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Stump-to-Mill Timber Production Cost Equations for Cable Logging Eastern Hardwoods

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Abstract

Logging cost simulators and data from logging cost studies have been assembled and converted into a series of equations that can be used to estimate the stump-to-mill cost of cable logging in mountainous terrain in the Eastern United States. These equations include the use of two small and four medium-size cable yarders and are appropriate for harvested trees ranging in diameter from 6 to 24 inches. Cost components can be determined easily with a hand calculator. A program that can be used with many desktop computers also is available that calculates the total stump-to-mill logging cost for specific logging conditions.

Introduction

Cost equations for stump-to-mill timber production were developed for logging hardwoods in the Eastern United States. The equations are applicable only to uphill skyline cable logging. They can be used for equipment selection, timber stand prescription planning, optimization of silvicultural decisions, break-even analysis, and silvicultural investment analysis. The equations summarized here include equipment that reflects nearly all of the conditions a logger or planner would encounter on steep, mountainous terrain in the Eastern United States.

The equations were developed by using 1984 new equipment, labor, and fuel costs (Table 1); time and motion study data from Baumgras[1] and others (Fisher and Peters 1983; Rossie 1983); USDA Forest Service regional timber appraisal guides; regression methods (Draper and Smith 1966); and simulation analysis (LeDoux and Butler 1981). Estimates of yield volume were derived from forest model plots.[2] Presented here are specific cost equations for felling, limbing, bucking, yarding, loading, and hauling. The equations are exclusive of profit.

[1]Baumgras, J. E. Time-study data for the Bitterroot Yarder. 1984. Unpublished report on file at the Northeastern Forest Experiment Station, 180 Canfield St., P.O. Box 4360, Morgantown, West Virginia 26505.

[2]One-acre forest model plot. (No date). Unpublished data on file at the Northeastern Forest Experiment Station, 180 Canfield St., P.O. Box 4360, Morgantown, West Virginia 26505.

Because the data from which these equations were developed are generated by simulators, they do not have the degree of variability that one finds in empirical cost data. Therefore, the R^2 values from the regressions are much higher than would result from regressions derived from sample data from actual field studies. The R^2 values indicate that the equations efficiently reproduce the simulator results. They do not demonstrate how well the simulation results compare with actual costs.

Felling, Limbing, and Bucking Cost Equation

Delay-free cost estimates (data points) for felling, limbing, and bucking with chain saws were developed for a range of diameters of harvested trees (Martin 1975). The stands chosen were from forest model plots of eastern hardwoods (Table 2). Each stand was thinned using a d/D ratio (arithmetic mean diameter of cut trees/arithmetic mean diameter of stand) of 1.0 to levels of 30 percent, 50 percent, and then clearcut. The trees cut from each treatment were bucked into logs[3] and the pooled data points (Table 3) used to develop a general equation for felling, limbing, and bucking cost by arithmetic mean diameter of cut trees:

[3]LeDoux, C. B. Hardwood log bucking simulator. 1984. Unpublished computer program on file at the Northeastern Forest Experiment Station, 180 Canfield St., P.O. Box 4360, Morgantown, West Virginia 26505.

Table 1.—Hourly yarding costs[a] for six yarding systems

Yarding system	Equipment[b]	Labor[c]	Chain saws[d]	Carriage	Radio signal[e]	Total
	----------	----------	Dollars/hr	----------	----------	----------
Bitterroot	6.26	13.00	2.65	0.61	1.09	23.61
Appalachian Thinner	14.35	26.00	2.65	0.00	1.09	44.09
Koller K-300	10.95	32.50	2.65	0.65	1.09	47.84
Ecologger I	18.81	32.50	2.65	0.72	1.09	55.77
Urus 1000-3	34.63	32.50	2.65	0.80	1.09	71.67
Skylok 78	78.13	39.00	2.65	0.88	1.09	121.65

[a]Includes all new equipment (costs obtained from equipment dealers).
[b]Includes depreciation, insurance, interest, operating costs (fuel, oil, lubricants, maintenance, repair, and taxes), and rigging.
[c]Rates obtained from cost guide for empirical appraisals, USDA Forest Service, Region 9, Amendment 112.
[d]Three chain saws.
[e]Three transmitters.

Table 2.—Stand data for forest model plots A2, B10, C8, D14, E13, F4, G4M, and H4M

Forest model plot	Average d.b.h.[a]	Merchantable volume[b]	Number of trees/acre[c]
	Inches	Ft^3	
A2	7.2	2652	222
B10	8.1	2528	214
C8	9.1	3556	245
D14	11.6	3124	166
E13	12.7	4922	183
F4	16.8	6315	176
G4M	20.4	6466	162
H4M	24.0	6871	174

[a]Trees 5 inches or larger in d.b.h. included in the average.
[b]Logs less than 4 feet long and less than 4 inches top diameter not included as merchantable volume.
[c]Trees 5 inches or larger in d.b.h. included.

Table 3.—Log size parameters by bucking rule for forest model plots A2, B10, C8, D14, E13, F4, G4M, and H4M

Forest model plot	Bucking rule	Log size			Standard deviation
		Mean	Minimum	Maximum	
	Lb	Ft^3			
A2	1500	9.6	0.6	24.9	9.1
	3000	11.2	0.7	48.8	13.2
	6000	12.9	0.7	99.5	20.6
B10	1500	9.7	0.5	24.5	7.8
	3000	11.6	0.7	45.1	11.5
	6000	12.2	0.7	75.6	13.2
C8	1500	11.4	0.5	24.9	8.4
	3000	13.7	0.7	48.2	12.9
	6000	15.7	0.8	86.5	18.9
D14	1500	--	--	--	--
	3000	17.7	0.7	49.2	14.4
	6000	21.1	1.7	97.2	21.1
E13	1500	--	--	--	--
	3000	25.2	0.5	66.6	15.7
	6000	33.3	0.7	99.8	28.3
F4	1500	--	--	--	--
	3000	33.1	0.5	54.8	14.4
	6000	57.4	0.8	100.0	34.5
G4M	1500	--	--	--	--
	3000	--	--	--	--
	6000	62.3	0.8	99.2	35.0
H4M	1500	--	--	--	--
	3000	--	--	--	--
	6000	55.8	0.8	99.2	39.0

$$\$/ft^3 = 0.43744 - 0.11407*LN(DBH)$$
$$R^2 = 0.983$$

where:

DBH = Arithmetic mean tree diameter at breast height, in inches
LN = Natural logarithm

Variable limits for DBH = 6 to 24 inches The limits on the variable diameter (DBH) should be observed carefully.

Yarding Cost Equations

Simulated, delay-free data points for yarding cost were developed for six uphill cable yarders under a wide range of diameters (DBH), volume cut per acre (VOAC), and average slope yarding distance (SYD). The stand and treatment conditions are identical to those used to develop data for felling, limbing, and bucking (Tables 2-3). The THIN (LeDoux and Butler 1981) model and time-study data cited previously were used to develop the delay-free data points by making numerous simulations. The simulated data points were pooled by yarder to develop delay-free cost equations for each of the six yarders. Nonlinear multiple regression analysis was used to summarize the delay-free data points and the independent variables (Table 4).

Table 4.—Simulated delay-free cost equations by yarder for forest model plots A2, B10, C8, D14, E13, F4, G4M, and H4M

Yarder	Equation	R^2
Skylok 78	$\$/ft^3 = 0.090775 + 0.000071*(SYD)^a + 739.473795*(1/(VOAC*DBH))^{b/c} + 0.594844*(1/DBH)$	0.703
Appalachian Thinner	$\$/ft^3 = -0.089289 + 81.991053*(1/VOAC) + 0.000269*(SYD) - 496.820821*(1/(VOAC*DBH)) + 1.535553*(1/DBH)$	0.870
Urus 1000-3	$\$/ft^3 = 0.203908 - 0.000387*(DBH^2) + 13.160361*(1/VOAC) + 0.000144*(SYD)$	0.795
Bitterroot	$\$/ft^3 = 0.161995 - 0.000783*(DBH^2) + 0.000172*(SYD)$	0.912
Koller K-300	$\$/ft^3 = 0.167004 - 0.000343*(DBH^2) + 0.000146*(SYD)$	0.823
Ecologger I	$\$/ft^3 = 0.707187 - 0.050285*(DBH) + 0.001089*(DBH^2) + 33.101018*(1/VOAC) + 0.000168*(SYD) - 2.095831*(1/DBH)$	0.842

[a]SYD = Average slope distance, feet; variable limits = 50 to 950.
[b]VOAC = Average volume removed per acre, cubic feet; variable limits = 780 to 6,871.
[c]DBH = Average tree diameter at breast height, inches; variable limits = 7 to 9 for the Bitterroot; 7 to 16 for Koller K-300; 7 to 24 for all others.

The equations are yarder specific and rigged in the following uphill configurations: Skylok 78[4] rigged as a running skyline; Appalachian Thinner rigged as a jammer; Urus 1000-3 rigged as a standing skyline; Bitterroot rigged as a shotgun; Koller K-300 rigged as a shotgun; and the Ecologger I rigged as a live skyline. These types of equipment as rigged reflect most of the conditions a logger would encounter on steep terrain. Of course, there are many yarding machines to choose from so our equipment equations are not exclusive.

Managers must be careful not to mismatch equipment with the size of logs to be removed. Mismatches can result in a combination of high costs and increased stand damage and safety hazards. The cost equations assume that the Koller K-300 will not be used in stands with trees larger than 16 inches and that the Bitterroot will not be used in stands where the average d.b.h. exceeds 9 inches.

Loading Cost Equation

Delay-free cost estimates (data points) for loading were developed with time-study data (Koger 1982) for a range of diameters of harvested trees. The stand and treatment conditions are identical to those used to develop equations for felling, limbing, bucking, and yarding (Tables 2-3). These data points were used to develop the following equation:

$$\$/ft^3 = -0.04282 + 1.02238*(1/DBH)$$
$$R^2 = 0.968$$

where:

DBH = Arithmetic mean tree diameter at breast height, in inches
Variable limits for DBH = 6 to 22 inches

The delay-free cost equation for loading was developed from data that represent an average of several types of loading machine. Some adjustment maybe necessary if these equations are used for loading machines that are other than "average."

Hauling Cost Equation

Empirical cost data from USDA Forest Service regional timber appraisal guides were used to develop an equation to predict log hauling costs for a range of truck classes operating on a range of road classes. The following equation was developed:

$$\$/ft^3/\text{haul mile} = -0.0071667 + 0.0008333*TC + 0.0037629*RC$$
$$R^2 = 0.792$$

where:

TC = Truck class
RC = Road class

Truck class limits are:

Class	Body type
5	Flat bed, 4x2, single axle
4	Flat bed, 6x4, tandem axle
3	Truck tractor 4x2, single axle with tandem trailer
2	Truck tractor, 6x4, tandem axle with tandem trailer
1	Truck tractor, 6x4, tandem axle with tandem 30-35 foot trailer w/additional 15-20 foot trailer

Road class limits are:

Class	Design speed (Miles/hour)
2	35
3	25
4	16
5	8
6	4

The hauling cost equation for loading should not be used for other road or truck classes; to do so could result in gross errors.

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[4] The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Logging Delays

The delay-free cost estimates must be adjusted for delays. Data for estimating logging delay percentages are sketchy. Delay percentage is the proportion of nonproductive time. One minus the proportion of nonproductive time is the proportion of productive time. For example, if the delay is 10 percent, the proportion of nonproductive time is 0.1 and the portion of productive time is 0.9. Delay-free cost estimates are adjusted by dividing them by the proportion of productive time to obtain the respective cost with delay. The literature indicates ranges of delay percentages for each of the cost components detailed in this report. Delay percentages are summarized by component in Table 5.

Delay-free costs should be adjusted for each component. For example, say a logger is estimating felling, bucking, and limbing costs for a hardwood stand with an average arithmetic tree diameter at breast height of 11.6 inches. Delay-free felling, bucking, limbing cost is:

= 0.43794 -0.11407*LN(11.6)
= 0.43794 -0.11407*(2.4510)
= 0.158.

Adjusting delay-free cost with an average delay percentage of 0.20 (Table 5) = 0.158/(1-0.20) = 0.158/0.80 or $0.197/ft^3$. Similar adjustments should be made for each cost component. The delay percentages summarized in Table 5 are not exclusive, so users may wish to substitute their own delay percentage based on experience or observation.

Table 5.—Delays for felling, bucking, limbing, yarding, loading, and hauling of eastern hardwoods, in percent

Cost component	Delay		
	Average	Minimum	Maximum
Felling, bucking, and limbing	0.20	0.07	0.47
Yarding[a]	0.27	0.09	0.61
Loading	0.08	0.02	0.19
Hauling	0.17	0.04	0.36

[a]Delay percentage includes road changing time and delay.

Move In and Out, Initial Rig Up and Down

Both move in and out and initial rig up and down costs likely will change with tract size, volume removed, distance or move, and equipment being moved. The literature is essentially void of costs for cable yarding machines operating in eastern forests. The recommended approach is that individual users estimate these costs for specific conditions and then add them to those estimated with the component cost equations presented here.

Using the Equations

The cost equations in this report reflect average conditions typically encountered in logging operations on steep, mountainous terrain in the Eastern United States. These equations provide detailed stump-to-mill cost estimates for thinning, partial cutting, shelterwood cutting, or clearcutting of hardwood stands in this region. The equations should be studied by potential users, compared with the current method of cost estimation, and used only within the limits of the conditions specified.

The cost and delay equations were developed on a component-by-component basis to allow users maximum flexibility in making changes as needed. If users have other cost estimates that are more specific to their conditions, those estimates should be substituted for the respective cost or delay component. A BASIC computer program that calculates costs with these equations is available from the author.[3] The program is specific to the Hewlett-Packard 9845T desktop computer.

Application of the Costing Methodology

To use these cost equations, the estimator will need to know the: (1) arithmetic mean tree d.b.h. to be harvested; (2) average volume cut per acre, in cubic feet; (3) average slope yarding distance, in feet; (4) yarder type (six to select from); (5) haul distance; (6) truck class; and (7) road class. These items can be obtained from inventory data and cruise data, and the logging plan for the tract in question.

Table 6 shows the stump-to-mill logging cost for a 30-acre tract. In this example, yarding is done with a Koller K-300; the round-trip hauling distance is 40 miles; the average slope yarding distance is 500 feet; the average volume removed is 1000 ft^3/acre; the road class is 3 and the truck class is 3; and the average d.b.h. of cut trees is 10 inches. The values used for these variables are not representative of actual conditions but were selected to make this example easy to follow.

Some adjustments to these estimated costs may be desirable depending on their intended use. The estimated costs do not include an allowance for profit and risk, but neither do they include recognition of the tax savings resulting from accelerated depreciation.

Table 6.--Estimated logging costs for sample 30-acre tract

Operation	Delay-free cost	Average delay	Costs with delay
	Dollars/ft^3	Percent	Dollars/ft^3
Fell, limb, buck	0.175	20	0.219
Yarding (Koller K-300)	0.206	27	0.282
Loading	0.059	8	0.064
Hauling	0.007	17	0.319
Total cost/ft^3	--	--	0.884

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