) lumber more valuable than two 16-foot logs and resulting sub length (12-, 10-, 8-foot) lumber plus the lumber realized from the 12-foot log? This emphasizes the strength of TREEVAL analysis based on lumber prices and recovery data. However, this strength is suited to a mill that can evaluate the harvested trees for its own pricing and recovery data. TREEVAL is less suited to stand valuation and log allocation for open market conditions where lumber prices and recovery data for mill purchasers (bidders) is proprietary.

Future Analysis

Development of an improved BF/CF ratio for pricing conversions to cubic values is warranted. The approach may be as simple as a frequency based weighted average using Cahill's values. Alternatively, OSU-BUCK outputs of values, BF and CF volumes for logs (by length and diameters) could permit development of a regression-based relationship. Additional "as-bucked" comparisons with optimal solutions for the COMBO set of log lengths would give an indication if field computer solutions are warranted. A heuristic based combinatorial analysis could provide insight to how a set of lengths (i.e., a three log, distinct length solution results in 6 possible patterns) should be allocated for a stem and sample of stems (consistency).

Summary

This research suggests an approach by which forest managers may improve bucking decisions and realized value from their timber. Additionally, mill managers may benefit from the creation of mill desirable lengths with reduced variability in delivered lengths. Log allocation demand may be matched with cutting patterns to stands for improved supply chain management. Logging contractors may be able to maintain or lower logging costs. Log marketers may develop $ per Ccf log pricing from $ per Mbf quotes.

Constraining allowable bucking lengths reduces the total value recovered from harvested stems. Cutting only 16- or 20-foot log lengths achieves only about 72 percent of the optimal value achieved when any log length is acceptable under a cubic foot basis. This low percentage is strongly related to the short log pricing structure.

Prices for logs shorter than 24-feet were 77 percent of 40-foot log prices, 80 percent of 32 and 36-foot log prices. OSU-BUCK maximized the length of recovered sawlog material under the CF analysis basis.

Cubic volume based log values converted by a BF/CF ratio appeared to value a given set of logs similarly as by the board foot values which they were generated for a thinning aged stand. This did not hold true for the single BF/CF value trial in an older stand. Care must be taken in widely applying a singular conversion value, especially involving 16- and 20-foot log lengths. Monitoring the resulting BF/CF ratio allows one to know if log valuations are amiss in the absence of independent CF log values.

The OSU-BUCK CF based solution approach is preferable to the BF based solution approach in its ability to minimize short logs, generate an acceptable percentage of preferred long logs without artificial price adjusters, and allocate more of the merchantable stem.

Bucking improvements are possible without computer assistance. Bucking log lengths that maximize recovered log length to the merchantable top diameter is an easily implemented solution. While not necessary when bucking on a CF basis, attention to Scribner diameter-length breakpoints is required when bucking on a BF basis, especially in young, thinning aged stands.

The strategy of bucked log lengths equal to combinations of 16- and 20-foot lengths, corresponding to 32-, 36-, and 40-foot woods-length logs achieved 96 to 98 percent of the CF based optimal value with allowable log lengths from 12 to 40 feet for the stands studied. This solution also had the lowest log count, an important factor in controlling logging costs. Strategies that limit allowable log lengths to a combination of a long log(s) and a short log simplify the analysis and actual bucking implementation. However, this is achieved at a cost of reduced sawlog recovery, in terms of length and volume. These other strategies also increase the number of logs to be yarded. These observations apply to 50-tree samples of two Douglas-fir stands. Additional approaches to developing a BF/CF ratio and analysis of other sample stands are suggested.

Targeted Journal: Forest Products Journal

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CHAPTER 4: DEVELOPMENT OF EFFICIENT CUTTING PATTERNS TO MAXIMIZE VALUE WITH A LOG ALLOCATION CONSTRAINT

Introduction

Cross cutting trees into logs (log bucking) is the first stage in product manufacture and thus sets the limits for downstream processing. Thus, log bucking has great influence on the value of the tree and subsequent wood products. Rules guiding tree bucking are divided into two groups: bucking-to-value and bucking-to-demand. In bucking-to-value (Nasberg, 1985; Sessions et al., 1989a; Nybakk et al., 2007), the objective is to divide the tree(s) into the most valuable combination of logs guided by a table of prices often described by a combination of length, diameter, taper, and surface quality. In bucking-to-demand (Mendoza and Bare, 1986; Murphy et al., 2004; Nordmark, 2005; Kivinen 2007), the objective is to divide the tree into the combination of logs that most closely fits a customer's order.

Bucking-to-value assumes that log prices explicitly reflect customer demand, where as bucking-to-demand infers an implicit set of prices without a specific set of prices. In the Pacific Northwest, a combined approach is often used. The customer will pay according to an agreed upon price list subject to the requirement that a minimum percentage of the logs purchased must be in logs greater than a specified minimum length (bucking-to-value with length constraint). From the landowner's point of view, the objective becomes how to fulfill the customer's order while maximizing the value of the logs produced.

To achieve bucking-to-value with a length constraint, the most common procedure is to use empirical rules developed from experience. Three other approaches to bucking-to-value with a length constraint have been used or proposed. One approach is to adjust the price table to find a set of prices that result in a log mix satisfying the length constraint (Sessions et al., 1989b; Pickens et al., 1997). In the price adjustment method, a set of pseudo prices is determined by experimentation on a sample of the trees. Then, during field implementation, the bucking of each tree is determined by a real time solution based on the specific measurements of the tree. A second approach is to solve the stand bucking problem as a mixed integer mathematical programming problem to develop a set of optimal tree bucking prescriptions to apply to the various trees expected in the stand (Eng and Daellenbach, 1985). In the mixed integer mathematical programming approach, a set of bucking prescriptions is developed. Then, during field implementation, the actual tree measurements are matched to the database used by the mixed integer program to identify the bucking prescription for the tree most closely matching that used in mixed integer program. A third approach is to use a heuristic method (TABU Search) to develop a set of cutting instructions concerning the sequence of logs to be cut from a tree based on a priority list (Laroze and Greber, 1997).

Each of the three methods has limitations. The price adjustment method requires a real-time computer solution in the field for each tree. The mixed integer method requires the cutting crew to match a complex bucking pattern to the tree from a complex table. Marshall et al. (2006) observed that such solutions are not particularly practical due to large number of cutting instructions and difficulty implementing with stem classes at the stand level. The cutting instructions from a priority list offers ease of use, but examination of cutting patterns by Pilkerton et al. (1988) failed to identify a set of priority patterns under Pacific Northwest operating conditions. However, Pilkerton and Kellogg (20xxb) showed a reduced set of five log lengths could achieve solutions better than current unaided bucking practices.

The objective of this research is to develop a fourth approach to bucking-to-value with a length constraint that would (a) be operationally less expensive to implement in the field than price guided individual tree optimization at the tree stump, (b) would markedly reduce the number of bucking patterns a faller would need to know, and (c) would not rely on a priority list for implementation. The operational setting is on steep, rugged terrain in the mountainous Pacific Northwest in situations where log making is done manually at the stump area by chainsaw because mechanized harvesting is not possible and under silvicultural treatments that preclude use of tree length yarding followed by mechanized processing on the landing due to concerns of residual stand damage.

Research Questions

1) What type of decision tool can be developed for field implementation that does not require an in-field computer?
2) How does solution quality and cost compare to an actual field experience?

Research Approach

The approach taken in this research is to develop a set of bucking prescriptions that a faller could use in the field through reference to a cutting card based upon tree height to a merchantable top diameter. To develop the cutting card, a sample of trees will be analyzed and the best bucking pattern determined for each tree. To maintain ease of implementation a set of bucking patterns will be restricted to combinations of preferred lengths demanded by customers. The quality of the solution will be measured against two criteria (1) the difference between what fallers actually did under current empirical guidelines and (2) the difference in stand value due to restriction of bucking patterns to “preferred” lengths versus “all acceptable” lengths. To test the ability of the algorithm to find high quality solutions, the algorithm will first be applied to an unconstrained problem where the minimum length restriction is not used. The global optimal solution for the unconstrained log bucking problem can be easily determined and quickly solved through dynamic programming using the methods demonstrated by Pnevmaticos and Mann (1972) and Sessions et al. (1989a). The constrained log bucking problem is a more complicated and more time-consuming mathematical programming problem.

Mathematical Model

The objective function is to maximize the profit to a landowner of a stand of trees subject to the demand constraint that a specified proportion of the volume must satisfy a length constraint. The decision variable in the problem is to determine the bucking pattern to be applied to each tree. The model formulation is

Maximize:

$$\Sigma_{p,i}\ \pi_{pi}\, y_{pi}$$

Subject to:

$$\Sigma_{p,i}\ v^{l}_{pi}\, y_{pi} \ /\ \Sigma_{p,i}\ v^{t}_{pi}\, y_{pi} \geq R^{l}$$

$$\Sigma_{p}\ y_{pi} = 1 \qquad \text{for all i}$$

$$y_{pi} = \{0, 1\} \qquad \text{for all p, i}$$

where

π_{pi} = tree value from bucking pattern *p* applied to tree *i*

y_{pi} = binary variable associated bucking pattern *p* applied to tree *i*

v^{l}_{pi} = volume in long logs resulting from applying bucking pattern *p* applied to tree *i*

v^{t}_{pi} = total volume resulting from applying bucking pattern *p* applied to tree *i*

R^{l} = required minimum percent of volume in logs exceeding a minimum length

Solution Method

The number of potential prescriptions for each tree grows exponentially with tree height, making solution times by normal mixed integer programming infeasible. For example, the number of ways a 40-foot log can be divided into lengths of 8 to 20 feet in 2-foot multiples is 73. The number of ways a 56-foot log can be divided into lengths of 8 to 20 feet is 814. To solve large mixed integer problems a number of heuristic methods have been developed. Three main lines of heuristic algorithms are stochastic neighborhood search including simulated annealing and threshold accepting, TABU search, and evolutionary algorithms including genetic algorithms (Reeves, 1993). All three methods have demonstrated the ability to find high quality solutions to combinatorial problems (Reeves, 1993; Glover and Kochenberger, 2003). The research uses a variant of simulated annealing especially developed for this problem. A goal programming objective function is used to guide the search where the objective function of maximizing stand value subject to length constraint is replaced with maximizing stand value minus the squared deviations between the target length constraint and the actual achievement. This revised objective function is somewhat similar to Lagrange's method for solving constrained optimization problems. In the Lagrange method, the constraints are moved up into the objective function where λ_i represents the shadow price, or marginal cost of relaxing the constraint *i*. The exponent has been used to keep all deviations positive as well as to express the decision maker's value system that larger deviations from the length goal are to be exponentially penalized as compared to small deviations from the goal. The problem formulation becomes:

Maximize:

$$\Sigma_{p,i} \; \pi_{pi} y_{pi} - \lambda(R^l - \Sigma_{p,i} \; v^l_{pi} y_{pi} / \Sigma_{p,i} \; v^t_{pi} y_{pi})^2$$

Subject to:

$$\Sigma_p \; y_{pi} = 1 \qquad \text{for all i}$$

$$y_{pi} = \{0, 1\} \qquad \text{for all p, i}$$

where

π_{pi} = tree value from bucking pattern *p* applied to tree *i*

y_{pi} = binary variable associated bucking pattern *p* applied to tree *i*

v^{l}_{pi} = long log volume resulting from applying bucking pattern *p* applied to tree *i*

v^{t}_{pi} = total volume resulting from applying bucking pattern *p* applied to tree *i*

R^{l} = required minimum percent of volume in logs exceeding a minimum length

λ = a penalty on the deviations from the volume length goal

The goal programming approach has worked well in other applications. The standard simulated annealing heuristic is a stochastic neighborhood search where a trial move is defined as changing the bucking pattern of one tree while holding all other trees at their current solution. If the trial move improves the value of the objective function the move is accepted (Figure 4.1), if the trial move does not improve the value of the objective function it may be accepted subject to a probability function. The purpose of accepting non-improving moves is to avoid being trapped in local optima. The probability acceptance function is arbitrary, but experience has shown that it should have the property of accepting larger disimprovements early in the solution process and smaller disimprovements later in the solution process. Accepting larger disimprovements early in the solution process makes the solution procedure independent of the starting solution.

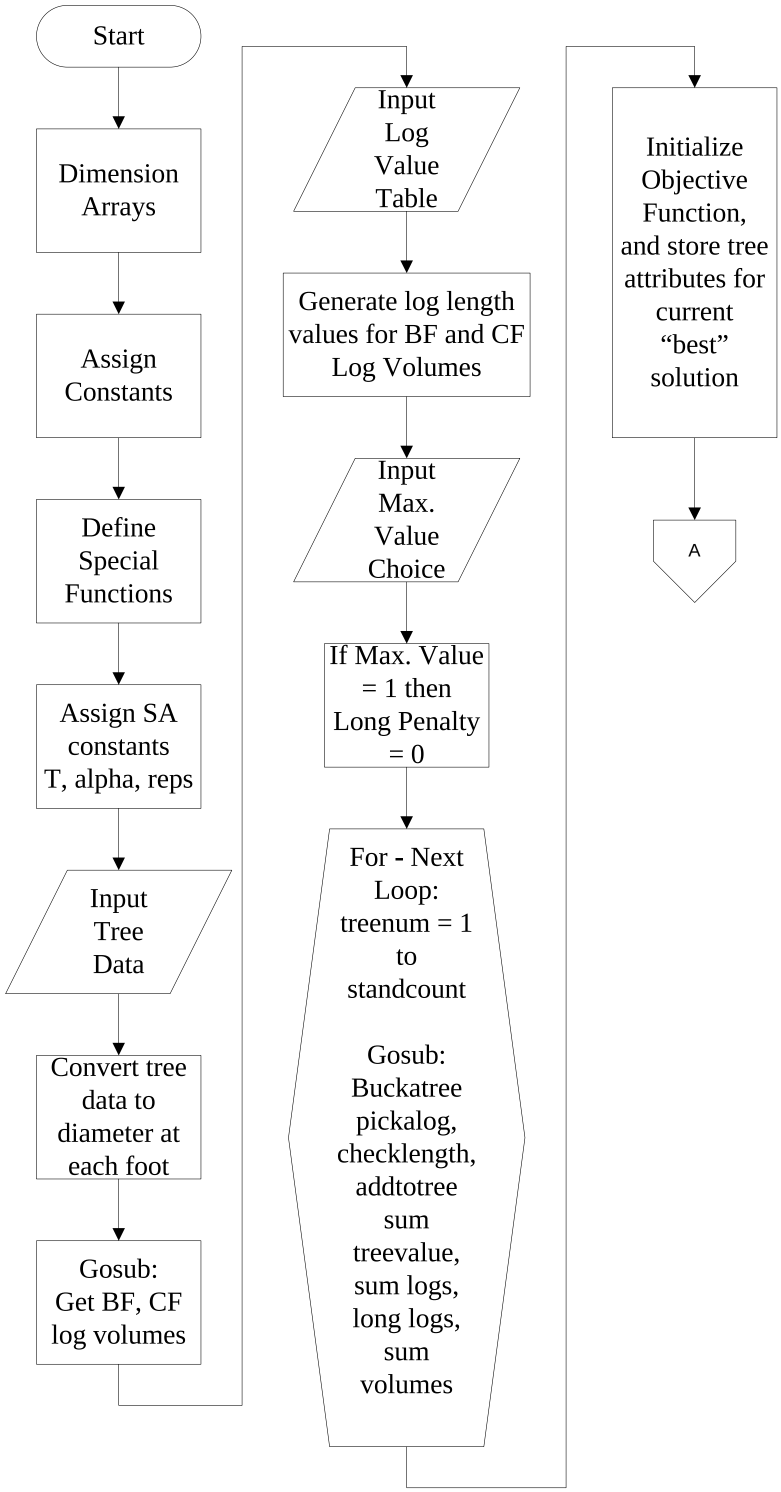

Figure 4.1. Flowchart for Simulated Annealing algorithm (p. 1 / 3).

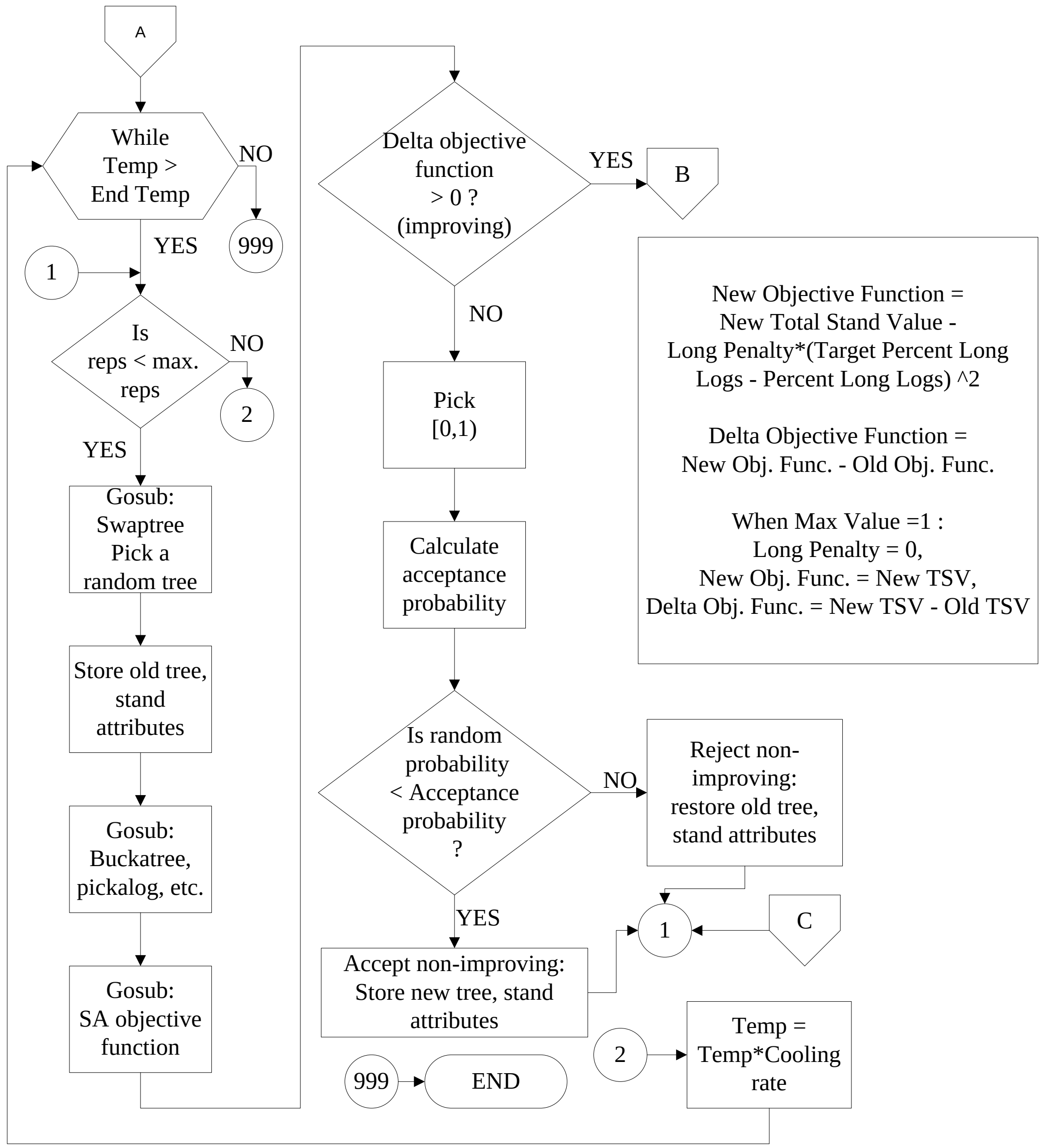

Figure 4.1: Flowchart for Simulated Annealing algorithm (Continued, p. 2 / 3).

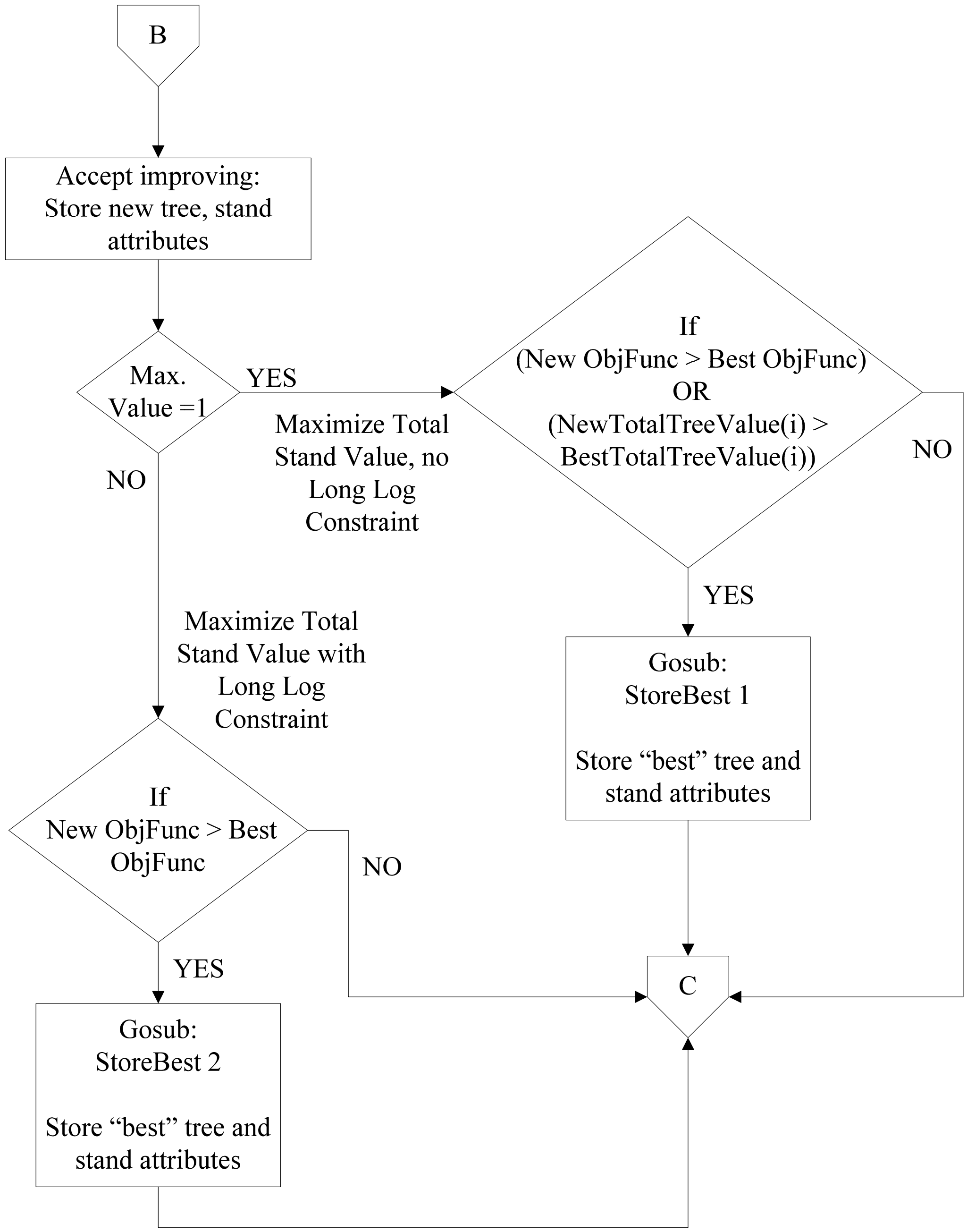

Figure 4.1: Flowchart for Simulated Annealing algorithm (Continued, p. 3 / 3).

The length of search is determined through the “cooling” schedule, which is controlled by several parameters known as the beginning “temperature”, the number of repetitions at each temperature, the ending temperature, and a temperature reduction factor that is often a geometric multiplier of the current temperature. The term “cooling schedule” is derived from the analogy of cooling molten metal from a high temperature to a low energy state with occasional “reheating” of the metal that is analogous to accepting disimprovements during the solution process. For example, for a beginning temperature (t_1) of 1000 “degrees” , an ending temperature (t_2) of 10 “degrees”, a repetition (*n*) at each temperature of 200 moves, and a geometric reduction factor (*r*) of 0.99 will result in approximately 91,642 potential moves during the solution process where the number of moves N is calculated as

$$N = n \ln (t_2/t_1) / \ln r.$$

In this research the probability acceptance function (P) was specified as

$$P = e^{(\Delta \text{ obj} / \text{t})}$$

where Δobj is the change in the objective function value associated with a trial change of bucking pattern *p* for tree *i* and *t* is the current temperature.

During initial testing of the standard simulated annealing algorithm in this research, a modified algorithm was developed that could reach convergence on a high quality solution for the unconstrained maximum value more quickly than the standard algorithm through incorporating a memory function and interaction between the best solution found to date during the solution process and the current solution (Figure 4.1).

Application

Stand Description

The modified simulated annealing heuristic was applied to two sample sets of 50 second-growth Douglas-fir (Pseudotsuga menziesii) trees. Stand 1 was a 45-year old stand and Stand 2 was a 65-year old stand. Stand 1 trees were located in the Oregon Cascade Range foothills, on the Oakridge Ranger District (Kellogg et al., 1998). Stand 2 trees were located on Starker Forest land east of Alsea, Oregon. The 45-year old stand represents a thinning aged stand and the cut tree size is similar to stands modeled in Chapter 2 (Pilkerton and Kellogg, 20xxa). The 65-year-old stand can be considered as either a regeneration harvest or a last thinning on stands projected for development of older forest characteristics.

The 50 sample trees (Table 4.1) were measured after felling/bucking and prior to yarding in each stand. Inside bark diameters at the butt and bucked log faces were measured to the nearest 0.1 inch. Lengths were measured (nearest 0.1 foot) at bucking cuts and to the total top.

Table 4.1. Tree height and diameter statistics for 50 sample trees for the two stands.

	Butt Diameter (inside bark, inches)		Height, Merch. Top (feet)		Top Diameter (inside bark, inches)		Volume (cubic ft.)
Stand	Average	Stand. Dev.	Average	Stand. Dev.	Average	Stand. Dev.	Average
1	9.9	2.1	73.4	9.7	2.1	n/a	23
2	18.4	5.0	101.8	19.6	8.6	n/a	123

Bucking Prescriptions

Two sets of bucking prescriptions were considered. The first set of bucking patterns comprised all log lengths (ALL) accepted by customers. The second set was a subset of the all log lengths (COMBO) suggested by research in Chapter 3. This subset of log lengths represent two preferred mill-length logs; 16 and 20 feet and three other lengths that are combinations of these two mill-lengths that may be bucked as woods-lengths of 32, 36, and 40 feet. The 16 and 20-foot lengths provide short log opportunities to increase utilization of the stem. These five lengths allow for bucking points at every 4 feet along a stem whose length is greater than or equal to 48 feet. Board foot volumes were derived from Scribner volume tables (NLRAG 1995). Cubic foot volumes were calculated using Smalian's formula, modified per NLRAG (1995).

Price Table

A log purchase order representative of Willamette Valley region mills with respect to acceptable lengths, preferred lengths, and log prices was used (Table 4.2).

Table 4.2. Log prices used in OSU-BUCK and simulated annealing programs for board foot and cubic foot based analysis. Sawlogs (to 5-inch diameter inside bark).

		Stand 1	Stand 2
Scaling Length	$ per Mbf	$ per Ccf	$ per Ccf
38 - 40	650.00	236.60	315.25
30 – 36	620.00	225.70	300.70
24 – 28	575.00	209.30	278.88
16 – 22	500.00	182.00	242.50
12 – 14	400.00	145.60	194.00
8	200.00	72.80	97.00

Solution Results and Discussion

The modified simulated annealing heuristic was run for the sample data from each stand. In order to test the ability of the heuristic to find high quality solutions, the heuristic was first run without the length constraint and compared to the known optimal solution (Table 4.3) using dynamic programming (OSU-BUCK; Sessions et al., 1993). Then the heuristic was run for each stand using all acceptable log lengths (ALL) and for the restricted set of log lengths (COMBO).

For the unconstrained objective of maximizing value without minimum percent long log requirement, the heuristic achieved 100 percent of the OSU-BUCK derived optimal solution for the 50 trees in Stands 1 and 2 (Table 4.3) with one minor exception (99.93 percent of optimal) where three trees had different and suboptimal patterns. These results suggest the heuristic program is computationally correct and that it can provide high quality solutions. The use of the COMBO log set decreases the number of logs, maintains or increases the percent of long logs, and reduces the number of log patterns compared to results with the acceptable full set of lengths.

For the constrained case where 80 percent of the volume must be in lengths greater than or equal to 36 feet, the difference in value for Stand 2 between the length constrained case and the unconstrained case is only $251 (1.3 percent, or $5.02 per tree) for the “ALL logs” analysis (Table 4.4). The restricted log set (COMBO) has a value $122 less than the ALL logs in meeting the 80 percent volume target. The differences for Stand 1 are smaller for both allowable length scenarios. This is likely due to the presence of alternative optimal or near optimal tree solutions that allow for the attainment of long logs with little loss of value.

Table 4.3. Summary stand values for OSU-BUCK and modified simulated annealing heuristic (SA) unconstrained analyses. Stands 1 and 2, board foot, cubic foot ALL lengths, and cubic foot COMBO lengths modeled.

Stand	Analysis Modeled	Total Value ($)	Logs (#)	Long Logs (#)	Patterns (#)
1	OSU-BUCK, BF, All	2466	92	16	n/a
1	SA, BF, All	2466	89	17	34
1	OSU-BUCK, CF, All	2346*	77	36	n/a
1	SA, CF, All	2339*	78	37	27
1	OSU-BUCK, CF, Combo	2262*	72	38	n/a
1	SA, CF, Combo	2259*	74	36	12
2	OSU-BUCK, BF, All	18768	157	60	n/a
2	SA, BF, All	18754	157	62	44
2	OSU-BUCK, CF, All	19134**	144	82	n/a
2	SA, CF, All	19135**	144	84	39
2	OSU-BUCK, CF, Combo	18776**	143	86	n/a
2	SA, CF, Combo	18777**	142	89	25

Footnote 1*. 2346 vs. 2339, 2262 vs. 2259: Analysis of individual tree results shows tree solutions having logs with same length and diameters with OSU-BUCK values $1.00 greater than simulated annealing due to rounding to the nearest $1.00 and cubic foot volume differences at the 0.01 precision. Adjusted total values are identical. The remainder of this manuscript will report the $2339 and $2259 values as 100 percent of optimal for comparatives with other simulated annealing derived results.

Footnote 2**. Stand 2 OSU-BUCK values less than simulated annealing results due to rounding on one log value.

Table 4.4. Effect of 80 percent long log constraint on total value of 50 trees. Stands 1 and 2, Cubic Foot analysis, ALL lengths and COMBO lengths modeled.

	Total Value for 50 trees			
	CF - All Lengths		CF-Combo Lengths	
Stand	Max $	Max $ 80% Long	Max $	Max $ 80% Long
1	2339	2328	2259	2242
2	19135	18884	18777	18762

Board foot analysis is included in Table 4.5 to highlight the known Scribner volume effect. The Scribner volume table creates a disincentive to long log creation unless value premiums for longer logs exceed volume gains that increase total value of the stem, especially in small diameter logs associated with thinning. The Scribner volume table used by Pacific Northwest log scaling bureaus was last revised July 1, 1972 (NLRAG, 1995).

Table 4.5. Percent long logs (by volume) under maximum value (unconstrained) for 50 trees. Stands 1 and 2, Cubic Foot analysis, ALL lengths and COMBO lengths modeled.

	Percent Long Logs (by volume)		
Stand	CF - All Lengths	CF-Combo Lengths	BF – All Lengths
1	63.3	62.3	26.3
2	72.3	77.0	51.0

Sensitivity Analysis

The choice of the long penalty factor, λ, affected the quality of the solution. Too large a penalty (1000) resulted in a failure to close in on an acceptable “best” total stand value (Table 4.6). Too small a penalty factor resulted in a lower than acceptable percent of long logs (Table 4.7). For Stand 2, a $6.00 difference in total stand value (0.03 percent) for long log percentages meeting 80 percent criteria (within +/- 0.5 percent) for penalty factors 6 to 10. Although the decision variables are integer, the rough interpretation of the penalty value near the point where the constraint is exactly met is that the penalty value represents the shadow price, or change in the stand value for a unit change (.01) in the long log constraint. Thus we see an increase in stand value of about $6 for a reduction in percentage of long logs from 79.8 to 79.5 when

λ ~$10. The interpretation would be more transparent if the squared deviations were not used.

Table 4.6. Heuristic sensitivity analysis on Stand 1 value and percent long logs to "long log penalty", λ. COMBO-based bucking approach, cubic foot basis.

Long Log Penalty Factor, λ	Long Logs (% by Vol)	Total Value ($)	Total Logs (#)	Total Long Logs (#)	Total Patterns (#)
1	79.0	2247	71	42	12
10	80.0	2239	70	43	12
100	80.1	2225	69	43	11
1000	66.5	2041	74	33	16

Table 4.7. Heuristic sensitivity analysis on Stand 2 value and percent long logs to "long log penalty", λ. COMBO-based bucking approach, cubic foot basis, 80 percent target.

Long Log Penalty Factor	Long Logs (% by Vol)	Total Value ($)
1	77.3	18776
2	78.1	18772
3	79.4	18765
4	79.4	18765
5	79.4	18764
6	79.6	18759
7	79.2	18758
8	79.2	18761
9	79.5	18762
10	79.8	18756

Earlier in the paper the number of moves in the simulated annealing heuristic was estimated as $N = n \ln (t_2/t_1) / \ln r$. All runs were started at t_1=100,000 degrees, n=5000, and r =.995 and t_2 = 10000 degrees so the number of potential moves were approximately 3.0 million. At 5000 potential changes of bucking pattern per temperature change, each of the 50 trees had, on average, the opportunity to change bucking patterns 100 times per temperature change. With Stand 1 the best solution was reached earlier than with Stand 2 (Table 4.8). This is attributed to the shorter length trees in Stand 1. Solutions in Stand 1 generally had two logs while in Stand 2 the trees had three and four logs. With restricted bucking patterns, COMBO reached "best" solutions very quickly – within the first 5000 trial solutions for Stand 1. It does appear the shorter trees of stand 1, combined with the reduced COMBO set of lengths, creates additional effort in achieving the 80 percent constraint. The "ALL length" unconstrained analyses for Stand 2 needed over two million trial moves to identify the "best" solution for both board foot and cubic foot volume basis.

Table 4.8. Heuristic computing "effort" as represented by number of moves to reach "best" solution for the heuristic analysis. Stands 1 and 2, five analysis approaches modeled.

Stand	Analysis Modeled	Moves to "Best" Solution
1	Cubic Foot, All Lengths	33,453
1	Cubic Foot, Combo	2,181
1	Board Foot, All Lengths	17,176
1	Cubic Foot, All, 80 % Long	5,873,593
1	Cubic Foot, Combo, 80 %	4,702,846
2	Cubic Foot, All Lengths	2,688,574
2	Cubic Foot, Combo	43,610
2	Board Foot, All Lengths	2,958,547
2	Cubic Foot, All, 80 % Long	6,208,442
2	Cubic Foot, Combo, 80 %	4,670,663

Cubic foot volume was the metric used to calculate the percent of long logs in the SA analysis. Table 4.9 presents average values for percent long logs based on log values, board foot volume, cubic foot volume, and log count. Computationally they are all easily determined. Mill purchase orders typically are on a volume basis. The seller or buyer cannot easily determine percent by value. Percent by log count would be the easiest computationally; however, this would require the faller to tally the total number of logs cut as well as the number of long logs.

Table 4.9. Comparison of percentage relationships for value, board foot volume, cubic foot volume, and log count under a long log 80 percent (CF volume basis) criterion. Stands 1 and 2.

Stand	Percent Value	Percent BF Vol.	Percent CF Vol.	Percent Log Count
1	82.2	78.6	80.0	56.7
2	81.2	79.4	79.4	62.3

Field Implementation

Use of the COMBO approach decreases the number of logs, maintains or increases the percent of long logs, and reduces the number of log patterns. The cost of using the COMBO approach, compared to optimal allocation using all lengths is shown as a negative value change (cost) per tree (Table 4.10). However, to attain this using a handheld computer, labor costs would increase; approaching $4.00 to $6.00 per tree for stands 1 and 2, respectively (Olsen et al., 1991). Use of the COMBO approach, with a cutting card, would save $2.28 and $3.56 in labor cost per tree over the handheld approach to obtain the values for solutions based on all lengths.

Table 4.11 compares the faller’s actual unaided field bucking solution, termed “As-Bucked”, with the COMBO approach under the 80 percent long log (by volume) mill order constraint. The COMBO approach improves the Stand 2 value of the 50 trees by $168.00, or $3.36 per tree ($2.73 / Ccf).

Table 4.10. Comparison of bucking strategy on total logs, long logs, and patterns (maximum value analysis). Stands 1 and 2, 50 trees, Board Foot and Cubic Foot analysis, ALL lengths and COMBO lengths modeled.

Stand	Analysis Modeled	Logs (#)	Long Logs (#)	Patterns (#)	Value ($)	Value Change ($ / tree)
1	Cubic Foot, All, 80% Long	77	44	22	2328	------
1	CF, COMBO, 80% Long	71	43	11	2242	-1.72
2	Cubic Foot, All, 80% Long	145	91	41	18884	------
2	CF, COMBO, 80% Long	141	91	22	18762	-2.44

Table 4.11. Comparison of current bucking "As-Bucked" and SA COMBO methodology approach for 50 trees with 80 percent long log constraint - Stand 2.

	Long Logs (% by Vol)	Total Value ($)	Value Increase (%)	Increase per tree ($)
As-Bucked	80	18594	-----	-----
COMBO	80	18762	0.9	3.36

As-Bucked solutions can exceed 90 percent long logs due to the simplistic approach of cutting mill preferred 40-foot logs. A modeled run targeting 90 percent long logs to simulate this resulted in $18,552 total value. The COMBO approach increases value by 1.1 percent or $4.20 per tree compared to the As-Bucked approach. The faller in Stand 1 only achieved 60 percent long logs. The COMBO approach, with 80 percent long logs, still improved recovery by $30 for the 50 trees, or $0.60 per tree over the As-Bucked solution. Using the COMBO cutting card approach can increase value for stand 1 by $2.61 per Ccf and from $2.73 to $3.41 per Ccf for stand 2 depending on the percentage of long logs achieved.

Achieving the COMBO approach will require the use of a cutting card indicating the log length pattern for a given total length to the merchantable top diameter (Table 4.12). The table also summarizes the frequency of the selected pattern(s) for a given length. Multiple pattern choices (i.e., lengths 58-61) give the user an option for alternative pattern(s) in the event the stem has a defect or obvious quality characteristic that suggests avoiding the primary pattern (41-17, for 58-foot tree).

A concern or potential criticism of the COMBO approach is the lack of potential bucking points at every foot along the tree. Stem bucking points to 160 feet height (four 40-foot logs) covered by COMBO lengths (trim excluded) are: 16, 20, 32, 36, 40, 48, 52, 56, 60, 64, 68...164. For heights greater than 48 feet (51 feet with trim allowance), bucking points occur at every 4 feet under the COMBO approach. At most, this will result in a “wasting” of 3 feet of merchantable diameter wood.

Current log purchaser cutting cards effectively reinforce the preferred lengths, especially long logs. In practice, a faller will cut 40-foot logs until he reaches the top length and cuts a remainder length. A worse case is the faller cuts a 40-foot log then discovers a defect or breakage within a distance less than the minimum log length, resulting in lost volume and value in a non-sawlog destined for the chip market or down woody debris.

Table 4.12. Sample of COMBO Pattern Cutting card developed from Stand 1 analysis under 80 percent long log criterion.

Length Range (feet)	Length Pattern (log length with trim)	Results of COMBO analysis (#) = frequency pattern used
17 – 20	17	0*
21 – 32	21	5
33 – 36	33	1
37 – 40	37	4
41 – 49	41	19
50 – 53	33-17	2
54 – 57	37-17	2
58 – 61	41-17, 37-21	(6), (1)
62 – 65	41-21	8
66 – 69	33-33	0*
70 – 73	33-37, 37-33	(1), (0)
74 – 77	37-37, 41-33	0*
78 – 81	41-37	1
82 – 87	41-41	0*

0* indicates no trees required this pattern, included for completeness of the lookup table

1 log solutions end with 41 feet
2 log solutions end with 82 feet
2 log solutions begin with 34 feet (17 - 17)
2 log solutions, minimum 1 long log, begin with 54 feet (37 - 17)
3 log solutions begin with 51 feet (17 - 17 - 17)
3 log solutions, minimum 1 long log, begin with 71 feet (37 - 17 - 17)

The suggested COMBO length based cutting card will provide the faller with a decision tool created from analysis of the complex relationships between log prices, stem forms, log volume, and purchase order criteria. The card provides a stronger decision tool which is simple to use, reinforces the need to walk the stem prior to bucking, and generates mill preferred lengths and long logs.

Future Analysis

This heuristic approach depends on sample tree data to calculate the cutting patterns resulting from mill price data. The datasets used in this analysis were gathered from felled trees. Of interest would be the effectiveness of tree data either gathered from simple cruising techniques or from the recently developed ground based LiDAR stem imaging system (Murphy, 2008).

The COMBO set of 16, 20, 32, 36, and 40 is based on a regional preference for these lengths. Individual mills may have alternate lengths consisting of one or more short (mill length) logs that create woods length logs. Development of COMBO cutting cards for alternative lengths would be an extension of this research.

There has been interest in log lengths in excess of the 40-foot scaling segment up to 56 feet. While lengths between 41 and 49 are not compatible with the COMBO set, lengths of 50 and 54 are in the set. A log length of 58-feet has multiple COMBO patterns. Use of Cab Over Engine truck tractors could accommodate 58-foot logs under current highway rules on designated routes.

This study limited reported patterns to the first three log lengths, independent of solutions with four logs, which occurred on approximately 10 percent of the stems in Stand 2. Analysis of volume and value by log position in four log length stems would determine if increasing pattern size is beneficial.

The objective function in this study considered logging costs as constant regardless of log mix. Logging costs per unit volume are usually lower for larger logs. If logging cost information is available by log size, it could be easy accommodated in the value coefficient for each bucking pattern.

The analysis here examined the usefulness of the heuristic in developing cutting cards based on two stands and time and cost reports from the literature. An actual field implementation of this methodology for verification and / or adjustments is a next step.

Summary

The modified simulated annealing heuristic as developed provides a useful approach for optimizing tree values for bucking-to-value (maximum value) with a purchase order constraint. The heuristic achieved 99.93 to 100 percent of the value when compared to a single-tree unconstrained optimization approach. The heuristic determined log mix achieved maximum value while generating 80 percent of the logs in preferred long logs. The use of a reduced COMBO set of log lengths comprising a combination of mill-length and woods-length logs also was evaluated. The COMBO lengths, combined with the simulated annealing heuristic, produced a set of log patterns that maximized value and met the long log constraint. As expected, the COMBO set had a lower value compared to a full set of merchantable log lengths. However, to achieve the additional value of the full set would require a field handheld computer and more of the faller's time, resulting in a lower net return compared to the COMBO cutting card approach. Moreover, the COMBO cutting card approach improved stand value compared to current bucking practices. Cutting cards developed from the COMBO approach provide the faller with a stronger yet simple decision tool for determining log lengths. The COMBO approach reduces the number of logs that a harvesting contractor has to handle, increases the number of long logs a mill prefers, delivers woods length logs that create higher value 16 and 20-foot lumber, decreases the number of log patterns a faller might consider, and increases stand value for the timber owner. The increased revenues achieved through this methodology could cover increased expenses associated with mobilization costs for multiple entries to operational sites due to seasonal closures or other costs in a dynamic economy.

Connection among the Manuscripts

The first manuscript identified opportunity costs associated with thinning harvests of public timber with seasonal harvest restrictions requiring cessation of operations. These costs, $1.00 to $2.00 per Ccf, indicate the need for cost savings or revenue improvements to offset reduction in net revenues to the logging contractor or timber purchaser. Manuscript 2 evaluated log bucking and log lengths in order to seek revenue improvements. Value improvements of about $4.00 per Ccf for similar sized trees are possible with a reduced set of log lengths. Manuscript 3 is an extension of Manuscript 2 to consider a purchase order constraint on value, develop a more efficient technique for evaluating the constraint's effect on value, and to develop cutting patterns for implementing the solution. This manuscript sought to quantify the gains that are achievable with the COMBO approach and for allocation constraints not imposed on Manuscript 2 solutions. Together these two manuscripts focus on capturing value from logs with bucking strategies in order to pay for the increased costs resulting from seasonal operating constraints as in Manuscript 1 or harvesting costs not yet encountered.

Targeted Journal: Journal of Forest Engineering

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CHAPTER 5: SUMMARY

This research was undertaken to address economic components of harvesting operations not previously studied for steep slope thinning harvests in the Douglas-fir region. On the expense side, mobilization costs associated with wildlife protection that restricted the harvest operating season were modeled for nine timber sales on the Siuslaw National Forest. These closures require the cessation of operations and relocation of yarding equipment to another site for full utilization. With respect to income, two studies were performed to evaluate the potential for developing and implementing a reduced set of log lengths that 1) optimizes revenues while meeting a purchase order objective of preferred long logs; and 2) can be easily implemented by a faller with the use of a cutting card of bucking patterns.

The first manuscript identified the opportunity cost associated with harvesting public timber under seasonal harvest restrictions requiring cessation of operations. The results of this study suggest multiple mobilization cycles are possible prior to completion of the timber sale. The cost of mobilization ranged from $1.48 to over $2.60 per Ccf for an array of sale volumes, cut tree sizes, cut trees per acre, one-way mobilization distance, and calculated production rates. This may seem small compared to total operational harvest costs of about $120 per Ccf. However, under competitive bidding, this one to two percent increase may determine the winning bidder, or if the winning bidder makes a profit. Viewed another way, a single one-way move may cost $3000 to $4000. Over the life of the timber sale, the resulting costs ranged from $7000 to $43000, depending on the number of mobilizations involved.

These results indicate the need for awareness of mobilization costs. Knowledge of these costs allows a planner, timber sale purchaser, or harvesting contractor to budget accordingly beyond the expected stump to truck harvest cost. Three potential applications of this research are: 1) logging contractors and sale planners may use mobilization cost results to develop bids and appraisals; 2) sale planners can plan timber sale size to minimize the number of entry cycles or approach the upper limit of an entry cycle; that is, keep required number of yarding days within an integer number of years so that an additional entry cycle is not required for a short period to finalize harvest; and 3) this approach may provide others with a method to quantify mobilization costs in general. Finally, the results suggest cost savings or revenue improvements should be sought to offset reduction in net revenues to the logging contractor or timber purchaser.

The second manuscript developed an approach to evaluate log bucking and log lengths in order to improve revenues. Two stands were analyzed using a single stem optimizer (OSU-BUCK). Stand ages were 45 and 65 years. A reduced set of allowable log lengths from all mill acceptable log lengths was identified. The reduced set included two mill-lengths (16 and 20-feet) and three woods-lengths resulting from combinations of the first two (32, 36, and 40-feet). Compared to the unaided field bucking approach, value improvement results were about $4.00 per Ccf for the 45 year old stand and $8.80 per Ccf, over $10.00 per tree, for the 65 year old stand. The values obtained with the reduced set of lengths were 96 to 98 percent of the value for the full set of lengths. To achieve the full value would require the use of a handheld computer in the field at the time of bucking. This would require additional time, expense, and expertise.

The reduced set of lengths resulted in the lowest log count, an important factor in controlling logging costs. An additional result of the reduced set of log lengths was the development of a decision tool, a simple cutting card to identify the pattern(s) for a given length to a merchantable top diameter. The reduced set of log lengths achieved 67 and 75 percent of the volume in preferred long logs for stands 1 and 2, respectively. A typical purchase order requirement is for 80 percent of the volume to be in preferred long logs. Thus, the value increases shown above would be reduced from the optimal to meet the constraint. The single stem optimizer can be used to determine the set of patterns that optimizes value and meets the constraint. However, the process can be inefficient. Full implementation requires the patterns for the cutting card approach optimize the value and meet the constraint.

The third manuscript addressed the need for meeting a log purchase order constraint. A modified Simulated Annealing (SA) heuristic was developed to address the mill purchase order constraint of a minimum volume of preferred lengths and provide a more efficient process for identifying the set of patterns for the cutting card. The identified reduced set of lengths (16, 20, 32, 36, and 40-feet) was implemented on the two stands evaluated in the second study.

The modified SA heuristic as developed provides a useful approach for optimizing tree values to solve the bucking-to-value (maximum value) problem with a log allocation constraint. The heuristic achieved 99.93 to 100 percent of the value when compared to a single-tree unconstrained optimization approach. The heuristic determined log mix achieved maximum value while generating 80 percent of the logs in preferred long logs using the reduced set of log lengths. Compared to the unaided field bucking solutions, a SA generated bucking solutions improved stand 2 value by $3.36 per tree or $2.73 per Ccf while meeting the 80 percent long log volume constraint. The set of patterns was easily incorporated into a cutting card showing the pattern(s) for a given length to a merchantable top diameter. This cutting card approach improved stand value compared to current bucking practices. Cutting cards developed from this approach provide the faller with a stronger yet simple decision tool for determining log lengths. This approach reduces the number of logs that a harvesting contractor has to handle, increases the number of long logs a mill prefers, delivers woods length logs that create higher value 16 and 20-foot lumber, decreases the number of log patterns a faller might consider, and increases stand value for the timber owner. The increased revenues, $2.73 per Ccf, achieved through this methodology could cover increased expenses associated with the first study's mobilization costs, $1.50 to 2.60 per Ccf, for multiple entries to operational sites due to seasonal closures or other costs incurred in thinning steep slope Douglas-fir forests.

Suggestions for Future Research

This heuristic approach depends on sample tree data to calculate the cutting patterns resulting from mill price data. The datasets used in this analysis were gathered from felled trees. Of interest would be the effectiveness of tree data either gathered from simple cruising techniques or from the recently developed ground based LiDAR stem imaging system.

The reduced set of 16, 20, 32, 36, and 40 feet bucking lengths was based on a regional preference for these lengths. Individual mills may have alternate lengths consisting of one or more short (mill length) logs that create woods length logs. Development of cutting cards for alternative lengths would be an extension of this research. There has been interest in bucking log lengths in excess of the 40-foot scaling segment. Highway legal log lengths of 56 to 58-feet would provide multiple patterns and provide mills with alternative mill-lengths to the headrig while reducing the number of logs handled in the mill yard.

The analysis here examined the usefulness of the heuristic in developing cutting cards based on two stands and time and cost reports from the literature. An actual field implementation of this methodology for verification and / or adjustments is a next step.

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APPENDICES

Appendix A: Chapter Two Analysis Methodology And Numerical Example

The methodology for Manuscript 1 (Chapter 2) followed these general steps:

1) Acquire sale cruise data (cut trees per acre, average cut tree volume)
2) Determine average slope yarding distance and percent slope (topographic map, GIS) for sale area.
3) Within STHARVEST, adjust machine cost values and relevance factors for modeled harvest system.
4) Perform STHARVEST analysis. Record resulting total harvest cost and specifically yarding cost ($/Ccf).
5) Record yarding cost per Productive Machine Hour (PMH) from Cable Yarding worksheet within STHARVEST.
6) Divide $/PMH by $/Ccf to obtain production rate, Ccf / PMH.
7) Multiply by utilization rate (ratio of PMH to scheduled machine hours, SMH) to get production per SMH. A 75 percent utilization (PMH / SMH) factor is used in STHARVEST and was used in this paper.
8) Multiply by scheduled hours per day to obtain daily production (Ccf / day)
9) Divide total sale volume by daily production to determine total days required to yard the sale.
10) Divide total days by annual operating days permitted by the seasonal restriction to determine years to harvest. A resultant with a fractional year in excess of an integer requires an additional entry (mobilization) beyond the integer number of entries. For example, 2.4 years requires three yarding

seasons or mobilization cycles. Mobilizations required beyond one mobilization cycle result in opportunity costs for the restriction modeled.

11) Calculate one-way mobilization distances, travel times, and associated costs.
12) Divide total one-way mobilization cost by total sale volume to get unit cost ($/Ccf).
13) Determine the number of one-way mobilizations required for the duration of the sale and multiply this by the unit mobilization cost. This result is the total cost per unit volume.
14) This value is expandable to total dollars on a sale or annual basis.

The following numerical example illustrates the calculations:

1) Cruise data provides 147 cut trees per acre, averaging 39 cubic feet per tree.
2) Topographic data for sale units provides 40 percent slope and 650 feet AYD.
3) Within STHARVEST, enter values from 1) and 2) in Inputs& Summary worksheet, adjust machine costs (Machine Cost worksheet) and relevance factors (specific Harvest System worksheet) as necessary.
4) Perform STHARVEST analysis. Resultant values of $111.56 and $79.07 per Ccf for total and yarding costs, respectively (Inputs & Summary worksheet).
5) Yarding cost per PMH = $257.00 (Cable Yarding worksheet).
6) Divide $/PMH by $/Ccf to obtain production rate, Ccf / PMH. $257.00 / $79.07 = 3.25 Ccf per PMH.
7) Multiply production rate by utilization rate. 3.25 Ccf / PMH * 0.75 (PMH/SMH) = 2.44 Ccf per SMH.

8) Multiply result by scheduled hours per day to obtain daily production (Ccf / day). 2.44 Ccf / SMH * 9 SMH / day = 21.96 Ccf / day.

9) Divide total sale volume by daily production, 11895 Ccf / 21.96 Ccf / day = 542 days to yard the sale.

10) Divide total days by annual operating days permitted by the seasonal restriction to determine years to harvest. 542 days / 161 operating days per restricted year = 3.4 years. 3.4 years is four yarding seasons, four total mobilization cycles.

11) Calculate one-way mobilization distances, travel times, and associated costs. 38 highway miles, 3 gravel road miles, 10.6 lowboy hours at $142.00 per hour = $1505; 5.2 yarder hours at $220.00 per hour = $1144; 3.2 loader hours at $95.00 = $304; total mobilization cost = $2953.

12) Divide total one-way mobilization cost by total sale volume to get unit cost ($/Ccf). $2953 / 11895 Ccf = $ 0.25 per Ccf.

13) Determine the number of one-way mobilizations required for the duration of the sale and multiply this by the unit mobilization cost. 4 (roundtrip mobilization cycles) * 2 (one-way mobilizations per roundtrip) * $0.25 / Ccf = $2.00 / Ccf. Without restriction, one roundtrip mobilization cycle is required = 1 * 2 * $0.25 / Ccf = $0.50 / Ccf.

14) Restriction imposes cost of ($2.00 - $0.50) / Ccf = $1.50 per Ccf. For the entire sale, $1.50 / Ccf * 11895 Ccf = $17,842.50, amount required to pay for life of sale mobilizations.

Appendix B: Chapter Four Program Code

```
REM                                        Stephen Pilkerton
REM                                        PHD Manuscript 3
REM                                        1 June 2009
REM

REM   Program to implement simulated annealing algorithm on the
REM   stand bucking optimization problem, buck 50 stems for
REM   optimal value.

OPTION BASE 1


REM   dimension arrays for analysis

    PRINT "Unused Stack Space", FRE(-2)
    PRINT "Array Space", FRE(-1)
REM SLEEP

      DIM totalht(50) AS INTEGER
      DIM htmerchtop(50)  AS INTEGER

      REDIM treedistdata(50, 10) AS INTEGER: REM (treenumber,
datapoint, 1 = butt)
      REDIM treediamdata(50, 0 TO 10) AS SINGLE: REM distance-
diameter data for tree form
      REDIM treedatainputs(50) AS INTEGER
REM
REM   Use REDIM later in program for these arrays, saves array memory

REM        DIM sed(50, 0 TO 143) AS SINGLE: REM small end diameter
REM        DIM led(50, 0 TO 143) AS SINGLE: REM large end diameter

      DIM ds(50, 0 TO 143) AS INTEGER: REM small end diameter
      DIM dl(50, 0 TO 143) AS INTEGER: REM large end diameter

      REDIM bfvol(30, 40) AS INTEGER: REM lookup table for board foot
volume (diameter, length)
REM
REM   Use REDIM later in program for these arrays, saves array memory

REM        DIM cfvol(5 TO 28, 5 TO 28, 1 TO 21) AS INTEGER: REM
lookup table for cubic foot volume (led,sed,length)

      DIM lengthprice(0 TO 20) AS INTEGER: REM  lower, upper lengths
of price()
      DIM price(20) AS SINGLE: REM  price per unit volume, for
lengthprice()
      DIM logprice(40) AS SINGLE: REM log price, $ per unit volume
(Mbf,Ccf), for (length)

      DIM bflogvalue(30, 40) AS INTEGER: REM lookup table for board
foot log value (diameter, length)
```

```
REM
REM   Use REDIM later in program for these arrays, saves array memory

REM        DIM cflogvalue(5 TO 28, 5 TO 28, 21) AS INTEGER: REM
lookup table for cubic foot log value (led,sed,length)

REM        DIM pattern(5 TO 21, 1 TO 21, 1 TO 21) AS INTEGER: REM
first 3 log length pattern

      DIM logcount(50) AS INTEGER
REM        DIM oldlogcount(50) AS INTEGER
REM        DIM newlogcount(50) AS INTEGER

      DIM loglength(50, 11) AS INTEGER: REM length of lognum for
(treenum, )
      DIM oldloglength(50, 11) AS INTEGER: REM length of lognum for
(treenum, )
      DIM newloglength(50, 11) AS INTEGER: REM length of lognum for
(treenum, )

      DIM logvalue(50, 11) AS INTEGER: REM value of (treenum,lognum)
      DIM oldlogvalue(50, 11) AS INTEGER: REM value of
(treenum,lognum)
      DIM newlogvalue(50, 11) AS INTEGER: REM value of
(treenum,lognum)

      DIM bflogvolume(50, 11) AS INTEGER: REM board foot volume
(treenum,lognum)
      DIM oldbflogvolume(50, 11) AS INTEGER: REM board foot volume
(treenum,lognum)
      DIM newbflogvolume(50, 11) AS INTEGER: REM board foot volume
(treenum,lognum)

      DIM cflogvolume(50, 11) AS SINGLE: REM board foot volume
(treenum,lognum)
      DIM oldcflogvolume(50, 11) AS SINGLE: REM board foot volume
(treenum,lognum)
      DIM newcflogvolume(50, 11) AS SINGLE: REM board foot volume
(treenum,lognum)

      DIM longlogcount(50) AS INTEGER
      DIM longlogvalue(50) AS INTEGER: REM value of longlogs in
(treenum,lognum)
      DIM bflonglogvolume(50) AS INTEGER: REM BF volume of longlogs
in (treenum,lognum)
      DIM cflonglogvolume(50) AS SINGLE: REM CF volume of longlogs in
(treenum,lognum)

      DIM totallengthlogs(50) AS INTEGER: REM total length of logs in
tree
      DIM totaltreevalue(50) AS INTEGER: REM total value of (treenum)
      DIM totaltreebflogvolume(50) AS INTEGER
      DIM totaltreecflogvolume(50) AS SINGLE

      DIM bestlogcount(50) AS INTEGER
```

```
      DIM bestloglength(50, 11) AS INTEGER: REM length of lognum
for treenum
      DIM bestlogvalue(50, 11) AS INTEGER: REM value of lognum in
treenum
      DIM bestbflogvolume(50, 11) AS INTEGER: REM value of lognum in
treenum
      DIM bestcflogvolume(50, 11) AS SINGLE: REM value of lognum in
treenum

      DIM bestlonglogcount(50) AS INTEGER
      DIM bestlonglogvalue(50) AS INTEGER
      DIM bestbflonglogvolume(50) AS INTEGER
      DIM bestcflonglogvolume(50) AS SINGLE

      DIM besttotallengthlogs(50) AS INTEGER
      DIM besttotaltreevalue(50) AS INTEGER
      DIM besttotaltreebflogvolume(50) AS INTEGER
      DIM besttotaltreecflogvolume(50) AS SINGLE



REM   initialize constants for analysis

      shortestlog = 8:  REM shortest allowable log length, feet

REM If combos = 1 at runtime, shortestlog is set to 16

      longestlog = 40:  REM longest allowable log length, feet
      trim = 1:         REM 1 foot of trim to scale length for total
log length
      taper = 6:        REM stem taper, 1 inch in x feet
      merchtop = 5:     REM merchantable top diameter, inch
      maxdiameter = 28: REM maximum diameter for analysis, inches
      standcount = 50: REM number of trees in stand
      targetpll = 80:   REM target percent long logs
      longlog = 36:     REM minimum log length considered a long log
      longpenalty = 10: REM penalty factor for missing target % long
logs

      bestobjfunction = -9999999

REM
REM     To standardize usage, log length = scale length + trim.
REM     scale length are in even 2-foot multiples, trim usually = 1
foot
REM

REM   define functions to be used

      DEF fnloglength : REM generate allowable log lengths in 2 foot
multiples plus trim

            fnloglength = shortestlog + (INT(((longestlog -
shortestlog) / 2 + 1) * RND) * 2) + trim
```

```
      END DEF


REM     Two End Conic Rule, cubic foot volume based on NW Log Rules
Advisory Group equation

REM        DEF fncflogvol (logled, logsed, scaleloglength, trim)

REM                fncflogvol = .005454 * (scaleloglength + trim) *
(((logsed + .7) ^ 2 + (logled + .7) ^ 2 + (logsed + .7) * (logled +
.7)) / 3)

REM        END DEF


REM     Smalian Rule, cubic foot volume,with trim and diameter
adjustments
REM     based on NW Log Rules Advisory Group equation.  OSUBUCK cubic
equation
REM     large, small end diameters are integer values of actual
diameter

      DEF fncflogvol (logled, logsed, scaleloglength, trim)

            fncflogvol = .005454 * (scaleloglength + trim) *
(((logsed + .7) ^ 2 + (logled + .7) ^ 2) / 2)

      END DEF


REM        DEF fnlogvalue (logsed, loglength)

REM               fnlogvalue = (20 * loglength) + (10 * logsed)
REM        END DEF




REM  initialize COOLING RATE (alpha, decrease in temperature
REM                          and nrep, number of iterations at given
temp)

      temp = 100000:              REM  initial temperature
      finaltemp = 5000:             REM  ending condition temp
      alpha = .995:            REM  decrease in temperature factor
      nrep = 5000:              REM  # of repetitions at temp



REM  initialize stand, OBJFUNCTION control variable for the stand


REM  Read stand data, TREE FORM DATA INPUTS from file

      PRINT
```

```
      INPUT "Please enter name of tree data file: "; treefile$

      OPEN treefile$ FOR INPUT AS #2

      FOR tree = 1 TO standcount

            count = 0: treediamdata(tree, 0) = 1

            INPUT #2, treenum

            WHILE treediamdata(tree, count) > 0

                 count = count + 1

                 INPUT #2, treedistdata(tree, count),
treediamdata(tree, count)

            WEND

            treedatainputs(tree) = count

      NEXT tree

      CLOSE #2


REM        FOR a = 1 TO standcount
REM                FOR b = 1 TO treedatainputs(a)
REM                        PRINT a, treedistdata(a, b),
treediamdata(a, b)
REM                NEXT b
REM                PRINT
REM        NEXT a



REM CONVERT TREE FORM DATA INPUTS INTO DIAMETERS AT EVERY FOOT

REM  REDIM allocates array space as needed, to save array space

       REDIM sed(50, 0 TO 143) AS SINGLE: REM small end diameter
       REDIM led(50, 0 TO 143) AS SINGLE: REM large end diameter



      FOR c = 1 TO standcount

            dist = 0: tapersection = 1

            top = treedatainputs(c) - 1

            sed(c, dist) = treediamdata(c, tapersection)
            ds(c, dist) = INT(treediamdata(c, tapersection))

            led(c, dist) = treediamdata(c, tapersection)
```

```
            dl(c, dist) = INT(treediamdata(c, tapersection))

            endptbuttdist = treedistdata(c, tapersection)
            endpttopdist = treedistdata(c, tapersection + 1)
            endptbuttdiam = treediamdata(c, tapersection)
            endpttopdiam = treediamdata(c, tapersection + 1)

REM PRINT "sed at butt", sed(c, dist)
REM PRINT endptbuttdist
REM PRINT endpttopdist
REM PRINT endptbuttdiam
REM PRINT endpttopdiam


            dist = dist + 1

            WHILE dist <= treedistdata(c, top)

                  IF dist <= endpttopdist THEN GOSUB calcdiameters

                  tapersection = tapersection + 1

                  endptbuttdist = treedistdata(c, tapersection)
                  endpttopdist = treedistdata(c, tapersection + 1)
                  endptbuttdiam = treediamdata(c, tapersection)
                  endpttopdiam = treediamdata(c, tapersection + 1)


            totalht(c) = dist - 1

            WEND

            x = totalht(c)

            IF sed(c, x) > merchtop THEN

                  htmerchtop(c) = x
            ELSE

                  WHILE sed(c, x) < merchtop
                  x = x - 1
                  WEND

                  htmerchtop(c) = x
            END IF

PRINT c, dist, sed(c, dist)
PRINT "totalht, merch ht ="; totalht(c), htmerchtop(c)

REM       IF c MOD 10 = 0 THEN SLEEP 10

       NEXT c


       REDIM sed(1, 1) AS SINGLE: REM small end diameter
```

```
       REDIM led(1, 1) AS SINGLE: REM large end diameter
       REDIM treedistdata(1, 1) AS INTEGER: REM (treenumber,
datapoint, 1 = butt)
       REDIM treediamdata(1, 1) AS SINGLE: REM distance-diameter data
for tree form
       REDIM treedatainputs(1) AS INTEGER

    REM redim 1,1 frees up array memory


REM end CONVERT TREE FORM DATA INPUTS INTO DIAMETERS AT EVERY FOOT


REM STOP

REM  LOAD LOG VALUE TABLES FROM DATA FILE

REM  Read LOG PRICE data, TREE FORM DATA INPUTS from file

      PRINT
      INPUT "Please enter name of log price data file: "; pricefile$

      PRINT
      INPUT "Enter 1 if Cubic Foot log values, otherwise Board Foot
log values "; cfvalues

      PRINT
      INPUT "Enter 1 if maximizing stand value without long log
constraint, otherwise meet constraint "; maxvalue

      IF maxvalue = 1 THEN longpenalty = 0: REM objective function =
MAX$

      REM  Also determines which STOREBEST subroutine to use

      PRINT

      INPUT "Enter 1 for Combo lengths = 16,20,32,36,40, otherwise
for 8-40 foot lengths "; combos

      IF combos = 1 THEN shortestlog = 16

      PRINT

      OPEN pricefile$ FOR INPUT AS #3

            count = 0

            count = count + 1

            INPUT #3, lengthprice(count), lengthprice(count + 1),
price(count)

            WHILE lengthprice(count) > 0
```

```
                  FOR d = lengthprice(count) TO lengthprice(count +
1)

                       logprice(d) = price(count)
                       PRINT count, d, logprice(d)

                  NEXT d

                  count = count + 2: REM  read lengths in pairs,
lower,upper for price

                  INPUT #3, lengthprice(count), lengthprice(count +
1), price(count)

             WEND

      CLOSE #3



REM STOP



REM

REM  Generate Log value tables based on log lengths and log prices
REM     Only one log value (bf.. or cf..) will be valid, due to the
use a single
REM     logprice() in the function calls.  This event is trapped in
REM     log value IF-THEN-ELSE.  Valid prices are INPUT from external
datafile.
REM

REM  REDIM allocates array space as needed, to save array space

      REDIM cfvol(5 TO 28, 5 TO 28, 21) AS INTEGER: REM lookup table
for cubic foot volume (led,sed,length)
      REDIM cflogvalue(5 TO 28, 5 TO 28, 21) AS INTEGER: REM lookup
table for cubic foot log value (led,sed,length)


      DEF fnbflogvalue (logsed, scaleloglength)

            fnbflogvalue = logprice(scaleloglength) * bfvol(logsed,
scaleloglength) / 1000

      END DEF


      DEF fncflogvalue (logled, logsed, scaleloglength)


            tablelength = (scaleloglength / 2) + 1
```

```
            fncflogvalue = logprice(scaleloglength) *
cfvol(logled, logsed, tablelength) / 10000
                        REM  divide by 10000 = 100 cf per cunit,
cfvol(integer) = 100 times actual
      END DEF


REM  INITIALIZE VOLUME RELATIONSHIPS FOR SCALE LENGTHS, SCALING
DIAMETERS


REM  get Scribner Board Foot Volume table

      GOSUB scribnervolume

REM

REM  GET CUBIC FOOT VOLUME TABLE FOR LENGTHS 1 TO 40, LED,SED = 1 TO
30

      GOSUB cubicvolume

REM

REM STOP


      FOR scalelength = shortestlog TO longestlog STEP 2

          FOR sed = merchtop TO maxdiameter

             bflogvalue(sed, scalelength) = fnbflogvalue(sed,
scalelength)

             FOR led = sed TO maxdiameter

              tablelength = (scalelength / 2) + 1

              cflogvalue(led, sed, tablelength) = fncflogvalue(led,
sed, scalelength)

             NEXT led

          NEXT sed

       NEXT scalelength

REM



REM  initialize stand, OBJFUNCTION control variable for the stand
```

```
REM  INITIALIZE TREE VALUES FOR STAND AND STEM FORMS ESTABLISHED

       FOR treenum = 1 TO standcount

            GOSUB buckatree

REM                PRINT treenum, merchht, totallengthlogs,
totaltreevalue
REM                PRINT
REM                FOR x = 1 TO logcount
REM                        PRINT treenum, x, loglength(treenum, x),
logvalue(treenum, x)
REM                NEXT x
REM                PRINT

            GOSUB objfunction
            PRINT "treenum= "; treenum

      NEXT treenum

REM  PRIME THE BEST SOLUTION INITIALLY FOR THE STAND

            besttotalstandvalue = totalstandvalue
            besttotalstandvalue1 = totalstandvalue
            besttotallogs = totallogs
            besttotallonglogs = totallonglogs
            besttotallonglogvalue = totallonglogvalue
            besttotalbflogvolume = totalbflogvolume
            besttotalcflogvolume = totalcflogvolume
            besttotalstandlengthlogs = totalstandlengthlogs
            besttotalbflonglogvolume = totalbflonglogvolume
            besttotalcflonglogvolume = totalcflonglogvolume


            bestpercentlonglogs = percentlonglogs

            bestpercentlonglogvalue = percentlonglogvalue
REM             bestpercentlonglogvolume = percentlonglogvolume
            bestpercentbflonglogvolume = percentbflonglogvolume
            bestpercentcflonglogvolume = percentcflonglogvolume


            bestobjfunction = objfunction

REM   GOSUB printintermediateresults


REM       PRINT
REM       PRINT totalstandvalue, totallogs, totallonglogs,
percentlonglogs, objfunction
```

```
REM PRINT:  PRINT "that is all for tonight"

REM   GOSUB printoutcurrent
      GOSUB printoutbest

REM SLEEP
    PRINT
    PRINT "Unused Stack Space", FRE(-2)
    PRINT "Array Space", FRE(-1)

PRINT
PRINT "Press any key to begin analysis "
SLEEP


RANDOMIZE 1

REM  BEGIN SIMULATED ANNEALING FOR STAND OPTIMIZATION PROBLEM


      pass = 0

      WHILE temp > finaltemp

           PRINT "Temperature entering WHILE LOOP is now = "; temp
           PRINT

           FOR count = 1 TO nrep

            pass = pass + 1

            REM  PICK A TREE, calculate new value obj. func., swap ?

            GOSUB swaptree
REM STOP
REM              GOSUB printintermediateresults
REM STOP


           NEXT count

           PRINT
           temp = temp * alpha
           PRINT "At end of WHILE loop, temp = ", temp: PRINT
REM STOP
REM           SLEEP

      WEND

      PRINT : PRINT
      PRINT "Final temperature is "; temp

      PRINT "Best solution found at temp = "; besttemp
      PRINT : PRINT
```

```
      GOSUB printoutbest
      PRINT : PRINT

      INPUT "Enter 1 if you would like to review the tree by tree
results "; viewresults
      IF viewresults = 1 THEN GOSUB printintermediateresults

    PRINT "Unused Stack Space", FRE(-2)
    PRINT "Array Space", FRE(-1)
REM SLEEP

      PRINT
      INPUT "Shall we save these results? Enter 1 for Yes: ",
savefile

      IF savefile = 1 THEN GOSUB patterns: GOSUB writetofile


END




REM   ###########################  subroutines
########################



buckatree:

REM    subroutine to pick a tree randomly, assign log lengths

      totaltreevalue = 0: totallengthlogs = 0: logcount = 0
      totaltreebflogvolume = 0: totaltreecflogvolume = 0

      merchht = htmerchtop(treenum)

REM BUTT LOG LENGTH = log1, next log = log2, etc..

      WHILE merchht - totallengthlogs >= (shortestlog + trim)

            GOSUB pickalog

      WEND

            GOSUB countlonglogs

      longlogcount(treenum) = longlogs

            GOSUB countlonglogvalue

      longlogvalue(treenum) = longlogvalue

      totaltreebflogvolume(treenum) = totaltreebflogvolume
      totaltreecflogvolume(treenum) = totaltreecflogvolume
```

```
	totallengthlogs(treenum) = totallengthlogs

		GOSUB countlonglogvolume

	bflonglogvolume(treenum) = bflonglogvolume
	cflonglogvolume(treenum) = cflonglogvolume


RETURN


pickalog:

REM    subroutine to pick a log randomly  LOG LENGTH, 2 FT multiple
plus TRIM

	IF combos <> 1 THEN

	loglength = fnloglength

	ELSE

	REM combination lengths 16, 20, 32, 36, 40 foot loglenths

	getlog = INT(5 * RND) + 1: REM  pick a number 1 to 5

	SELECT CASE getlog
		CASE IS = 1
			loglength = 16 + trim
		CASE IS = 2
			loglength = 20 + trim
		CASE IS = 3
			loglength = 32 + trim
		CASE IS = 4
			loglength = 36 + trim
		CASE IS = 5
			loglength = 40 + trim
	END SELECT

	END IF

	GOSUB checklength

RETURN


checklength:

REM subroutine to check log length(s) < = merchantable height

	 totallengthlogs = totallengthlogs + loglength
```

```
       IF totallengthlogs <= merchht THEN

            GOSUB addtotree

       ELSE totallengthlogs = totallengthlogs - loglength

       END IF

RETURN



addtotree:

REM  subroutine to add log to tree, sum up

      diameter = ds(treenum, totallengthlogs)
      logled = dl(treenum, totallengthlogs - loglength)

      scaleloglength = loglength - trim

      bflogvol = bfvol(diameter, scaleloglength)

REM        cflogvol = fncflogvol(logled, diameter, scaleloglength,
trim)

       tablelength = (scaleloglength / 2) + 1

       cflogvol = cfvol(logled, diameter, tablelength) / 100
                  REM divide by 100 to convert integer to actual
xx.xx cf

      IF cfvalues = 1 THEN

            logvalue = cflogvalue(logled, diameter, tablelength)
      ELSE
            logvalue = bflogvalue(diameter, scaleloglength)

      END IF

      totaltreevalue = totaltreevalue + logvalue
      totaltreevalue(treenum) = totaltreevalue

      logcount = logcount + 1
      logcount(treenum) = logcount

      loglength(treenum, logcount) = loglength

      logvalue(treenum, logcount) = logvalue

      bflogvolume(treenum, logcount) = bflogvol
      cflogvolume(treenum, logcount) = cflogvol
```

```
      totaltreebflogvolume = totaltreebflogvolume + bflogvol
      totaltreecflogvolume = totaltreecflogvolume + cflogvol

RETURN



countlonglogs:

REM  subroutine to count long logs in a tree solution

      longlogs = 0

      FOR x = 1 TO logcount(treenum)
            IF loglength(treenum, x) >= longlog THEN

                  longlogs = longlogs + 1

            END IF
      NEXT x

RETURN



countlonglogvalue:

REM  subroutine to sum value of long logs in a tree solution

      longlogvalue = 0

      FOR x = 1 TO logcount(treenum)
            IF loglength(treenum, x) >= longlog THEN

            longlogvalue = longlogvalue + logvalue(treenum, x)

            END IF

      NEXT x

RETURN



countlonglogvolume:

REM  subroutine to sum value of long logs in a tree solution

      bflonglogvolume = 0: cflonglogvolume = 0

      FOR x = 1 TO logcount(treenum)
            IF loglength(treenum, x) >= longlog THEN

            bflonglogvolume = bflonglogvolume + bflogvolume(treenum,
x)
```

```
            cflonglogvolume = cflonglogvolume +
cflogvolume(treenum, x)

            END IF

      NEXT x

RETURN



objfunction:

REM  subroutine to sum new total stand value, calculate percent long
logs,
REM  and calculate the objective function initially to start SA
analysis.

      totalstandvalue = totalstandvalue + totaltreevalue(treenum)

      totallogs = totallogs + logcount(treenum)

      totallonglogs = totallonglogs + longlogcount(treenum)

      totallonglogvalue = totallonglogvalue + longlogvalue(treenum)

      percentlonglogs = totallonglogs * 100 / totallogs

      percentlonglogvalue = totallonglogvalue * 100 / totalstandvalue

      totalbflogvolume = totalbflogvolume +
totaltreebflogvolume(treenum)
      totalcflogvolume = totalcflogvolume +
totaltreecflogvolume(treenum)

      totalstandlengthlogs = totalstandlengthlogs +
totallengthlogs(treenum)

      totalbflonglogvolume = totalbflonglogvolume +
bflonglogvolume(treenum)
      totalcflonglogvolume = totalcflonglogvolume +
cflonglogvolume(treenum)

      percentbflonglogvolume = totalbflonglogvolume * 100 /
totalbflogvolume
      percentcflonglogvolume = totalcflonglogvolume * 100 /
totalcflogvolume



REM        objfunction = totalstandvalue - longpenalty *
(percentlonglogvalue - targetpll) ^ 2
REM        objfunction = totalstandvalue - longpenalty *
(percentlonglogs - targetpll) ^ 2
```

```
REM        objfunction = totalstandvalue - longpenalty *
(percentbflonglogvolume - targetpll) ^ 2

      objfunction = totalstandvalue - longpenalty *
(percentcflonglogvolume - targetpll) ^ 2


      besttotaltreevalue(treenum) = totaltreevalue(treenum)
      bestlogcount(treenum) = logcount(treenum)
      bestlonglogcount(treenum) = longlogcount(treenum)
      bestlonglogvalue(treenum) = longlogvalue(treenum)
      besttotaltreebflogvolume(treenum) =
totaltreebflogvolume(treenum)
      besttotaltreecflogvolume(treenum) =
totaltreecflogvolume(treenum)
      besttotallengthlogs(treenum) = totallengthlogs(treenum)
      bestbflonglogvolume(treenum) = bflonglogvolume(treenum)
      bestcflonglogvolume(treenum) = cflonglogvolume(treenum)



      FOR c = 1 TO logcount(treenum)
            bestloglength(treenum, c) = loglength(treenum, c)
            bestlogvalue(treenum, c) = logvalue(treenum, c)
            bestbflogvolume(treenum, c) = bflogvolume(treenum, c)
            bestcflogvolume(treenum, c) = cflogvolume(treenum, c)
      NEXT c


RETURN



swaptree:

REM  subroutine to pick a random tree, evaluate for improvement of
obj. function

      oldtotalstandvalue = totalstandvalue
      oldtotallogs = totallogs
      oldtotallonglogs = totallonglogs
      oldtotallonglogvalue = totallonglogvalue
      oldtotalbflogvolume = totalbflogvolume
      oldtotalcflogvolume = totalcflogvolume
      oldtotalstandlengthlogs = totalstandlengthlogs
      oldtotalbflonglogvolume = totalbflonglogvolume
      oldtotalcflonglogvolume = totalcflonglogvolume

      oldpercentlonglogs = percentlonglogs
      oldpercentlonglogvalue = percentlonglogvalue
      oldpercentbflonglogvolume = percentbflonglogvolume
      oldpercentcflonglogvolume = percentcflonglogvolume
```

```
      oldobjfunction = objfunction


REM  pick a random tree

      treenum = INT(standcount * RND) + 1

      oldtotaltreevalue = totaltreevalue(treenum)
      oldlogcount = logcount(treenum)
      oldlonglogcount = longlogcount(treenum)
      oldlonglogvalue = longlogvalue(treenum)
      oldtotaltreebflogvolume = totaltreebflogvolume(treenum)
      oldtotaltreecflogvolume = totaltreecflogvolume(treenum)
      oldtotallengthlogs = totallengthlogs(treenum)
      oldbflonglogvolume = bflonglogvolume(treenum)
      oldcflonglogvolume = cflonglogvolume(treenum)



      FOR d = 1 TO oldlogcount

            oldloglength(treenum, d) = loglength(treenum, d)
            oldlogvalue(treenum, d) = logvalue(treenum, d)
            oldbflogvolume(treenum, d) = bflogvolume(treenum, d)
            oldcflogvolume(treenum, d) = cflogvolume(treenum, d)
      NEXT d


      GOSUB buckatree


      newtotaltreevalue = totaltreevalue(treenum)
      newlogcount = logcount(treenum)
      newlonglogcount = longlogcount(treenum)
      newlonglogvalue = longlogvalue(treenum)
      newtotaltreebflogvolume = totaltreebflogvolume(treenum)
      newtotaltreecflogvolume = totaltreecflogvolume(treenum)
      newtotallengthlogs = totallengthlogs(treenum)
      newbflonglogvolume = bflonglogvolume(treenum)
      newcflonglogvolume = cflonglogvolume(treenum)


      FOR e = 1 TO newlogcount

            newloglength(treenum, e) = loglength(treenum, e)
            newlogvalue(treenum, e) = logvalue(treenum, e)
            newbflogvolume(treenum, e) = bflogvolume(treenum, e)
            newcflogvolume(treenum, e) = cflogvolume(treenum, e)
      NEXT e


      GOSUB saobjfunction
```

```
REM calculate the differences between old, new bucking solutions

      deltaobjfunction = newobjfunction - oldobjfunction
REM           deltaobjfunction = newtotaltreevalue -
oldtotaltreevalue

REM PRINT "new obj value, old obj value "; newobjfunction,
oldobjfunction
REM        PRINT "treenum = "; treenum

      IF deltaobjfunction > 0 THEN

        improved = improved + 1
        PRINT "                   improving deltaobjfunction = ";
deltaobjfunction
        PRINT

        GOSUB storenew

        IF maxvalue = 1 THEN GOSUB storebest1 ELSE GOSUB storebest2

      REM   GOSUB printintermediateresults


      ELSE
         randomprob = RND
         PRINT "non improving deltaobjfunction = "; deltaobjfunction
         PRINT
REM
REM  Maximizing, deltaobjfunction < 0, no "-" sign needed in EXP()
REM
         acceptancethreshhold = EXP(deltaobjfunction / temp)

         IF randomprob < acceptancethreshhold THEN

            PRINT : PRINT
            notimprovedaccepted = notimprovedaccepted + 1
            PRINT "not improving, but accepted":
            PRINT "random prob = "; randomprob:
            PRINT "acceptance threshhold ="; acceptancethreshhold:
            PRINT
                  PRINT "pass = "; pass:

            GOSUB storenew
            notimprove = 1

       REM       GOSUB printintermediateresults
         ELSE

            rejected = rejected + 1
            PRINT "not improving, not accepted"
            PRINT

            GOSUB restoreold
```

```
       REM       GOSUB printintermediateresults
         END IF

      END IF
REM
REM  *********** END OF SWAPTREE SUBROUTINE, RETURN TO MAIN PROGRAM
REM

RETURN




saobjfunction:

REM  subroutine to calculate new objective function for Simul.
Annealing analysis


      deltatotalstandvalue = newtotaltreevalue - oldtotaltreevalue
      newtotalstandvalue = oldtotalstandvalue + deltatotalstandvalue

      deltalogcount = newlogcount - oldlogcount
      newtotallogs = oldtotallogs + deltalogcount

      deltalonglogcount = newlonglogcount - oldlonglogcount
      newtotallonglogs = oldtotallonglogs + deltalonglogcount

REM PRINT " tree number = ", treenum
REM PRINT "newlonglogcout, oldlonglogcount, deltallc"
REM PRINT newlonglogcount, oldlonglogcount, deltalonglogcount
REM PRINT "newtotallonglogs, oldtotallonglogs, deltalonglogcount"
REM PRINT newtotallonglogs, oldtotallonglogs, deltalonglogcount

REM SLEEP

      deltatotallonglogvalue = newlonglogvalue - oldlonglogvalue
      newtotallonglogvalue = oldtotallonglogvalue +
deltatotallonglogvalue

      deltatotalbflogvolume = newtotaltreebflogvolume -
oldtotaltreebflogvolume
      newtotalbflogvolume = oldtotalbflogvolume +
deltatotalbflogvolume

      deltatotalcflogvolume = newtotaltreecflogvolume -
oldtotaltreecflogvolume
      newtotalcflogvolume = oldtotalcflogvolume +
deltatotalcflogvolume

      deltatotalstandlengthlogs = newtotallengthlogs -
oldtotallengthlogs
      newtotalstandlengthlogs = oldtotalstandlengthlogs +
deltatotalstandlengthlogs
```

```
      deltatotalbflonglogvolume = newbflonglogvolume -
oldbflonglogvolume
      newtotalbflonglogvolume = oldtotalbflonglogvolume +
deltatotalbflonglogvolume

      deltatotalcflonglogvolume = newcflonglogvolume -
oldcflonglogvolume
      newtotalcflonglogvolume = oldtotalcflonglogvolume +
deltatotalcflonglogvolume


      newpercentlonglogs = newtotallonglogs * 100 / newtotallogs

      newpercentlonglogvalue = newtotallonglogvalue * 100 /
newtotalstandvalue

      newpercentbflonglogvolume = newtotalbflonglogvolume * 100 /
newtotalbflogvolume

      newpercentcflonglogvolume = newtotalcflonglogvolume * 100 /
newtotalcflogvolume


REM     newobjfunction = newtotalstandvalue - longpenalty *
(newpercentlonglogvalue - targetpll) ^ 2
REM     newobjfunction = newtotalstandvalue - longpenalty *
(newpercentlonglogs - targetpll) ^ 2
REM     newobjfunction = newtotalstandvalue - longpenalty *
(newpercentbflonglogvolume - targetpll) ^ 2

     newobjfunction = newtotalstandvalue - longpenalty *
(newpercentcflonglogvolume - targetpll) ^ 2

REM        newobjfunction = newtotalstandvalue: rem  USE FOR MAX
VALUE SOLUTION


RETURN




storenew:

REM  subroutine to store new values for standvalue, logs, longlogs,
objfunction

      totalstandvalue = newtotalstandvalue
      totallogs = newtotallogs
      totallonglogs = newtotallonglogs
      totallonglogvalue = newtotallonglogvalue
      totalbflogvolume = newtotalbflogvolume
      totalcflogvolume = newtotalcflogvolume
      totalstandlengthlogs = newtotalstandlengthlogs
      totalbflonglogvolume = newtotalbflonglogvolume
```

```
        totalcflonglogvolume = newtotalcflonglogvolume

        percentlonglogs = newpercentlonglogs
        percentlonglogvalue = newpercentlonglogvalue
        percentbflonglogvolume = newpercentbflonglogvolume
        percentcflonglogvolume = newpercentcflonglogvolume

        objfunction = newobjfunction

        totaltreevalue(treenum) = newtotaltreevalue
        logcount(treenum) = newlogcount
        longlogcount(treenum) = newlonglogcount
        longlogvalue(treenum) = newlonglogvalue
        totaltreebflogvolume(treenum) = newtotaltreebflogvolume
        totaltreecflogvolume(treenum) = newtotaltreecflogvolume
        totallengthlogs(treenum) = newtotallengthlogs
        bflonglogvolume(treenum) = newbflonglogvolume
        cflonglogvolume(treenum) = newcflonglogvolume


        FOR f = 1 TO newlogcount
              loglength(treenum, f) = newloglength(treenum, f)
              logvalue(treenum, f) = newlogvalue(treenum, f)
              bflogvolume(treenum, f) = newbflogvolume(treenum, f)
              cflogvolume(treenum, f) = newcflogvolume(treenum, f)
        NEXT f

        REM  PRINT "through storenew"

RETURN



storebest1:

REM  subroutine to store best overall and individual tree solutions


REM STOREBEST VERSION 1 - USE WHEN MAXIMIZING VALUE without PERCENT
LONG LOG TARGET
REM catches case when newtreevalue > besttreevalue, but obj < bestobj
REM

        IF ((newobjfunction > bestobjfunction) OR (newtotaltreevalue >
besttotaltreevalue(treenum))) THEN

              deltabesttotalstandvalue = newtotaltreevalue -
besttotaltreevalue(treenum)
              besttotalstandvalue = besttotalstandvalue +
deltabesttotalstandvalue

              deltabesttotallogs = newlogcount - bestlogcount(treenum)
              besttotallogs = besttotallogs + deltabesttotallogs
```

```
            deltabesttotallonglogs = newlonglogcount -
bestlonglogcount(treenum)
            besttotallonglogs = besttotallonglogs +
deltabesttotallonglogs

            deltabesttotallonglogvalue = newlonglogvalue -
bestlonglogvalue(treenum)
            besttotallonglogvalue = besttotallonglogvalue +
deltabesttotallonglogvalue

            deltabesttotalbflogvolume = newtotaltreebflogvolume -
besttotaltreebflogvolume(treenum)
            besttotalbflogvolume = besttotalbflogvolume +
deltabesttotalbflogvolume

            deltabesttotalcflogvolume = newtotaltreecflogvolume -
besttotaltreecflogvolume(treenum)
            besttotalcflogvolume = besttotalcflogvolume +
deltabesttotalcflogvolume

            deltabesttotalstandlengthlogs = newtotalstandlengthlogs -
besttotalstandlengthlogs
            besttotalstandlengthlogs = besttotalstandlengthlogs +
deltabesttotalstandlengthlogs

            deltabesttotalbflonglogvolume = newbflonglogvolume -
bestbflonglogvolume(treenum)
            besttotalbflonglogvolume = besttotalbflonglogvolume +
deltabesttotalbflonglogvolume

            deltabesttotalcflonglogvolume = newcflonglogvolume -
bestcflonglogvolume(treenum)
            besttotalcflonglogvolume = besttotalcflonglogvolume +
deltabesttotalcflonglogvolume

            bestpercentlonglogs = besttotallonglogs * 100 /
besttotallogs
            bestpercentlonglogvalue = besttotallonglogvalue * 100 /
besttotalstandvalue
            bestpercentbflonglogvolume = besttotalbflonglogvolume *
100 / besttotalbflogvolume
            bestpercentcflonglogvolume = besttotalcflonglogvolume *
100 / besttotalcflogvolume

            bestobjfunction = besttotalstandvalue

            besttotaltreevalue(treenum) = newtotaltreevalue
            bestlogcount(treenum) = newlogcount
            bestlonglogcount(treenum) = newlonglogcount
            bestlonglogvalue(treenum) = newlonglogvalue
            besttotaltreebflogvolume(treenum) =
newtotaltreebflogvolume
            besttotaltreecflogvolume(treenum) =
newtotaltreecflogvolume
            besttotallengthlogs(treenum) = newtotallengthlogs
```

```
            bestbflonglogvolume(treenum) = newbflonglogvolume
            bestcflonglogvolume(treenum) = newcflonglogvolume

            FOR g = 1 TO newlogcount
                 bestloglength(treenum, g) = newloglength(treenum, g)
                 bestlogvalue(treenum, g) = newlogvalue(treenum, g)
                 bestbflogvolume(treenum, g) =
newbflogvolume(treenum, g)
                 bestcflogvolume(treenum, g) =
newcflogvolume(treenum, g)
            NEXT g

            besttemp = temp
            bestpass = pass

REM              PRINT "throught storebest"
      END IF

RETURN



storebest2:

REM  subroutine to store best overall and individual tree solutions


REM STOREBEST VERSION 2 - USE WHEN MAXIMIZING VALUE WITH PERCENT LONG
LOG TARGET
REM catches case when newtreevalue > besttreevalue, but obj < bestobj
REM
REM  OLD storebest2, moved here 22 MAY 09

REM STOREBEST VERSION 2 - USE WHEN MAXIMIZING VALUE WITH PERCENT LONG
LOG TARGET

         IF (newobjfunction > bestobjfunction) THEN


            besttotalstandvalue = newtotalstandvalue
            besttotallogs = newtotallogs
            besttotallonglogs = newtotallonglogs
            besttotallonglogvalue = newtotallonglogvalue
            besttotalbflogvolume = newtotalbflogvolume
            besttotalcflogvolume = newtotalcflogvolume
            besttotalstandlengthlogs = newtotalstandlengthlogs
            besttotalbflonglogvolume = newtotalbflonglogvolume
            besttotalcflonglogvolume = newtotalcflonglogvolume

            bestpercentlonglogs = besttotallonglogs * 100 /
besttotallogs
            bestpercentlonglogvalue = besttotallonglogvalue * 100 /
besttotalstandvalue
            bestpercentbflonglogvolume = besttotalbflonglogvolume *
100 / besttotalbflogvolume
```

```
            bestpercentcflonglogvolume = besttotalcflonglogvolume
* 100 / besttotalcflogvolume

            oldbestobjfunction = bestobjfunction
            bestobjfunction = newobjfunction




REM  prepare trap case where improving current solution stores
newtree with besttrees
REM  resulting in incorrect totals for values based on summing best
trees
REM  IF BestTSV = BestTSV1 then just add tree to best trees for
efficiency
REM  ELSE need to sum all current tree solutions and store them as
best
REM  requring nested FOR-NEXT loops through all trees and all logs

            deltabesttotalstandvalue1 = newtotaltreevalue -
besttotaltreevalue(treenum)
            besttotalstandvalue1 = besttotalstandvalue1 +
deltabesttotalstandvalue1


PRINT "********************************";
PRINT besttotalstandvalue, besttotalstandvalue1

REM SLEEP


            IF besttotalstandvalue = besttotalstandvalue1 THEN

                besttotaltreevalue(treenum) = newtotaltreevalue
                bestlogcount(treenum) = newlogcount
                bestlonglogcount(treenum) = newlonglogcount
                bestlonglogvalue(treenum) = newlonglogvalue
                besttotaltreebflogvolume(treenum) =
newtotaltreebflogvolume
                besttotaltreecflogvolume(treenum) =
newtotaltreecflogvolume
                besttotallengthlogs(treenum) = newtotallengthlogs
                bestbflonglogvolume(treenum) = newbflonglogvolume
                bestcflonglogvolume(treenum) = newcflonglogvolume

                FOR g = 1 TO newlogcount
                  bestloglength(treenum, g) = newloglength(treenum,
g)
                  bestlogvalue(treenum, g) = newlogvalue(treenum, g)
                  bestbflogvolume(treenum, g) =
newbflogvolume(treenum, g)
                  bestcflogvolume(treenum, g) =
newcflogvolume(treenum, g)
                NEXT g
```

```
            ELSE


                FOR x = 1 TO standcount
                  besttotaltreevalue(x) = totaltreevalue(x)
                  bestlogcount(x) = logcount(x)
                  bestlonglogcount(x) = longlogcount(x)
                  bestlonglogvalue(x) = longlogvalue(x)
                  besttotaltreebflogvolume(x) =
totaltreebflogvolume(x)
                  besttotaltreecflogvolume(x) =
totaltreecflogvolume(x)
                  besttotallengthlogs(x) = totallengthlogs(x)
                  bestbflonglogvolume(x) = bflonglogvolume(x)
                  bestcflonglogvolume(x) = cflonglogvolume(x)

                  FOR y = 1 TO logcount(x)
                      bestloglength(x, y) = loglength(x, y)
                      bestlogvalue(x, y) = logvalue(x, y)
                      bestbflogvolume(x, y) = bflogvolume(x, y)
                      bestcflogvolume(x, y) = cflogvolume(x, y)
                  NEXT y

                NEXT x

                besttotalstandvalue1 = besttotalstandvalue

            END IF

            besttemp = temp
            bestpass = pass

REM     PRINT "throught storebest"
REM   GOSUB printintermediateresults

      END IF



RETURN




restoreold:

REM  subroutine to restore original values for selected tree

      totalstandvalue = oldtotalstandvalue
      totallogs = oldtotallogs
      totallonglogs = oldtotallonglogs
      totallonglogvalue = oldtotallonglogvalue
      totalbflogvolume = oldtotalbflogvolume
      totalcflogvolume = oldtotalcflogvolume
```

```
        totalstandlengthlogs = oldtotalstandlengthlogs
        totalbflonglogvolume = oldtotalbflonglogvolume
        totalcflonglogvolume = oldtotalcflonglogvolume

        percentlonglogs = oldpercentlonglogs
        percentlonglogvalue = oldpercentlonglogvalue
        percentbflonglogvolume = oldpercentbflonglogvolume
        percentcflonglogvolume = oldpercentcflonglogvolume

        objfunction = oldobjfunction

        totaltreevalue(treenum) = oldtotaltreevalue
        logcount(treenum) = oldlogcount
        longlogcount(treenum) = oldlonglogcount
        longlogvalue(treenum) = oldlonglogvalue
        totaltreebflogvolume(treenum) = oldtotaltreebflogvolume
        totaltreecflogvolume(treenum) = oldtotaltreecflogvolume
        totallengthlogs(treenum) = oldtotallengthlogs
        bflonglogvolume(treenum) = oldbflonglogvolume
        cflonglogvolume(treenum) = oldcflonglogvolume


        FOR h = 1 TO oldlogcount
              loglength(treenum, h) = oldloglength(treenum, h)
              logvalue(treenum, h) = oldlogvalue(treenum, h)
              bflogvolume(treenum, h) = oldbflogvolume(treenum, h)
              cflogvolume(treenum, h) = oldcflogvolume(treenum, h)
        NEXT h

RETURN



REM --------------------------------------------------------

printout:
        PRINT "TOTAL       TOTAL        TOTAL           PERCENT
OBJ. "
        PRINT "STAND       LOG          LONG            LONG
FUNCTION"
        PRINT "VALUE       COUNT        LOGS            LOGS
VALUE"
        PRINT "=======     ======       ======          =======
========"
        PRINT besttotalstandvalue, besttotallogs, besttotallonglogs,
bestpercentlonglogs, bestobjfunction



RETURN
```

```
REM ----------------------------------------------------------

printoutbest:

      PRINT "BEST         BEST         BEST             BEST $
BEST"
      PRINT "TOTAL        TOTAL        TOTAL            PERCENT
OBJ. "
      PRINT "STAND        LOG          LONG             LONG
FUNCTION"
      PRINT "VALUE        COUNT        LOGS             LOGS
VALUE"
      PRINT "=======      ======       ======           =======
========"
      PRINT besttotalstandvalue, besttotallogs, besttotallonglogs,
bestpercentlonglogvalue, bestobjfunction
      PRINT "percent long logs by log count =", bestpercentlonglogs
      PRINT "percent long logs by BF volume =",
bestpercentbflonglogvolume
      PRINT "percent long logs by CF volume =",
bestpercentcflonglogvolume


RETURN

REM ----------------------------------------------------------


REM ----------------------------------------------------------

printoutcurrent:


      PRINT "TOTAL        TOTAL        TOTAL            PERCENT
OBJ. "
      PRINT "STAND        LOG          LONG             LONG
FUNCTION"
      PRINT "VALUE        COUNT        LOGS             LOGS
VALUE"
      PRINT "=======      ======       ======           =======
========"
      PRINT totalstandvalue, totallogs, totallonglogs,
percentlonglogvalue, objfunction
      PRINT "percent long logs by log count =", percentlonglogs



RETURN

printintermediateresults:

 FOR z = 1 TO standcount
      PRINT "tree # "
      PRINT z
```

```
      PRINT : PRINT "CURRENT:"
      PRINT "treevalue     logs      longlogs     total lengthlogs
merchht"
      PRINT totaltreevalue(z), logcount(z), longlogcount(z),
totallengthlogs(z), htmerchtop(z)
      PRINT
      PRINT "tree #    log #  best length, best value"
      FOR xz = 1 TO logcount(z)
            PRINT z, xz, loglength(z, xz), logvalue(z, xz)
REM SLEEP
      NEXT xz


      PRINT : PRINT "BEST:"

      PRINT "treevalue     logs      longlogs     total lengthlogs
longlong value"
      PRINT besttotaltreevalue(z), bestlogcount(z),
bestlonglogcount(z), besttotallengthlogs(z), bestlonglogvalue(z)
      PRINT
      PRINT "tree #    log #  best length, best value"
      FOR xz = 1 TO bestlogcount(z)
            PRINT z, xz, bestloglength(z, xz), bestlogvalue(z, xz)
REM  SLEEP
      NEXT xz
      PRINT : PRINT
SLEEP

 NEXT z
      PRINT "pass # = ", pass

REM        PRINT : PRINT
      GOSUB printoutcurrent
REM SLEEP
      GOSUB printoutbest

      PRINT : PRINT "improved ="; improved
      PRINT "notimprovedaccepted = "; notimprovedaccepted
      PRINT "rejected = "; rejected
      PRINT

tsv = 0: FOR x = 1 TO 50: tsv = tsv + besttotaltreevalue(x): NEXT x:
PRINT "tsv="; tsv
ll = 0: FOR x = 1 TO 50: ll = ll + bestlogcount(x): NEXT x: PRINT
"logcount ="; ll
tlv = 0: FOR x = 1 TO 50: FOR y = 1 TO bestlogcount(x): tlv = tlv +
bestlogvalue(x, y): NEXT y: NEXT x: PRINT "tlv ="; tlv
llv = 0: FOR x = 1 TO 50: llv = llv + bestlonglogvalue(x): NEXT x:
PRINT "longlogvalue", llv
llc = 0: FOR x = 1 TO 50: llc = llc + bestlonglogcount(x): NEXT x:
PRINT "llcount", llc
   REM     IF (improved + notimprovedaccepted + rejected) = 1352 THEN
PRINT "put in sleeps": STOP
   IF tsv <> besttotalstandvalue THEN PRINT : PRINT : PRINT
"tsv<>besttsv": STOP
```

```
   IF ll <> besttotallogs THEN PRINT : PRINT : PRINT
"ll<>besttotallogs": STOP
   IF llc <> besttotallonglogs THEN PRINT : PRINT : PRINT
"llc<>besttotallonglogs": STOP

IF bestobjfunction > oldbestobjfunction THEN
PRINT "********************************"
PRINT "best improved"
PRINT
oldbestobjfunction = bestobjfunction
SLEEP
END IF

RETURN




REM -------------------------------------------------------


scribnervolume:

REM  subroutine to calculate Scribner Board Foot Volume for log
length by log diameter
REM  length = scale length = log length - trim, diameter is small end
diameter
REM  Scribner volume factors, Northwest Log Rules Advisory Group,
7/1/1972

      OPEN "scribner.dat" FOR INPUT AS #1

REM  for diameters 1 to 5 inches

      FOR diameter = 1 TO 5
            INPUT #1, factor

            FOR length = 1 TO 40
                  bfvol(diameter, length) = 10 * CINT((length *
factor) / 10)
            NEXT length

      NEXT diameter


REM  for diameters 6 to 11 inches, lengths = 1 to 15 feet

      FOR diameter = 6 TO 11
            INPUT #1, factor

            FOR length = 1 TO 15
                  bfvol(diameter, length) = 10 * CINT((length *
factor) / 10)
            NEXT length
```

```
      NEXT diameter

REM  for diameters 6 to 11 inches, lengths = 16 to 31 feet

      FOR diameter = 6 TO 11
            INPUT #1, factor

            FOR length = 16 TO 31
                  bfvol(diameter, length) = 10 * CINT((length *
factor) / 10)
            NEXT length

      NEXT diameter

REM  for diameters 6 to 11 inches, lengths = 32 to 40 feet

      FOR diameter = 6 TO 11
            INPUT #1, factor

            FOR length = 32 TO 40
                  bfvol(diameter, length) = 10 * CINT((length *
factor) / 10)
            NEXT length

      NEXT diameter

REM  for diameters 12 to 30 inches

      FOR diameter = 12 TO 30
            INPUT #1, factor

            FOR length = 1 TO 40
                  bfvol(diameter, length) = 10 * CINT((length *
factor) / 10)
            NEXT length

      NEXT diameter

CLOSE #1

REM        FOR diameter = 1 TO 30
REM                FOR length = 1 TO 40
REM                        PRINT "diameter = "; diameter, "length =
"; length, "volume =",
REM                        PRINT bfvol(diameter, length)
REM                NEXT length
REM                PRINT
REM        NEXT diameter


RETURN



calcdiameters:
```

```
REM  subroutine to calculate small end diameter at every foot along
stem

      dist1 = endptbuttdist
      dist2 = endpttopdist

      diam1 = endptbuttdiam
      diam2 = endpttopdiam
      distincrement = 1

      WHILE dist <= endpttopdist

            PRINT dist1, dist2, diam1, diam2


            REM PRINT dist PRINT "stopped" SLEEP

            sedincrement = distincrement * (diam2 - diam1) / (dist2 -
dist1)

            sed(c, dist) = diam1 + sedincrement
            ds(c, dist) = INT(sed(c, dist))

            led(c, dist) = diam1 + sedincrement
            dl(c, dist) = INT(led(c, dist))


            PRINT c
            PRINT dist, sed(c, dist), ds(c, dist), led(c, dist),
dl(c, dist)

            dist = dist + 1
            distincrement = distincrement + 1


      WEND

RETURN


cubicvolume:

REM  subroutine to calculate Cubic Foot Volume for log length by log
diameter
REM  length = scale length = log length - trim, diameters at large,
small ends
REM  Length and diameters adjusted as per Northwest Log Rules
Advisory Group, 7/1/1972

      FOR length = 1 TO 21

          loglength = (2 * length) - 1
          scalelength = loglength - trim
```

```
          FOR sed = 5 TO 28

            FOR led = sed TO 28

                   cfvol(led, sed, length) = INT(100 *
fncflogvol(led, sed, scalelength, trim))
                       REM multiply by 100 to change from single to
integer
                       REM need to divide by 100 in volume and value
calculations
            NEXT led

          NEXT sed

      NEXT length

RETURN



REM

patterns:

REM  subroutine to determine patterns of first 3 logs in tree
REM  uses table length for actual length for array storage efficiency
REM   loglength = scale length + trim (ie, 41 feet)
REM   scalelength = loglength less trim (ie, 40 feet)
REM   table length = (scalelength / 2) + 1   (40 feet = 21 table
length)
REM   table length = 1 is a scalelength = 0, no log

      REDIM bfvol(1, 1) AS INTEGER: REM lookup table for board foot
volume (diameter, length)
REM redim (1,1) frees up array memory

      REDIM pattern(5 TO 21, 1 TO 21, 1 TO 21) AS INTEGER: REM first
3 log length pattern

      totalpatterns = 0

      FOR x = 1 TO standcount

            lg(1) = 1: lg(2) = 1: lg(3) = 1

            IF bestlogcount(x) <= 3 THEN logsinpattern =
bestlogcount(x) ELSE logsinpattern = 3


            FOR y = 1 TO logsinpattern: REM Maximum = 3, first 3 logs

                  lg(y) = (bestloglength(x, y) - trim) / 2 + 1
            NEXT y
```

```
            pattern(lg(1), lg(2), lg(3)) = pattern(lg(1), lg(2),
lg(3)) + 1

            IF pattern(lg(1), lg(2), lg(3)) = 1 THEN totalpatterns =
totalpatterns + 1
       NEXT x

       PRINT
       PRINT "Total number of patterns = "; totalpatterns
       PRINT

RETURN



REM

writetofile:

REM subroutine to write data results to output file
REM
REM
    PRINT
    PRINT "Unused Stack Space", FRE(-2)
    PRINT "Array Space", FRE(-1)
REM SLEEP

    REDIM cfvol(1, 1, 1) AS INTEGER: REM lookup table for cubic foot
volume (led,sed,length)
REM redim 1,1,1 frees up array space for writing output file
REM


      INPUT "Please enter name of data file for storing results :";
outputfile$

      OPEN outputfile$ FOR OUTPUT AS #4

      WRITE #4, "output filename =", outputfile$
      WRITE #4, "tree input file =", treefile$
      WRITE #4, "log price file =", pricefile$
      WRITE #4, "cfvalues = ", cfvalues
      WRITE #4, "maximize value = ", maxvalue
      WRITE #4, "combos used = ", combos
      WRITE #4, "long penalty factor =", longpenalty
      WRITE #4, "temp", temp, "finaltemp", finaltemp, "alpha", alpha,
"nrep", nrep
      WRITE #4, "best temp at ", besttemp
      WRITE #4, "best pass at ", bestpass
      WRITE #4, "total reps =", pass
      WRITE #4,
      WRITE #4, "besttotalstandvalue", besttotalstandvalue
      WRITE #4, "besttotallogs", besttotallogs
      WRITE #4, "besttotallonglogs", besttotallonglogs
      WRITE #4, "besttotallonglogvalue", besttotallonglogvalue
```

```
      WRITE #4, "besttotalbflogvolume", besttotalbflogvolume
      WRITE #4, "besttotalcflogvolume", besttotalcflogvolume
      WRITE #4, "besttotalstandlengthlogs", besttotalstandlengthlogs
      WRITE #4, "besttotalbflonglogvolume", besttotalbflonglogvolume
      WRITE #4, "besttotalcflonglogvolume", besttotalcflonglogvolume
      WRITE #4,
      WRITE #4, "bestpercentlonglogs", bestpercentlonglogs
      WRITE #4, "bestpercentlonglogvalue", bestpercentlonglogvalue
      WRITE #4, "bestpercentbflonglogvolume",
bestpercentbflonglogvolume
      WRITE #4, "bestpercentcflonglogvolume",
bestpercentcflonglogvolume
      WRITE #4,
      WRITE #4, "bestobjfunction", bestobjfunction
      WRITE #4,

      FOR treenum = 1 TO standcount
            WRITE #4, "tree #", treenum, "total ht",
totalht(treenum), "merch ht", htmerchtop(treenum)
            WRITE #4, "best total tree value",
besttotaltreevalue(treenum)
            WRITE #4, "best logcount", bestlogcount(treenum)
            WRITE #4, "best long log count",
bestlonglogcount(treenum)
            WRITE #4, "best long log value",
bestlonglogvalue(treenum)
            WRITE #4, "best total tree bf log vol",
besttotaltreebflogvolume(treenum)
            WRITE #4, "best total tree cf log vol",
besttotaltreecflogvolume(treenum)
            WRITE #4, "best total length logs",
besttotallengthlogs(treenum)
            WRITE #4, "best bf long log vol",
bestbflonglogvolume(treenum)
            WRITE #4, "best cf long log vol",
bestcflonglogvolume(treenum)
            WRITE #4, ""
            WRITE #4, "", "", "", "", treenum, "length", "butt dia",
"diameter", "value", "bf vol", "cf vol"

            ldist = 0: sdist = 0

                FOR g = 1 TO bestlogcount(treenum)

                  sdist = sdist + bestloglength(treenum, g)
                  ldia = dl(treenum, ldist)
                  sdia = ds(treenum, sdist)

                  WRITE #4, "", "", "", "", g, bestloglength(treenum,
g), ldia, sdia, bestlogvalue(treenum, g), bestbflogvolume(treenum,
g), bestcflogvolume(treenum, g)

                  ldist = ldist + bestloglength(treenum, g)

                NEXT g
```

```
            WRITE #4,
        NEXT treenum

        WRITE #4, "total pattern count =", totalpatterns
        WRITE #4,

        FOR a = 21 TO 5 STEP -1
            log1 = (a - 1) * 2

            FOR b = 21 TO 1 STEP -1
              log2 = (b - 1) * 2

              FOR c = 21 TO 1 STEP -1
                  log3 = (c - 1) * 2

                  IF pattern(a, b, c) >= 1 THEN WRITE #4, log1, log2,
log3, pattern(a, b, c)
              NEXT c
            NEXT b
        NEXT a

        WRITE #4,

        WRITE #4, "end of date output file"

        CLOSE #4

RETURN



REM




REM *****************************************************************
REM END OF PROGRAM CODE, SUBROUTINES     ***********************
REM STORED CODE BEYOND THIS POINT        ***********************
REM *****************************************************************




loglengths:

REM  subroutine to print out loglengths by tree

      FOR treenum = 1 TO standcount
            FOR x = 1 TO logcount(treenum)
                  PRINT USING "###     ### "; treenum;
loglength(treenum, x)
            NEXT x
            PRINT
      NEXT treenum
```

```
RETURN


REM --------------------------------------------------------

REM  END OF ALL PROGRAM CODE
```

Appendix C: Chapter Three and Four - Stand 1 Tree Data

Chapter Three and Four - Stand 1 Tree Data:

Tree number, DISTance from butt, Diameter Inside Bark, DIST, DIB,…,0,0

```
1,0,9.5,32,6.7,71,2,0,0
2,0,9.6,33,5.8,72,2,0,0
3,0,10.5,41,7.6,79,2,0,0
4,0,11,41,7.5,75,2.5,0,0
5,0,7,21,6,58,2,0,0
6,0,10.5,33,7.1,78,2,0,0
7,0,13.5,41,9.5,87,2,0,0
8,0,8.6,21,5.7,54,2,0,0
9,0,11,33,7.5,80,2,0,0
10,0,10,33,5.8,62,2,0,0
11,0,8.7,33,6.4,69,2,0,0
12,0,13.5,41,9.7,74,3.5,0,0
13,0,8,33,5.8,66,2,0,0
14,0,8,33,5.8,66,2,0,0
15,0,12,33,8.2,83,2,0,0
16,0,7.8,21,5.8,58,2,0,0
17,0,11.8,33,5.8,74,2,0,0
18,0,9.6,37,7.2,69,2.4,0,0
19,0,11.4,37,7.2,74,2,0,0
20,0,7.2,35,5.3,68,2,0,0
21,0,10.8,41,7.6,64,5,80,2,0,0
22,0,7,35,6.7,52,2,0,0
23,0,10.2,37,6.6,66,2,0,0
24,0,12,40,8.6,74,2.5,0,0
25,0,8.3,33,6,58,3.9,0,0
26,0,13.3,41,9.4,69,5,79,2,0,0
27,0,8.5,33,5.3,66,2,0,0
28,0,8,41,6.4,76,2,0,0
29,0,15.3,41,9,84,2,0,0
30,0,13,41,9.5,93,2,0,0
31,0,6.4,33,5.8,71,2,0,0
32,0,12.1,41,9.6,79,5.4,87,2,0,0
33,0,9,37,6.4,88,2,0,0
34,0,10.6,37,8.9,82,2.2,0,0
35,0,10.6,41,8.8,89,2,0,0
36,0,7,37,6.4,81,2.2,0,0
37,0,12,41,7.6,85,2,0,0
38,0,7.4,33,4.8,62,2,0,0
39,0,8.6,37,6.8,74,2,0,0
40,0,11.2,37,7.2,79,2.4,0,0
41,0,8.6,35,6,61,2,0,0
42,0,12,41,7.2,83,2,0,0
43,0,9.6,37,6.1,71,2,0,0
44,0,10.8,41,6.7,78,3,0,0
45,0,9.1,33,6.4,70,2,0,0
46,0,13,41,9,90,2,0,0
47,0,7.1,37,4.7,64,2,0,0
48,0,8,37,5.8,61,4,67,2,0,0
49,0,8.4,37,7.2,75,2,0,0
50,0,8.2,33,6,68,2,0,0
```

Appendix D: Chapter Three And Four - Stand 2 Tree Data

Chapter Three and Four - Stand 2 Tree Data:

Tree number, DISTance from butt, Diameter Inside Bark, DIST, DIB,…,0,0

```
1,0,19.5,20,16.5,40,14.5,60,13.5,80,12.5,95,11.5,0,0
2,0,24.5,20,21.5,41,17.5,61,16.5,82,14.5,99,13.5,100,12.5,120,9.5,140,6.5,0,0
3,0,20.5,20,16.5,41,14.5,61,13.5,82,11.5,102,9.5,113,6.5,0,0
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