An Evaluation of the Effects of Log Length on Timber Values in Thinning

Stephen J. Pilkerton
Loren D. Kellogg

Abstract

This research investigated an economic component of harvesting operations not previously studied for steep-slope thinning harvests in Douglas-fir (*Pseudotsuga menziesii*) stands in the Pacific Northwest. Of interest was the influence of allowable log lengths and the effect on revenues with a bucking-to-value strategy. Resulting log lengths influence revenues and logging costs important to forest managers, logging contractors, and mill managers. Here, a reduced set of log lengths was evaluated that approaches computer-generated optimal values and creates the potential for development of a bucking decision tool having the form of a bucking pattern cutting card. The reduced set of five log lengths (two mill-length logs and three woods-length logs resulting from combinations of the mill-length logs) was also compared with the full set of allowable lengths for value recovery and fiber utilization. Resulting values were 96 and 98 percent of full-set optimal values for 45- and 65-year-old stands, respectively. Value recovery exceeds that with current unaided bucking practices. The resulting bucking patterns can be easily incorporated into a cutting card based on length to merchantable top. This approach reduces the number of logs handled, increases mill-preferred long logs, decreases pattern count, and increases recovered value. Potential value gains of \$4.09 to \$8.80 per 100 cubic feet for the two stands are discussed with respect to mill constraints. Use of a combinatorial heuristic is suggested for matching produced logs to mill purchase orders. The board foot–to–cubic foot ratios used for the cubic foot–based analysis are also discussed.

Bucking, or crosscutting, 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 before 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 in-woods, real-time solutions (Garland et al. 1989). The importance of log lengths has 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-mill efforts have focused on generating finished product values from a given log based on product dimensions and quality. 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 while accounting for stumpage, harvesting, and transportation 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 $\leq$20 ft) that western Oregon mills may consider less desirable. Length-measuring

The authors are, respectively, Research Forest Engineer and Lematta Professor of Forest Engineering, Forest Engineering, Resources and Management Dept., Oregon State Univ., Corvallis (steve.pilkerton@oregonstate.edu, loren.kellogg@oregonstate.edu).
This paper was received for publication in February 2011. Article no. 11-00021.

Forest Prod. J. 61(3):202–209.

devices, diameter encoders, and computers on cut-to-length systems, coupled with mill price lists for length–diameter combinations, enable operational improvements toward 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.

This study evaluated 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, a distribution of log lengths acceptable 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 harvesting 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 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.

Using the log valuation and stem optimization capabilities of the OSU-BUCK software, the first objective of this research was to examine the value and volume differences for stems optimally bucked with a complete set of allowable log lengths and a reduced set of five lengths (COMBO) 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. The second research objective was to evaluate the validity of using a board foot–to–cubic foot (BF/CF) ratio to convert log prices in dollars per 1,000 BF ($/Mbf) to dollars per 100 CF ($/Ccf) as an approach to developing cubic foot–based pricing in the absence of mill-provided values.

Methods

The study evaluated the effect of log length on value and volume recovery of two sample sets of Douglas-fir 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.

Fifty sample trees were measured after felling/bucking and before 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 ft) at bucking cuts and in total to the top of the tree.

Average inside bark butt diameter for Stand 1 sample trees was 9.9 inches (standard deviation [SD] = 2.1 in.). Average stem length was 73.4 feet (SD = 9.7 ft) to a top diameter averaging 2.1 inches. These values compare favorably with stand diameter at breast height and height values of 9.8 inches and 71 feet, respectively (Kellogg et al. 1999). Average tree merchantable volume was 23 CF.

Stand 2 average inside bark butt diameter for the sample trees was 18.4 inches (SD = 5.0 in.). Average recovered stem length was 101.8 feet (SD = 19.6 ft) 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 CF per tree. Total length of the 50 sample stems was 3,670 feet in Stand 1 and 5,092 feet in Stand 2. These values were used to verify full allocation of each stem in the sample set.

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

Logging and hauling costs were set at zero to focus the analysis on log values. Because 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 5-inch, small-end scaling diameter (inside bark). The scenarios were

1. AS-BUCKED: As-Bucked[1] log lengths (12 to 40 ft) for butt and 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.
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 Northwest Log Rules Advisory Group (NLRAG 1995), 40-foot maximum scaling segment.
4. CF-COMBO: Optimally bucked; log lengths limited to 16, 20, 32, 36, and 40 feet; 1 foot of trim; 40-foot cubic foot volume basis.
5. CF (16): Optimally bucked, 16-foot log length only, 0.5-foot trim, 40-foot cubic foot volume basis.
6. CF (20): Optimally bucked, 20-foot log length only, 0.5-foot trim, 40-foot cubic foot volume basis.
7. CF (16, 20): Optimally bucked, 16- and 20-foot log

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

Table 1.—Log prices used in OSU-BUCK board foot– and cubic foot–based analysis.

Scaling length (ft)	$/Mbf	Stand 1 ($/Ccf)	Stand 2 ($/Ccf)
Sawlogs[a]			
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

[a] Sawlogs to 5-inch-diameter, inside bark.

lengths only, 0.5-foot trim, 40-foot cubic foot volume basis.

8. CF (16, 40): Optimally bucked, 16- and 40-foot log lengths only, 40-foot cubic foot volume basis.
9. CF (16, 20, 40): Optimally bucked, 16-, 20-, and 40-foot log lengths only, 40-foot cubic foot volume 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. CF-COMBO

The resulting sawlog data were imported into a spreadsheet and summarized, including total value of the sawlogs, board foot volume, cubic foot 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 1

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 $2,228. Using the BF/CF ratio of 3.64, the cubic foot–based value for the same logs was $2,214, a difference of $14 and a decrease of 0.63 percent. The mean BF/CF ratio for the 76 sawlogs was 3.73 (Table 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) solution achieved 90.4 percent of the optimal $2,466 under the board foot basis. Interestingly, the same log lengths achieved 94.4 percent of the optimal $2,346 under the cubic foot basis. The bucker bucked approximately 55 percent of all logs in 32-, 36-, or 40-foot lengths. More than 80 percent of the AS-BUCKED butt logs were in these three lengths.

The BF-OPTIMAL (Scenario 2) solution created more than 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-ft butt logs) and 1 inch in 5 feet for the fourth stem (12-ft butt log). Scribner scale rules provide for a taper of 1 inch in 10 feet.

The CF-OPTIMAL (Scenario 3) solution bucked more than 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-OPTIMAL 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 cubic foot solutions are not as sensitive to excessive taper. It should be noted that the BF/CF ratio calculated by dividing the total board foot volume by the total cubic foot volume for this scenario is 3.63. The mean BF/CF ratio for these 73 sawlogs is 3.71 (Table 2). The cubic foot bucking algorithm generated an additional 37 and 18 CF of volume compared with that achieved under Scenarios 1 and 2, respectively. This result reflects the increased total length of sawlogs for Scenario 3 (CF-OPTIMAL) compared with the first two scenarios. Note at the bottom of Table 2 the 0.42 CF per linear foot of sawlog. All scenarios had the required 3,670-foot allocation of total stem length.

One of the criticisms of the board foot–based 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 (Scenario 2) solution cutting 92 logs compared with 76 logs for the AS-BUCKED (Scenario 1) solution. The CF-OPTIMAL (Scenario 3) solution cut 73 logs, fewer than both the AS-BUCKED and BF-OPTIMAL solutions (Table 2).

Scenario 4 (CF-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[2] 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, while creating the fewest sawlogs (Table 2), still achieved 96.4 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- and 20-foot scenario, which matched the 4,000 BF of volume generated by the 16-foot scenario. Note that both scenarios had BF/CF ratios of more than 4.1. Scenario 6 (20-ft lengths only) had the lowest board foot volume of any scenario, likely because 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).

For Scenario 7, the 16-foot logs were only slightly favored (56.5%) over the 20-foot logs. This preference for 16-foot logs increases to 60 percent on a butt-logs-only

[2] Overrun is the 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.

Table 2.—Summary of sawlog values and volumes bucked from 50 sample trees for nine scenarios in Stand 1.[a]

	Scenarios								
	1: AS-BUCKED	2: BF-OPTIMAL	3: CF-OPTIMAL	4: CF-COMBO	5: CF (16)	6: CF (20)	7: CF (16, 20)	8: CF (16, 40)	9: CF (16, 20, 40)
Total sawlog value ($)	2,214	2,466	2,346	2,262	1,681	1,631	1,776	2,155	2,188
Value on BF basis ($)	2,228	2,466							
BF volume	3,610	4,170	3,710	3,520	4,000	3,340	4,000	3,400	3,390
CF volume	986	1,005	1,023	994	911	894	965	945	964
Average BF/CF ratio	3.73	4.24	3.71	3.65	4.41	3.66	4.15	3.86	3.69
Total no. of sawlogs	76	92	73	71	129	100	124	73	73
Total length of sawlogs (ft)	2,328	2,384	2,411	2,319	2,129	2,050	2,262	2,184	2,244
No. of fiber logs	50	50	50	50	50	50	50	50	50
Total length of fiber logs (ft)	1,342	1,286	1,259	1,351	1,541	1,620	1,408	1,486	1,426
Fiber CF volume	159	135	144	161	195	218	174	185	175
Total CF volume	1,144	1,140	1,167	1,155	1,107	1,113	1,139	1,130	1,139
CF fiber/CF total (%)	13.9	11.8	12.4	14.0	17.7	19.6	15.3	16.4	15.4
$ Total/CF total	1.95	2.16	2.01	1.96	1.52	1.47	1.56	1.91	1.92
$ Total/CF sawlog	2.25	2.45	2.29	2.28	1.84	1.82	1.84	2.28	2.27
BF/LF	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

[a] BF = board foot; CF = cubic foot; LF = linear foot.

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-OPTIMAL scenario value. It should be recognized that the prices for 16- and 20-foot log lengths were 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 unlike Scribner and other board foot rules, which use small-end diameters only, cubic log scaling rules account for actual taper.

The choice of log lengths is important. Analysis of the potential bucking points on an 80-foot stem shows only five and four locations with 16- and 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-, or 40-ft lengths) provides 14 potential bucking points to an 80-foot merchantable top. However, if the long log used has a 32-foot length, mill recovery of lumber is limited to 8 through 24 feet if a minimum 8-foot mill-length log is assumed. By comparison, logs of 36 and 40 feet 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 lengths scenario (COMBO), the best three log lengths scenario consisted of 16-, 20-, and 40-foot lengths. The best two log lengths scenario consisted of 16- and 40-foot log lengths. Table 3 summarizes these results in terms of total length and cubic foot volume of sawlog manufactured, number of sawlogs, percent fiber, and percent by volume of long logs ($\geq$36 ft). 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 ‘‘camp-run’’ (single log price per unit volume, independent of length or grade) scenario (all lengths from 12 to 40 ft), the length of recovered sawlogs is a maximum at 2,479 feet, or 67.6 percent of the total stem length analyzed for the 50 stems. In contrast, the two log lengths solution only utilizes 60 percent of the stem length for sawlogs. Fifty fiber logs were produced under each scenario. For the sample trees evaluated, no less than 12 percent of the cubic foot volume would become fiber material with a 5-inch minimum diameter requirement for sawlogs.

Stand 2

The AS-BUCKED solution approach generated 94 percent of the OSU-BUCK optimal value on a board foot basis (BF-OPTIMAL). The CF-COMBO approach generated 98 percent of the CF-OPTIMAL value. The 50 trees created 158, 152, and 148 sawlogs for the BF-OPTIMAL, AS-BUCKED, and CF-COMBO solutions, respectively (Table 4). 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 of potential sawlog compared with the CF-COMBO solution. This is caused by the board foot scaling rules in long, small-diameter logs; that is, a 36-foot by 6-inch log has 60 BF, compared with 40 BF if that log were extended to 40 feet but with a 5-inch scaling diameter as a result.

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 $/

Table 3.—Summary of five, three, and two log lengths scenarios compared with "As-Bucked" solution for Stand 1.[a]

	Scenarios			
	AS-BUCKED	CF-COMBO	CF (16, 20, 40)	CF (16, 40)
No. of log lengths	15	5	3	2
Total length of sawlogs (ft)	2,328	2,319	2,244	2,184
CF sawlog volume	986	994	964	945
Total no. of sawlogs	76	71	73	73
Long logs (≥36 ft, % by volume)	60	67	80	82
% fiber	13.9	14.0	15.4	16.4
No. of fiber logs	50	50	50	50
Total length of fiber logs (ft)	1,342	1,351	1,426	1,486
Fiber CF volume	159	161	175	185
Total CF volume	1,144	1,155	1,139	1,130

[a] CF = cubic foot.

Ccf log prices. For Stand 2, under the board foot values, the 50 stems were valued at $17,645. Using the BF/CF ratio of 4.85, the cubic foot–based value for the same logs was $18,594—a difference of $949 and an increase of 5.4 percent. The mean BF/CF ratio for the 152 sawlogs was 4.36 (Table 4). Recall that the $/Ccf 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 $/Ccf from $/Mbf in larger-diameter stands. A BF/CF ratio of 4.60 is derived for pricing conversion using the resulting value ($17,645) and volumes (27,970 BF, 6,087 CF) for the sawlogs. This BF/CF ratio was not used, but it 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 to utilize as much of the merchantable stem as possible within the allowable log lengths. This is an improvement over the BF-OPTIMAL solution, in which short logs are incorporated more often due to Scribner scaling rules. Additionally, the percentages of long logs (lengths $\geq$ 36 ft) were 49 and 69 percent for board foot– and cubic foot–based optimal solutions, respectively. The CF-COMBO approach generated 76 percent of the volume in long logs, 63 percent of which was 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 is shown in Table 5.

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

The cubic foot–based optimal solutions from OSU-BUCK improve on the criticisms of board foot–based optimal solutions: They minimize short logs, cut the desirable percentage of long logs without artificial price adjusters, and allocate more of the stem length to sawlogs.

Discussion

The single value average for the BF/CF ratio used in the Stand 1 analysis created a difference of 5 percent between the board foot– and cubic foot–based optimal values. The different log-length solutions account for some of this difference. The optimal board foot solutions were entered as User Solutions under the cubic foot basis in anticipation of this possibility. The resulting cubic foot–based value of $2,180 for the board foot–based bucking solution is 92.9 percent of the CF-OPTIMAL value. This shows that the apparent increase of $120 ($2,466 − $2,346) for the 50 stems when bucked on a board foot basis is related to the well-known step-function of Scribner scale for scaling diameters less than 11 inches. The increase of $120 is related to increased board foot scale. Compare the board

Table 4.—Summary of Stand 2 sawlog values and volumes bucked from 50 sample trees for four different scenarios.[a]

	Scenarios			
	1: AS-BUCKED	2: BF-OPTIMAL	3: CF-OPTIMAL	4: CF-COMBO
Total sawlog value ($)	18,594	18,742	19,042	18,696
Value on BF basis ($)	17,645	18,742		
BF volume	27,970	30,270	28,900	28,290
CF volume	6,087	6,196	6,209	6,119
Average BF/CF ratio	4.36	4.59	4.39	4.42
Total no. of sawlogs	152	158	150	148
Total length of sawlogs (ft)	5,046	5,013	5,044	4,980
Long logs (≥36 ft, % by volume)	80	49	69	75
$ Total/CF volume	3.05	3.02	3.07	3.06
BF/LF	5.54	6.04	5.73	5.68
CF/LF of sawlog	1.21	1.24	1.23	1.23

[a] BF = board foot; CF = cubic foot; LF = linear foot.

Table 5.—Percent volume by log-length distribution for the CF-COMBO solution

Log length (ft)	Volume (%)
36 and 40	76
32	17
16 and 20	7

foot volumes of 4,170 and 3,710 in Table 2 for Scenarios 2 and 3. Another point of evidence is the BF/CF ratio of 4.24 resulting from Scenario 2. The BF/CF ratio will maximize at the beginning of a step function for a given log diameter. Because cubic foot volume increases with log length and the board foot 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 6). The board foot–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. Interestingly, a high BF/CF ratio occurs in 6-inch-diameter logs. This is even evident in Cahill's (1984) table, with a higher BF/CF ratio for 6-inch-diameter logs (3.32) than for 7-inch-diameter logs (3.25).

As seen in the board foot and cubic foot value analyses 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 they are difficult to apply in practice. Some mills purchase logs on a weight basis (\$/ton). This is likely a conversion from analysis of proprietary known weights and board foot recovery. It is difficult to evaluate various board foot–to–cubic foot pricing conversion strategies without this information.

Timberland owners have a need for pricing conversions. Cubic foot volume measurements more accurately reflect products (e.g., lumber, veneer, chips, and flakes) and

Table 6.—Scribner board foot (BF) volume table by scaling diameter and length.[a]

	Diameter, small end, inside bark (in.)							
Length (ft)	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

[a] Blanks denote identical volumes within a column from previous breakpoints; for example, a 5-inch-diameter log has 20 BF from 16 through 22 feet.

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, log marketers 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 Stands 1 and 2 suggest Cahill's (1984) values can be used as a starting point for the 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 (i.e., of higher value) than 20-foot lengths. Higher value may be more a function of recoverable log length in a given stem. For example, a stem that has a 40-foot length to a 5-inch top would be fully recovered with 20-foot logs (provided adequate trim is available) compared with 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 as opposed to 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 that the COMBO scenario has such a high recovery percentage, given only five log lengths 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-length logs of 32, 36, and 40 ft). This holds for both thinning-aged 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 with the CF-OPTIMAL solution, the AS-BUCKED (bucker's choice) solution resulted in a decreased potential revenue of \$2.44 per tree. The CF-COMBO solution resulted in a decrease of \$1.50 per tree. Evaluation of the effort required to capture these gains is critical, because falling/bucking costs can approach \$0.50 per minute (Olsen et al. 1997).

Obtaining the data to optimally evaluate the stem takes additional time. At breakeven revenue (i.e., increased value of logs less cost of obtaining data inputs), an additional 5 minutes could be spent by the bucker to optimally improve the bucking pattern. Olsen et al. (1991) estimates that 4 minutes per tree is required for second-growth Douglas-fir stems. For breakeven revenue, this would need to be reduced to 2 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 for the logging contractor costs the timber owner $1.50 per tree. The simplified set of log lengths in the CF-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/Ccf.

The magnitude of gains is larger for larger trees (Stand 2). Comparing AS-BUCKED and CF-COMBO to the BF-OPTIMAL solutions under $/Mbf pricing shows potential value improvements of $21.94 and $11.12 per tree, respectively. The CF-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/Ccf. The CF-COMBO solution is computer based; thus, input costs (i.e., 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 data set. 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 in which the bucker measures merchantable stem length and looks up the log-length pattern (Table 7). 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.

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 foot–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 had a 32-foot 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 sublength (18-, 16-, 14-, 12-, 10-, 8-ft) lumber more valuable than two 16-foot logs and resulting sublength (14-, 12-, 10-, 8-ft) 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, in which lumber prices and recovery data for mill purchasers (bidders) are proprietary.

Table 7.—Log bucking pattern (sequential log lengths) as a function of merchantable length.[a]

Total merchantable length (ft)	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

[a] For example clarity, trim requirement = 0.

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 (1984) values. Alternatively, OSU-BUCK outputs of values as well as board foot and cubic foot volumes for logs (by length and diameters) could permit development of a regression 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 regarding how a set of lengths (i.e., a three-log, distinct-length solution results in six 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. Timber owners may develop $/Ccf log pricing from $/Mbf quotes.

Constraining allowable bucking lengths reduces the total value recovered from harvested stems. Cutting only 16- or 20-foot log lengths produces 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. OSU-BUCK maximizes the length of recovered sawlog material under the cubic foot–based analysis.

The cubic foot–based log values converted by a BF/CF ratio appeared to value a given set of logs similarly as the board foot values that 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.

The OSU-BUCK cubic foot–based solution approach is preferable to the board foot–based solution 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 cubic foot basis, attention to Scribner diameter–length breakpoints is required when bucking on a board foot basis, especially in young, thinning-aged stands.

The COMBO strategy of bucked log lengths equal to combinations of 16- and 20-foot mill-length logs, corresponding to 32-, 36-, and 40-foot woods-length logs, achieved 96 to 98 percent of the cubic foot–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. 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.

Acknowledgments

The authors thank Sue Willits, USDA Forest Service, Pacific Northwest Research Station, for her query which initiated, and for securing funding for, this research. The authors also thank Dennis Dykstra, USDA Forest Service, Pacific Northwest Research Station; Scott Leavengood, Oregon Wood Innovation Center, Oregon State University; and the two peer reviewers for their comments and improvements to this manuscript.

Literature Cited

Briggs, D. G. 1994. Forest products measurements and conversion factors: With special emphasis on the U.S. Pacific Northwest. Contribution 75. Institute of Forest Resources. University of Washington, Seattle. 161 pp.

Cahill, J. M. 1984. Log scale conversion factors. *In:* User's Guide for Cubic Measurement. T. A. Snellgrove, T. D. Fahey, and B. S. Bryant (Eds.). University of Washington, Seattle. pp. 58–65.

Evanson, T. 1996. Computer assisted log making. Report 21(4). Logging Industry Research Organization, Rotorua, New Zealand.

Faaland, B. and D. Briggs. 1984. Log bucking and lumber manufacturing using dynamic programming. *Manage. Sci*. 30(2):245–257.

Fahey, T. D. and D. C. Martin. 1974. Lumber recovery from second-growth Douglas-fir. Research Paper PNW-RP-177. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon. 20 pp.

Fight, R. D. and J. T. Chmelik. 1998. Analysts guide to FEEMA for financial analysis of ecosystem management activities. General Technical Report FPL-GTR-111. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. 5 pp.

Fight, R. D., J. T. Chmelik, and E. A. Coulter. 2001. Analysts Guide: TreeVal for Windows, Version 2.0. General Technical Report PNW-GTR-514. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon. 21 pp.

Garland, J., J. Sessions, and E. D. Olsen. 1989. Manufacturing logs with computer-aided bucking at the stump. *Forest Prod. J*. 39(3):62–66.

Hallock, H., P. Steele, and R. Selin. 1979. Comparing lumber yields from board-foot and cubically scaled logs. Research Paper FPL 324. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. 16 pp.

Haynes, R. W. and R. D. Fight. 1992. Price projections for selected grades of Douglas-fir, Coast hem-fir, inland hem-fir, and ponderosa pine. Research Paper PNW-RP-447. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon. 20 pp.

Herajarvi, H. and E. Verkasalo. 2002. Timber grade distribution and relative stumpage value of mature Finnish *Betula pendula* and *B. pubescens* when applying different bucking principles. *Forest Prod. J*. 52(7/8):40–51.

Kellogg, L. D., M. M. Miller, Jr., and E. D. Olsen. 1999. Skyline thinning production and costs: Experience from the Willamette Young Stand Project. Research Contribution 21. Forest Research Laboratory, Oregon State University, Corvallis. 33 pp.

Kellogg, L. D., G. V. Milota, and B. Stringham. 1998. Logging planning and layout costs for thinning: Experience from the Willamette Young Stand Project. Research Contribution 20. Forest Research Laboratory, Oregon State University, Corvallis. 20 pp.

Kivinen, V.-P. 2007. Design and testing of stand-specific bucking instructions for use on modern cut-to-length harvesters. Academic Dissertation 37. Faculty of Agriculture and Forestry, University of Helsinki.

Malinen, J. and T. Palander. 2004. Metrics for distribution similarity applied to the bucking to demand procedure. *Int. J. Forest Eng*. 15(1): 33–40.

Maness, T. C. and D. M. Adams. 1991. The combined optimization of log bucking and sawing strategies. *Wood Fiber Sci*. 23(2):296–314.

Marshall, H. D., G. Murphy, and K. Boston. 2006. Three mathematical models for bucking-to-order. *Silva Fenn*. 40(1):127–142.

Mendoza, G. A. and B. B. Bare. 1986. A two-stage decision model for log bucking and allocation. *Forest Prod. J*. 36(10):70–74.

Middleton, G. R. and B. D. Munro. 1989. Log and lumber yields. *In:* Second Growth Douglas-Fir: Its Management and Conversion for Value. R. M. Kellogg (Ed.). Special Publication SP-32. Forintek Canada Corp., Vancouver, British Columbia. pp. 66–74.

Murphy, G., H. Marshall, and M. C. Bolding. 2004. Adaptive control for bucking on harvesters to meet order book constraints. *Forest Prod. J*. 54(12):114–121.

Nagubadi, R. V., R. D. Fight, and R. J. Barbour. 2003. Valuing a log: Alternative approaches. Research Note PNW-RN-541. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon. 15 pp.

Nordmark, U. 2005. Value recovery and production control in bucking, log sorting, and log breakdown. *Forest Prod. J*. 55(6):73–79.

Northwest Log Rules Advisory Group (NLRAG). 1995. Official rules for the following log scaling and grading bureaus: Columbia River, Grays Harbor, Northern California, Puget Sound, Southern Oregon, Yamhill. 1982 ed., reprinted 1995. NLRAG, Eugene, Oregon. 48 pp.

Olsen, E., B. Stringham, and S. Pilkerton. 1997. Optimal bucking: Two trials with commercial OSU-BUCK software. Research Contribution 16. Forest Research Laboratory, Oregon State University, Corvallis. 32 pp.

Olsen, E. D., S. Pilkerton, J. Garland, and J. Sessions. 1991. Questions about optimal bucking. Research Bulletin 71. Forest Research Laboratory, Oregon State University, Corvallis. 18 pp.

Patterson, D. W., H. V. Wiant, Jr., and G. B. Wood. 1993. Log volume estimations: The centroid method and standard formulas. *J. Forestry* 91(8):39–41.

Pearse, P. H. and S. Sydneysmith. 1966. Method for allocating logs among several utilization processes. *Forest Prod. J*. 16(9):87–98.

Pickens, J. B., G. W. Lyon, A. Lee, and W. E. Frayer. 1993. HW-BUCK game improves hardwood bucking skills. *J. Forestry* 91(8):42–45.

Pnevmaticos, S. M. and S. H. Mann. 1972. Dynamic programming in tree bucking. *Forest Prod. J*. 22(2):26–30.

Random Lengths. 2008. The weekly report of North American forest products markets. Vol. 64. Random Lengths Publications, Eugene, Oregon.

Sessions, J. 1988. Making better tree-bucking decisions in the woods: An introduction to optimal bucking. *J. Forestry* 86(10):43–45.

Sessions, J. B., S. J. Pilkerton, E. D. Olsen, and B. J. Stringham. 1993. OSU-BUCK User's Manual. Forest Engineering Department, Oregon State University, Corvallis. 160 pp.

Wang, J., C. B. LeDoux, and J. F. McNeel. 2004. Optimal tree-stem bucking of northeastern species of China. *Forest Prod. J*. 54(2): 45–52.

Willits, S. A. and T. D. Fahey. 1988. Lumber recovery of Douglas-fir from the Coast and Cascade Ranges of Oregon and Washington. Research Paper PNW-RP-400. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon. 32 pp.