Stump-to-Truck Cable Logging Cost Equations for Young-Growth Douglas-fir

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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 cost of logging young-growth coastal Douglas-fir (*Pseudotsuga menziesii *[Mirb.] Franco var.* menziesii*) in mountainous terrain of the Pacific Northwest. These equations were developed for two small cable yarders and one medium-sized yarder and are applicable for harvests of timber from 6 to 24 inches in diameter on slopes of 10 to 50%. Cost components can be easily calculated on a hand calculator. A computer program that can be adapted to many desktop computers and that will calculate the total stump-to-truck logging cost for a specified set of logging conditions is also available.*

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In this paper we present new equations that can be used for estimating the cost of logging Douglas-fir from stump-to-truck in the Pacific Northwest. The equations are applicable only to uphill skyline cable logging. They can be used in making timber appraisals, planning timber stand prescriptions, optimizing silvicultural decisions, and performing break-even analyses and silvicultural investment analysis. The equations reflect types of equipment and configurations that span most situations that a logger or planner would encounter on the mountainous terrain of the Pacific Northwest.

The equations were developed by using 1983 labor costs; new equipment and fuel costs; time and motion study data (Adams 1967, Fieber 1979, Gabrielli 1980, LeDoux 1983, 1984, LeDoux and Adams 1983, McIntire 1981, Neilson 1977, Schneider 1978, Van Winkle 1977); regional appraisal guides (U.S. Department of the Interior 1977, U.S. Department of Agriculture 1979); regression methods (Draper and Smith 1966); and simulation analysis (LeDoux and Butler 1981, LeDoux and Brodie 1982). Growth and yield volume estimates were derived from McArdle et al. *1961) and DFSIM (Curtis et al. 1981). The cost equations presented here are for felling, limbing, and bucking; yarding; loading; road changing; and moving in, moving out, rigging up and rigging down. An equation for determining the number of logs per 1,000 ft^3 of wood by average dbh of cut trees is also provided. Cost equations are based on straight-line depreciation, estimated salvage value, and a 15% rate of return on invested capital.

Because the data from which these equations are developed are generated by simulators, they do not have the variability normally found in empirical cost data. The R^2 values from the regressions are therefore much higher than would result from regressions based on sample data from actual field studies. The R^2 values show that the equations do a good job of reproducing the simulator results. They do not indicate how well the simulator results compare with actual costs.

All volumes and all costs per unit of volume relate to ft^3 volumes. Because there are so many variations of bd/ft volumes, we do not attempt to convert any data to a bd/ft basis. See Dykstra (1978) for a discussion of conversion ratios and a table of conversion ratios for some stands in the Douglas-fir region.

EQUATIONS FOR ESTIMATING FELLING, LIMBING, AND BUCKING COST

Delay-free estimates (data points) of felling, limbing, and bucking costs were developed for a range of diameters of harvested trees (Adams 1967, Curtis et al. 1981, McArdle et al. 1961, Starnes 1983). The stands chosen were Douglas-fir site III and IV. Each stand was thinned with a d/D ratio (diameter of cut trees/diameter of stand) of 1.0 at ages 40, 60, 80, 100, and 120 to levels of 10, 20, 30, 40, and 50%, and then was clearcut. Trees 5.0 in dbh and larger were utilized to a 4-in top. The cut trees from each treatment were bucked into logs (Starnes 1983), and the pooled data points (Table 1) were used to develop a general equation for felling, limbing, and bucking costs by arithmetic mean diameter of cut trees:

$$\$/MCF = -17.4 + 876/DBH$$
$$R^2 = 0.97$$

where

MCF = thousand cu ft

DBH = arithmetic mean dbh in inches

The variable limits for DBH are 6 to 24 in.

It is important that the stated variable limits for the equations be carefully observed. Extrapolations beyond the variable limits specified for this equation and other equations may give implausible results.

Delay-free costs must be adjusted to allow for nonproductive time. Delay percentage is the proportion of nonproductive time expressed as a percentage of total time. One minus the proportion of nonproductive time is the proportion of productive time. For example, if the delay is 10%, the proportion of nonproductive time is 0.1, and the proportion of productive time is 0.9. The delay-free cost is adjusted by dividing it by the proportion of productive time to get the cost with delay.

Data for estimating delay for all phases of logging are sketchy. The delay equations presented in this paper are generally based on ranges of delay reported in various studies. Nonproductive time can be highly variable, however, and may be related to operator skill and local operating practices. Users may be able to im-

Table 1. Distribution of log sizes for Douglas-fir site III and IV.

Stand age (yr)	Log volumes (ft^3) Mean	Minimum	Maximum	Standard deviation	Average log length (ft)
40	6.2	3.9	18.6	3.2	29.08
60	11.9	4.2	47.5	9.3	31.59
80	18.1	3.6	72.1	15.7	32.35
100	24.3	3.4	94.6	21.5	33.88
120	30.0	3.5	124.3	27.2	34.38

prove cost estimates for particular situations by adjusting the delay equations to more closely represent their experience. Available literature indicates that there is a delay of about 4% for felling, limbing, and bucking in clearcutting. For thinning delays, we establish two points: 17% delay at 0.4 *MCF*/ac and 4% delay at 4.3 *MCF*/ac. These two points are connected with a straight line. The resulting equation for felling, limbing, and bucking delay is:

$$\text{Percent delay} = 18.3 - 3.33(VOAC)$$

where

$VOAC$ = volume removed per acre in *MCF*

The variable limits for *VOAC* are 0.4 to 4.3 *MCF*; when *VOAC* exceeds 4.3, delay is 4%.

Assume, for example, that we are developing felling, limbing, and bucking costs for thinning a stand with an arithmetic mean diameter of cut trees of 10 in ($DBH = 10$), and a volume/ac removal of 1,000 ft^3 ($VOAC = 1$). The delay-free cost would be $70/*MCF*. Delay percentage for *VOAC* of 1 *MCF* is 15%. The total felling, limbing, and bucking cost estimate would therefore be 70/0.85 = $82/*MCF*.

The felling, limbing, bucking delay-free cost equation and the associated delay equation can be used to develop felling, limbing, and bucking cost estimates for harvest operations on mountainous terrain.

EQUATIONS FOR ESTIMATING YARDING COSTS

Simulated delay-free yarding cost data points were developed for three uphill cable yarders under a wide range of diameters, volumes cut per acre, and average slope yarding distances. For a rectangular unit with random distribution of trees, the average slope yarding distance is just half the distance along the slope from the yarder to the back edge of the unit. For units of other shapes the average slope yarding distance may be more difficult to estimate. The stand and treatment conditions are identical to those used to develop the felling, limbing, and bucking data (Table 1). The THIN cable yarding simulation model (LeDoux and Butler 1981) and time-study data (Fieber 1979, McIntire 1981, Neilson 1977) were used to develop the delay-free data points by simulation. The simulated data points were pooled by yarder to develop delay-free cost equations for each of the three yarders. Regression analysis was used to develop the following equations for delay-free yarding costs:

Koller K-300 yarder:[1]

$$\$/MCF = 491.4 - 40.48(DBH) + 0.8886(DBH)^2 + 0.1205(SYD) + 16.1/VOAC,$$

$$R^2 = 0.94$$

Igland Jones Mini-Alp yarder:

$$\$/MCF = 652.1 - 56.23(DBH) + 1.2372(DBH)^2 + 0.1631(SYD) + 26.6/VOAC,$$

$$R^2 = 0.94$$

Washington 078 yarder:

$$\$/MCF = 737.4 - 61.09(DBH) + 1.2926(DBH)^2 + 0.1497(SYD) + 52.7/VOAC,$$

$$R^2 = 0.94$$

where

DBH = arithmetic mean dbh in inches,
SYD = average slope yarding distance in feet,
$VOAC$ = volume removed per acre in *MCF*.

The variable limits for *DBH* are 6 to 24 in; for *SYD*, 100 to 1200 ft; and for *VOAC*, 0.4 to 15 *MCF*.

These equations should be used only for estimating costs for uphill yarding rigged in the specified configurations. The equation for the Koller K-300 yarder should be used for estimating costs for a small yarder rigged in a shotgun configuration, the equation for the Igland Jones, for estimating costs for a small yarder rigged with a haulback; and the equation for the Washington 078, for a medium-sized yarder rigged in a running skyline configuration. Managers must be careful to match their equipment with the size of logs to be removed. Mismatches may result in some combination of high costs, increased stand damage, and safety hazards. For cost equations, the assumption is that the Koller K-300 and the Igland Jones will not be used for trees larger than 16-in diameter.

Delay-free yarding cost estimates should be adjusted for delay as described earlier, by the following equation:

$$\text{Percent delay} = 22.9 - 2.61(VOAC)$$

where

$VOAC$ = volume removed per acre in *MCF*.

The variable limits for *VOAC* are 0.4 to 5.4 *MCF*; when *VOAC* exceeds 5.4, delay is 9%.

EQUATIONS FOR ESTIMATING LOADING COSTS

Estimates of delay-free loading costs (data points) were developed from Schneider's (1978) time-study data for a range of diameters of harvested trees. The stand and treatment conditions are identical to those used to develop the felling, limbing, bucking, and yarding equations (Table 1) These data points were used to develop the following equation for delay-free loading costs:

$$\$/MCF = -9.8 + 545/DBH,$$

$$R^2 = 0.98$$

where

DBH = arithmetic mean dbh in inches.

The variable limits for *DBH* are 6 to 24 in.

Estimates of the delay-free loading costs should be adjusted for delays as described earlier, by the following equation:

$$\text{Percent delay} = -4.0 + 104/DBH$$

where

DBH = arithmetic mean dbh in inches.

The variable limits for *DBH* are 6 to 13 in; when *DBH* exceeds 13.0, delay is 4%.

Both the equation for delay-free loading costs and the equation for loading delay were developed from data that represented an average of

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

several types of loading machines. If these equations are used for loading machines that are substantially different from "average," some adjustment may be appropriate.

EQUATIONS FOR ESTIMATING ROAD CHANGING COSTS

Estimates of delay-free road changing costs were developed from Van Winkle's (1977) time-study data for a range of typical span lengths. The delay-free data points were used to develop the following equation for delay-free road changing costs:

$$\$/\text{road change} = 43 + 0.0001271\,(SPAN)^2$$

$$R^2 = 0.98$$

where

$SPAN$ = distance from yarder tower to skyline anchor or tailhold in feet.

The variable limits for $SPAN$ are 300 to 3000 ft.

An equation for average road change delay was also developed:

$$\text{Percent delay} = 4.9 + 0.0052(SPAN)$$

where

$SPAN$ = distance from yarder tower to skyline anchor or tailhold in feet.

The variable limits for $SPAN$ are 300 to 1,950 ft. When $SPAN$ exceeds 1950 ft, delay is 15%.

Flexibility exists for users to substitute alternate delay percentages to reflect higher or lower road changing efficiencies. Caution should be exercised to ensure that the value chosen for $SPAN$ is, in fact, the entire span length. For example, if a logger is setting up to log a skyline road that requires actual yarding of logs to 900 ft but must rig to a span of 2,200 ft to get enough lift, then the correct value for $SPAN$ would be 2,200 ft. The equation for delay-free road changing costs and the equation for road changing delay can be used to develop estimates for road changing costs for the specified conditions and yarders. Road changing as defined here includes pivoting to other anchors from the same landing.

EQUATION FOR COSTS OF MOVING IN AND MOVING OUT AND INITIAL RIGGING UP AND RIGGING DOWN

Empirical cost data (U.S. Department of the Interior 1977, U.S. Department of Agriculture 1979) were used in developing an equation to predict average costs of moving in and moving out and of initial rigging up and rigging down for small- and medium-sized yarders. The equation is specific to rigging for uphill yarding; adequate guyline and tailhold anchors are assumed to exist. The equation should not be used to develop costs for larger yarders that must be separated into several components for transport. The equation for costs of moving in and moving out and of rigging up and rigging down is:

$$\$/\text{move} = 1240 + 12.55\,(\text{round-trip miles})$$

where the variable limits for round-trip miles are 10 to 150 miles.

EQUATION FOR ESTIMATING NUMBER OF LOGS PER 1000 CUBIC FEET

Most federal contracts currently require log haulers to physically brand both ends of every log moved from a specific site. The cost for branding can be determined by multiplying the number of logs per 1000 cubic feet of harvest by the cost per log for branding. The following equation was developed using stand data summarized in Table 1 and can be used to predict the number of logs per 1000 cubic feet by DBH:

$$\text{Number of logs per 1000 cubic feet} = -47.9 + 1678/DBH,$$

$$R^2 = 0.97$$

where

DBH = arithmetic mean dbh in inches.

The variable limits for DBH are 6 to 24 in.

The average log lengths shown in Table 1 result from a bucking rule that specifies 40 ft as the preferred length.

APPLICATION AND USE OF THE EQUATIONS

The cost equations summarized here reflect conditions typically encountered in logging operations on mountainous terrain. The estimates provide detailed stump-to-truck cost estimates for thinning, partial cutting, shelterwood cutting, or clearcutting of coast Douglas-fir stands in the Pacific Northwest. The equations should be studied by potential users and should be compared with the user's current method of cost estimation. We developed the cost and delay equations on a component-by-component basis to allow users maximum flexibility in making changes. If users have other cost estimates that they feel are more specific to their conditions, those estimates should be substituted for the respective cost or delay component. A BASIC computer program to calculate costs using these equations is available from Chris B. LeDoux, Northeastern Forest Experiment Station, USDA Forest Service, Morgantown, WV 26505. The program is specific to the Hewlett-Packard 9845T desktop computer.

EXAMPLE APPLICATION OF THE COST METHODOLOGY

To use these cost equations, the user will need: (1) arithmetic mean tree DBH to be harvested, (2) average volume cut per ac in thousand cubic feet ($VOAC$), (3) average slope yarding distance in ft (SYD), (4) total skyline span in ft ($SPAN$), (5) yarder type (three to select from), (6) moving distance in round-trip miles, (7) number of skyline roads, and (8) the size of the unit to be logged in acres. These items can be obtained from inventory data, cruise data, and logging plans. Example:

1. cut trees with an average dbh of 10 in
2. average volume cut of 1000 cu ft/ac
3. average slope yarding distance of 500 ft
4. total span length of 2000 ft
5. Igland Jones yarder
6. round-trip move of 10 miles
7. 10 skyline roads
8. 10-ac tract

Table 2 shows, as appropriate, each delay-free cost component, the delay

Table 2. Estimated logging costs.[1]

Operation	Delay-free costs ($)	Delay (%)	Costs with delay ($)	Cost for unit ($)
Felling, limbing, and bucking	70/MCF	15	82/MCF	820
Yarding (Igland Jones)	322/MCF	20	402/MCF	4020
Branding	—	—	18/MCF	180
Loading	45/MCF	6	48/MCF	480
Moving and rigging	—	—	1,366/harvest area	1366
Skyline road changes	551/change	15	648/change	6480
Total cost	—	—	—	13,346

[1] Diameter breast height (DBH) = 10 inches, volume per acre ($VOAC$) = one 1,000 cubic feet (MCF), slope yarding distance (SYD) = 500 feet, $SPAN$ = 2,000 feet, branding cost = $0.15/log, harvest unit is 10 acres, round-trip distance for moving equipment is 10 miles, and 10 yarding corridors are required to harvest the unit. The values selected for the variables in this example are intended to make the example easy to follow rather than to be representative of actual conditions.

percent, and the cost with delay for the specified conditions.

Some adjustments to these estimated costs, depending on their intended use, may be desirable. The costs do not include hauling costs for logs from the harvest area to the mill. If delivered log cost is the most relevant value, the user will want to add in the hauling cost and perhaps the cost of stumpage. The estimated costs do not include a separate allowance for profit and risk, but they do include depreciation and salvage value and a 15% rate of return on invested capital.

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