Cable logging production rate equations for thinning young-growth Douglas-fir

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Abstract

A cable logging thinning simulation model and field study data from cable thinning production studies have been assembled and converted into a set of simple equations. These equations can be used to estimate the hourly production rates of various cable thinning machines operating in the mountainous terrain of western Oregon and western Washington. The equations include seven small- and medium-sized cable yarders and are applicable to uphill thinnings of Douglas-fir from low to high volume removals. Hourly production rates can be easily calculated on a hand calculator using log size, volume removed per acre, and average yarding distance as inputs. The equations can be used to develop reasonable approximations of delay-free hourly production for several cable yarders operating in thinnings, under a variety of site and stand conditions.

Young-growth forests of Douglas-fir in the mountains of the Pacific Northwest will require intensive management to help meet the nation's demand for wood. Such management may require multiple thinning entries into the stands when the trees are small (8). Equipment for cable logging these entries must be carefully chosen to ensure profitable operations.

Forest planners and logging managers will need to predict production rates of various yarders rigged in different configurations to analyze forest management strategies. Although many turn-time prediction equations have been developed (1), forest planners and managers find most of these turn-time equations very difficult to use because some of the required independent variables such as volume per turn and logs per turn are difficult to estimate accurately without simulation. Further, once the cumbersome independent variables have been quantified, the equations yield time per turn which must be converted into volume produced per hour.

Generally, most forest planners and logging managers do not have access to data sets or simulation models to develop reliable estimates. They can, however, use multiple regression equations derived through the use of simulation. The purpose of this paper is to present production rate equations for several cable logging systems. The equations can be used by logging managers and forest planners to develop hourly production rate estimates for thinning operations in young-growth Douglas-fir stands.

Background and procedure

Time and motion data (4, 5, 6, 10, 11, 12, 14) developed for thinnings of young-growth Douglas-fir in the mountains of western Oregon and Washington were used as input to the cable yarding THIN (2, 7) simulation model in order to develop an array of yarder specific production rate equations. The time-study data spanned several cable yarding and prebunch and swing configurations operating in a wide range of uphill thinning treatments (13). The resulting equations are applicable only to uphill cable thinnings of Douglas-fir and within the limits of each variable.

The stand characteristics and input data required were developed by simulating the thinning of a typical Douglas-fir site III stand (9). The stand was thinned using a d/D ratio (average arithmetic diameter of cut trees/average arithmetic diameter of stand) of 1.0 at ages 40, 60, 80, 100, and 120 at intensities of 10, 20, 30, 40, and 50 percent. The trees cut from each treatment were bucked into logs (13). The resulting log distributions (Table 1) were then fed into the THIN model. Numerous data points were developed for each yarding,

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TABLE 1. — *Log size parameters for Douglas-fir site III.*[a]

Stand age	Log size parameters				Mean log length
	Mean	Min.	Max.	SD[b]	
(yr.)	(ft.^{3})				(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

[a] The estimates for the log-size parameters are based on a bucking rule that specifies 40 feet as the preferred log length.
[b] Standard deviation.

TABLE 2. — *Payload capacity, crew size, and number of chokers flown by yarding configuration for Douglas-fir site III.*

Yarding configuration	Payload capacity[a]	Crew size	Chokers flown
	(lb.)		
Mini Alp	3,291	3	3
Koller with and without skidder	2,817	3	3
Peewee	3,655	4	3
Skagit SJ-2	3,051	4	3
West Coast	8,609	4	3, 4, and 5
Schield Bantam (swinging)	4,036	4	3
Skagit GU-10 (prebunching)	2,500	3	2

[a] Differences in payloads were obtained by assuming one representative ground profile for all yarders. Payload differences are due to differences in tower height, line diameter, and yarding configuration.

prebunch, and swing configuration. Each data point includes the delay-free hourly production rate in cubic feet (the dependent variable), the volume removed per acre in cubic feet, the average log size in cubic feet, and the average slope yarding distance (the independent variables). The independent variables were selected because values for them can easily be obtained from cruise or inventory data. Production rate per hour in cubic feet was chosen as the dependent variable since this is what most planners or loggers require. The same random number seed was used for all simulations, thus keeping the initial conditions similar for all configurations.

The payload capacity, crew size, and number of chokers flown are shown in Table 2. Although other combinations of payloads, crew sizes, and chokers flown could be used, those shown in Table 2 are representative of a normal range and consistent with the field study data.

Analysis of data

The simulated production rate data points were analyzed using multiple nonlinear regression methods (3). The dependent variable (production rate per hour in cubic feet) was regressed against nonlinear transformations of volume removed per acre in cubic feet (VOAC), the average log size in cubic feet (LOGVOL), and the average slope yarding distance (ASYD). The results are summarized in Table 3 by machine and configuration. All variables were statistically significant at the $p = 0.05$ level.

TABLE 3. — *Simulated skyline thinning delay-free equations by yarder for Douglas-fir site III.*

Yarding configuration	Equation	R^2
Mini Alp, standing skyline, single and multispan with haulback, 3 chokers with Igland-Jones single and multispan carriage	$Y = + 464.05380 - 0.29340\,X_1 - 453135.37054\,X_2 + 0.11276\,X_4$	.81
Koller K-300, standing skyline, single and multispan, gravity outhaul, 3 chokers, Koller SKA-1 carriage without skidder	$Y = + 549.96063 - 0.38256\,X_1 - 412304.72884\,X_2 + 0.19825\,X_4$	.84
Koller K-300, standing skyline, single and multispan, gravity outhaul, 3 chokers, Koller SKA-1 carriage, with John Deere 440-C choker skidder swing away from Koller landing	$Y = + 615.53229 - 0.45680\,X_1 - 449357.00156\,X_2 + 0.22712\,X_4$	.84
Peewee, running skyline, single span, 3 chokers	$Y = + 591.95611 - 0.40840\,X_1 - 621828.29021\,X_2 + 0.18432\,X_4$	.81
Skagit SJ-2, live skyline single span, gravity outhaul, 3 chokers, Christy carriage	$Y = + 484.74971 - 0.20051\,X_1 - 493857.91292\,X_2 + 0.10072\,X_4$	.67
West Coast, standing skyline, single span, haulback, 3 chokers, West Coast carriage	$Y = + 616.65800 - 0.37505\,X_1 - 728220.13805\,X_2 + 0.85110\,X_4$	.89
West Coast, standing skyline, single span, haulback, 4 chokers, West Coast carriage	$Y = + 803.70136 - 0.39039\,X_1 - 177728.75982\,X_3 + 0.79953\,X_4$	.85
West Coast, standing skyline, single span, haulback, 5 chokers, West Coast carriage	$Y = + 893.69114 - 0.38286\,X_1 - 215729.34049\,X_3 + 0.72506\,X_4$	.83
Prebunching with truck mounted Skagit GU-10, block rigged in tree, 2 chokers	$Y = + 801.80940 - 0.77889\,X_1 - 389564.01917\,X_2 + 1.58482\,X_4$	.85
Swing with Schield Bantam T-350, live skyline, single span, gravity outhaul, 3 chokers, Maki carriage	$Y = + 792.45963 - 0.48175\,X_1 - 406645.76385\,X_2 + 1.84715\,X_4$	.95

Variable definitions:
Y = Hourly production rate (ft.^{3})
X_1 = Average slope yarding distance (ft.) (ASYD)
X_2 = (1.0/(LOGVOL*VOAC)), [ft.^{3}*ft.^{3} removed/acre]$^{-1}$
X_3 = (1.0/VOAC), [ft.^{3} removed/acre]$^{-1}$
X_4 = (LOGVOL*LOGVOL), [ft.^{3} * ft.^{3}]
Variable limits:
ASYD = 50 – 950 ft.
VOAC = 355 – 7,535 ft.^{3}/acre
LOGVOL = 6 – 18 for prebunching and swinging, 6 – 30 for all others (ft.^{3})

The sign of the partial regression coefficients matches practical experience, that is, as slope yarding distance increases, hourly production rate decreases. Conversely, hourly production rate increases with increases in log size and volume removed per acre. Estimates developed for silvicultural treatments other than thinnings and exceeding the stated variable limits could result in gross errors. The equations should be used only within the variable limits and should not be used to predict hourly production for systems or configurations other than those shown in Table 3.

Application and use of the equations

The equations are yarder specific, spanning several small- and medium-sized yarders currently available on the west coast (13). The stand volumes and diameter limits envelop normally encountered thinning treatments. The equations can be used to develop skyline thinning production estimates. The estimates can be used for equipment selection, timber stand prescription planning, optimization of silvicultural decisions, break-even analysis, and silvicultural investment analysis.

For example, by holding VOAC and ASYD constant at 3,500 cubic feet removed per acre and 450 feet, respectively, we develop Figure 1 to illustrate the impact of average log size on hourly production rate for all configurations studied. Clearly, increasing log size increases hourly productivity for all configurations. However, average log size affects machines' hourly production rates differently. For example, for this combination of ASYD and VOAC, the Koller K300 yarder outproduces the SJ-2 yarder when the average log size is 13 cubic feet or larger. Although the Koller K300 is more competitive on a production basis, it may not be on a cost-per-unit-produced basis.

The curve for the Schield Bantam (swinging) involves the machine swinging prebunched wood up the skyline corridor, while the Koller K300 with skidder-swing curve involves a rubber-tired skidder swinging logs away from the Koller K300 deck down the haul road spur. Figures such as these can be developed easily using the equations presented in this paper.

Although the Koller K300, Peewee, Skagit SJ2, and Mini Alp curves might suggest that hourly production rate is insensitive to changes in average piece size, closer inspection of the curves shows increases in production rate with increases in average log size. Further, the above machines generally have low mainline pull and limited payload capacity. Thus, hourly production will increase with increasing log size until payload capacity becomes limiting, at which point hourly production rates stabilize regardless of average log size or volume removed per acre. However, logs much bigger than the maximum average log size shown in Figure 1 may be too large for these limited capacity machines.

Adjustments

The equations presented here produce delay-free hourly production rates and must be adjusted to reflect yarding delays. Yarding delays are highly variable and extremely difficult to predict. Although it would be beyond the scope of this paper to deal with all yarding delays, we do provide average delay adjustment factors by machine configuration (Table 4). The adjustment factors are based on observed yarding delay averages during the respective time studies. Table 4 factors do not include delays for either road and landing changes or move in and rig up. Planners and managers can substitute their own delay adjustment factors based on other field studies or practical experience.

An example

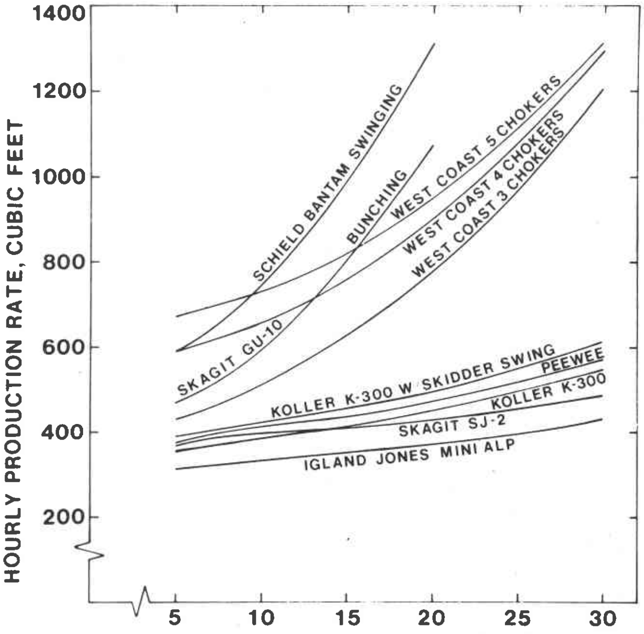

Figure 1. — Simulated hourly production by average log size for Douglas-fir site III conditions: VOAC = 3,500 cubic feet removed per acre, ASYD = 450 feet.

TABLE 4. — *Adjustment factors for thinning delays by yarding configuration for site III Douglas-fir.*

Configuration	Adjustment factor[a]
Mini Alp	0.76
SJ-2	.79
Peewee	.83
Koller without skidder swing	.79
Koller with skidder swing	.78
West Coast	.78
Prebunching	.77
Swinging	.83

[a] The factor adjusts for delays such as personal, mechanical, resetting chokers to free hangup, sorting rigging, landing delays, repositioning turn on deck, moving carriage stop, breaking line, line fouled on drum. The factor does not adjust for either road and landing changes or initial move in and rig up.

At this point, an example of how to use the equations and delay factors to estimate hourly productivity is appropriate. Problem: a forest planner wishes to develop hourly production rates for an area that averages 4,000 cubic feet removed per acre (VOAC); the average log size is 13 cubic feet (LOGVOL); and the average slope yarding distance is 400 feet (ASYD); the planner wishes to develop estimates for the Peewee yarder. Substitute the average parameter values into the equation (from Table 3) for the Peewee yarder; delay-free hourly production rate $= 591.95611 - 0.40840(400) - 621828.29021((1.0/13*4000)) + 0.18432(13*13)$, yields an estimate of 447.78 cubic feet per hour. Since this estimate is delay-free, the planner should adjust for delay by using an adjustment factor of 0.83 (from Table 4); thus, $(447.78)*(0.83) = 371.66$ cubic feet per hour. The planner may want to make further adjustment for move in, rig up, road and landing changes, or other related expenses. The other equations can be used similarly to develop estimates for cable thinning young-growth Douglas-fir stands.

Conclusions

Managers and planners should study the equations carefully and compare them with methods in current use. The equations have value to planners and managers estimating cable thinning production rates for coastal Douglas-fir. Although the equations individually may appear complicated or cumbersome to use, they could easily be programmed on mainframe, desktop, microcomputer, or hand-held calculators to ease the computational burden. Further, since machine rate computations vary yearly and widely, and individual users cost out their machinery differently, we simply focused on developing production rate estimators. Accordingly, individual users can apply their hourly, daily, or yearly cost estimates for respective machines to develop their own specific production costs.

To use the production rate equations, users will need to know the 1) average slope yarding distance; 2) average log size; and 3) average volume removed per acre. These inputs can be obtained from inventory and cruise data, and the logging plan for the tract in question. These input values would then simply be substituted into the equations of interest to develop delay-free hourly production rates for the machine(s) of interest. Appropriate adjustments for delays should then be applied. Users may then wish to express the results in dollars per unit produced by applying their own specific machine rates.

Although a methodology using time study data, simulation techniques, and multiple nonlinear regression methods will not provide forest planners and logging managers with all the answers they need to decide how to cable thin specific stands, it does give them a user-friendly, easy to use array of equations with which to develop reliable production rate estimates for machines operating in thinnings. The result should be better forest management decisions.

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