Felling and Skidding Costs Associated with Thinning a Commercial Appalachian Hardwood Stand in Northern West Virginia[1]

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ABSTRACT. Detailed cost information on thinning operations is needed to develop economic guidelines for managing immature central Appalachian hardwood stands. Three thinning treatments were applied in a 50-yr-old mixed-oak, cove hardwood stand in northern West Virginia. A commercial logging contractor using chain saws and a rubber-tired skidder conducted the logging operations. Time-study data were used to compute production rates for felling marked trees and skidding tree-length logs to roadside landings for each thinning treatment. Production rates ranged from 2.7 to 3.0 cunits/hr depending on the residual stocking treatment. The cost of merchantable material at roadside ranged from $10.79 to $11.99 per cunit. Regression equations for predicting felling and skidding times were developed for each treatment. Data from these equations can be used in estimating production rates and costs for similar thinning operations. A nomogram is provided for estimating felling and skidding costs for a 60% residual stocking treatment, the current recommended silvicultural prescription for stands similar to the study area.

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Thinning immature hardwood stands presents an opportunity for increasing the size and quality of future hardwood timber supplies (USDA For. Serv. 1982). Such increases are needed to meet expected increases in demand. To evaluate thinning alternatives, forest managers and landowners need reliable cost data for a range of thinning intensities. This paper compares felling and skidding costs associated with three thinning treatments applied in a commercial Appalachian hardwood stand. Equations are presented for predicting felling and skidding times, and a nomogram is provided for estimating production costs.

The 60-ac study area is located on the West Virginia University Forest in northern West Virginia. Treated stands were previously unmanaged and approximately 50 yr old. Site index, base age 50, was 90 for yellow-poplar and 80 for northern red oak, the 2 most common species.

STUDY METHODS

The study area was divided into twenty 3-ac experimental units. Each experimental unit was assigned at random to one of four treatments: thinning to 75%, 60%, or 45% residual stocking, or unthinned (control). During the summer of 1982, cut trees were selected to provide the desired residual stocking on each unit. The upland hardwood guide was used to measure residual stand stocking (Gingrich 1967).

A permanent 0.5-ac growth plot was established within each 3-ac experimental unit, leaving a 2.5-ac exterior buffer zone. The growth plots were inventoried (all trees 1.0 in dbh and larger) before logging, and residual trees were tagged to provide future growth data relating to each treatment. While the initial stands were uniformly overstocked (Table 1), the stocking guide used overestimates percent stocking for stands having a significant component of such species as yellow-poplar. Yellow-poplar accounted for 41% of the merchantable cubic foot volume in the initial stand, and black cherry accounted for an additional 12%. Red oak comprised 15% of merchantable volume; other oaks, 18%; and miscellaneous hardwoods the remaining 14%. Although yellow-poplar was a major component of the initial stand, it was of lesser importance compared to oak in the residual stand. Oaks accounted for 18% of the volume removed and 48% of the residual volume.

Merchantable volume in cubic feet (wood only) was calculated to a minimum top diameter of 8.0 in inside bark using the model developed by Kozak and others (1969) and adapted to Appalachian hardwoods by Martin (1981). Board foot volume was estimated with the International ¼-in log rule and form class 78 volume tables

Logging Site and System

The study was conducted at an elevation of 2100 ft on slopes not exceeding 23%. A truck road 0.5 mi in length was constructed to provide access from a paved highway to the study site. Approximately 2.25 mi of skid road were constructed within the site. Logging was done in the spring of 1983, under relatively wet conditions.

Merchantable timber was purchased and removed by a commercial logging contractor. Two experienced crews, each using chain saws and a John Deere 540B rubber-tired skidder, conducted the thinning operation. Each crew consisted of a feller and a skidder operator. Up to five chokers per hitch were used in skidding (Fig. 1).

Time Studies

Time-study data were collected for both logging crews; each crew was observed and timed independently Times were recorded for two activities: tree-felling and log-skidding. Productive felling time included walking to the tree, swamping, actual cutting, limbing and topping, and bucking Delays included refueling and sharpening the saw, waiting for the skidder, cutting trees below the limit of merchantability (7.6 in dbh), coffee breaks, and personal time.

Productive skidding time included traveling unloaded from the deck to the woods, choking logs, winching logs, moving to secure additional logs, traveling loaded back to the deck, unhooking, and some bucking on the deck. Delays included winching stoppages, traffic jams with other heavy equipment, equipment maintenance, waiting for topping or bucking, coffee breaks, and personal time.

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Table 1. Characteristics of the initial, cut, and residual stands for the three thinning levels on the West Virginia University Forest, 1983.

Residual stocking treatment (%)	Stand	Stems/ac		Basal area/ac (ft²)		Stocking (%)		Merchantable volume/ac[a]	
		1.0–7.5 in dbh	7.6 in and larger	1.0–7.5 in dbh	7.6 in and larger	1.0–7.5 in dbh	7.6 in and larger	Cubic foot	Board foot
75	Initial	370	157	23.1	114.7	29	96	2,849	9,098
	Cut	63	65	10.8	44.2	12	37	1,127	2,680
	Residual	307	92	12.3	70.5	17	59	1,722	6,418
60	Initial	314	157	24.2	128.6	29	106	3,366	11,496
	Cut	86	85	15.8	69.3	17	57	1,831	5,400
	Residual	228	72	8.4	59.3	12	49	1,535	6,096
45	Initial	276	144	21.0	124.3	26	101	3,270	10,993
	Cut	84	88	14.2	80.8	16	65	2,175	7,120
	Residual	192	56	6.8	43.5	10	36	1,095	3,873

[a] Only trees 11.6 in dbh and larger were included in the board-foot volume.

For both felling and skidding, productive time and delay time elements were measured to the nearest 0.01 min by stopwatch. The total time for a felling or skidding cycle was determined by summing the individual elements. The volume produced in a cycle was determined from tree or log measurements recorded during the time study. Time-study data are summarized in Table 2.

RESULTS

A regression equation was developed for each thinning treatment to predict productive felling time per tree as a function of merchantable cubic foot volume per tree (Table 3). Thinning treatment and volume per tree were statistically significant at the 5% level. Other measured variables, including species, dbh, initial stand stocking, initial basal area per acre, and a ratio of the number of harvested trees to the total number of trees per acre, were not significant. Delay time was not included in the dependent variable, time (minutes) per tree, because most felling delays were related to the system as a whole rather than to the individual tree.

For skidding, a regression equation was developed for each treatment to predict skidding time as a function of three significant independent variables: number of logs per turn, one-way skidding distance, and cubic foot volume per turn (Table 4). Other variables, including average slope, percent slope greater than or equal to 12%, and the product of load and slope were not significant. The dependent variable, time (minutes) per skid turn, included productive time and all delays except crew breaks, personal time, etc. These activities resulted in nonproductive time that was not related to individual skid turns.

The three equations were solved using least squares analysis with the following statistics: R^2 was 0.66; the standard error of regression was 2.95; and the F-ratio was 36.

Fig. 1. An average of four tree-length logs were removed in each skidding cycle.

Production Rates

The regression equations were used to predict felling and skidding production time in each treatment. Predicted times were based on selected values for the independent variables. Felling production time was predicted using the average volume per tree computed from the marked cut in each treatment. Skidding production time was predicted using 4 logs per turn, a one-way skidding distance of 600 ft, and the mean volume per turn observed in the time study. These values were selected to represent the average conditions in the study area and to provide a basis for comparing the treatments (Table 5).

Volume figures used in the equations were combined with the predicted cycle times to compute production rate estimates for felling and skidding in cunits (100 ft³) per hour using the formula:

$$P = \frac{\text{volume per cycle (ft}^3\text{)}}{\text{predicted cycle time (min)}} \times \frac{60 \text{ min/hr}}{100 \text{ ft}^3\text{/cunit}}$$

where

P = production rate in cunits per hour, excluding all delays and nonproductive time for felling and excluding nonproductive time only for skidding.

Delays were accounted for using adjustment factors determined from

Table 2. Summary of time-study data for three thinning levels, West Virginia University Forest, 1983.

Operation	Residual stocking treatment (%)	Number of observations	Productive time (hr)	Total time (hr)	Merchantable volume produced (ft³)
Felling	75	100	3.48	7.55	3,211
	60	100	4.43	11.57	3,500
	45	100	3.79	8.45	3,201
Skidding	75	45	8.93	12.08	3,176
	60	42	9.14	10.34	3,405
	45	47	10.63	12.57	3,914

Table 3. Felling time equations and regression statistics for three thinning levels.

Percent stocking	R^2	Standard error of regression	F-ratio	Felling time equations[a]
75	0.87	0.6796	334	$Y = 0.9837 + 0.017954\,X + 0.000216\,X^2$
60	0.70	1.1767	111	$Y = 1.1826 + 0.038342\,X + 0.000053\,X^{2b}$
45	0.67	0.6680	97	$Y = 0.9528 + 0.051289\,X - 0.000162\,X^2$

[a] Y = productive felling time in minutes per tree, excluding delays and nonproductive time.
X = Merchantable cubic-foot volume per tree.
[b] Coefficient of X^2 is not significant at 5% level.

the time study data in each treatment. For felling, the adjustment factor was 0.50, indicating that predicted cycle time is 50% of total cycle time. This relationship between productive felling time and total felling time also was found in previous studies (Sarles et al. 1984, Miyata 1980). For skidding, the adjustment factor was 0.91, indicating that predicted cycle time is 91% of total cycle time. This factor accounted for nonproductive time (coffee breaks, etc.) not included in the predicted skidding time per turn. The same adjustment factor was used for each treatment to make direct comparisons of the predicted cycle times and production rates (Table 5).

In all treatments, the skidding operation was the "weak link" in the logging system—that part of the system with lowest output per hour (Baumgras and Martin 1978). The weak link determines the production rate of the entire system and provides a basis for computing the cost per unit of production for all system components combined. For example, the estimated production rate for felling in the 60% residual stocking treatment was 3.2 cunits (100 ft³ of wood only) per hour (Table 5). For skidding, the estimated production rate was 3.0 cunits per hour. In combination, the two system components are limited by the lower production rate of the skidding operation. Thus, production of merchantable volume at the landing in the 60% treatment was 3.0 cunits per hour. Estimated production in the 75% and 45% treatments was 2.7 and 3.0 cunits per hour, respectively (Table 5).

Production Costs

Costs were determined by dividing the production rate of the system's weak link into the cost per hour for all system components combined (Table 6). In this study, felling, bucking, and skidding costs totalled $32.36 per hour. Wages were assumed to be $7.00 per hour plus 28% mandatory fringe benefits for Social Security, Workman's Compensation, and Unemployment Insurance. Machine costs were estimated using cost factors (Miyata 1980) and the manufacturer's recommended maintenance schedule for the equipment used. The total labor and machine cost was $10.13 per hour for felling and $22.23 per hour for skidding. Bucking was done in the woods or at the landing, depending on the circumstances. Thus, these hourly costs include bucking. Using these cost estimates and the production rates determined from the regression equations, the combined cost of felling, bucking, and skidding showed moderate differences among the treatments (Table 6).

DISCUSSION

The regression equations developed in this study provided a basis for computing logging costs from stump to log deck for three thinning treatments. While felling, bucking, and skidding costs are important, total logging costs also include the costs of loading, hauling, and road construction. Thus, the results of this study are useful for predicting only a portion of

Table 4. Skidding time regression coefficients for three thinning levels.

Regression terms	Regression coefficients		
	75% stocking	60% stocking	45% stocking
Intercept (b_0)	2.2221[a]	2.2221[a]	2.2221[a]
Number of logs per load (b_1)	0.143824[a]	0.701948	1.194436
Skidding distance (b_2)	0.013420	0.009186	0.006684
Size of load in merchantable ft³ (b_3)	0.050646	0.050646	0.050646

[a] Not significant at 5% level; intercept significant at 6% level.

Table 5. Estimated felling and skidding production rates for three thinning levels, West Virginia University Forest, 1983.

Operation	Residual stocking treatment	Selected variables used in equations			Predicted time per cycle (min)	Delay adjustment factor	Estimated[e] production rate (cunits/hr)
		Number of logs	One-way distance (ft)	Volume per cycle (ft³)			
Felling	75	—	—	17.3[a]	1.36[c]	0.50	3.8
	60	—	—	21.5	2.03	0.50	3.2
	45	—	—	24.7	2.12	0.50	3.5
Skidding	75	4	600	70.6[b]	14.43[d]	0.91	2.7
	60	4	600	81.1	14.65	0.91	3.0
	45	4	600	83.3	15.23	0.91	3.0

[a] Mean volume per tree computed from the marked cut.
[b] Mean volume per cycle observed in the time study.
[c] Predicted felling time per tree includes productive time only.
[d] Predicted skidding time per turn includes productive time and all delays except crew breaks, personal time, etc.

[e] $\text{Production rate} = \dfrac{\text{ft}^3\text{ per cycle}}{\text{min/cycle}} \times \dfrac{60\text{ min/hr}}{100\text{ ft}^3\text{/cunit}} \times \text{delay adjustment factor.}$

Table 6. Comparison of production rates and costs for three thinning treatments.

Residual stocking treatment (%)	Production rate[a] (cunits/hr)	Total labor[b] and machine cost ($/hr)	Felling, bucking,[c] and skidding cost ($/cunit)
75	2.7	32.36	11.99
60	3.0	32.36	10.79
45	3.0	32.36	10.79

[a] Based on skidding production.
[b] Includes wages for two crew members plus machine costs for a wheeled skidder and a chain saw.
[c] Bucking was done by the feller or on the deck depending on the circumstances.

total logging costs associated with thinning operations.

The 60% residual stocking treatment is the current recommended silvicultural prescription for stands similar to the study area (Gingrich 1967). The other treatments were applied to determine the effect of different thinning intensities on harvesting costs Estimated costs in the 60 and 45% residual stocking treatments were equal under the conditions studied. One reason for this is the similarity in the volume removed per skid turn. The average volume was 81 ft^3 per turn in the 60% treatment and 83 ft^3 per turn in the 45% treatment. Even though the treatments differed with respect to residual stocking, the marked cut in merchantable trees (7.6 in dbh and larger) was similar. The number of merchantable trees removed differed by only 3 trees per acre. Average volume per tree was higher in the 45% treatment, but due to occasional

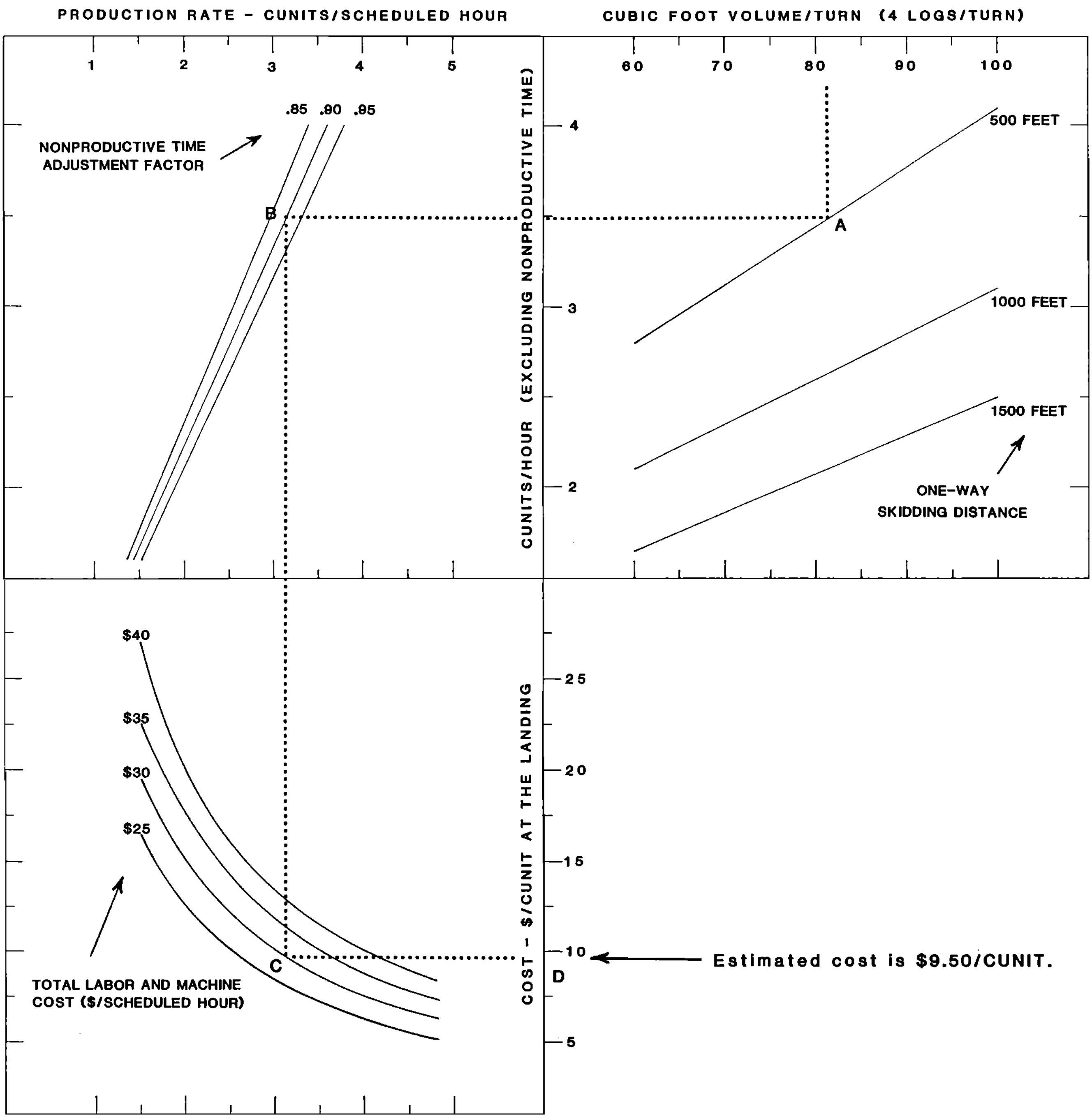

Fig. 2. Sample graphical computation of felling, bucking, and skidding cost in a 50-yr-old Appalachian hardwood stand thinned to 60% residual stocking.

bucking in the woods, average volume per skid turn was not increased accordingly.

In the 75% treatment, the estimated cost of merchantable volume at the landing was $1.20 more per cunit than in the heavier thinning treatments. Volume per skid turn was 70.3 ft^3, about 11 ft^3 less than in the recommended treatment. To increase average turn volume and lower costs, the crew could have increased the load from 4 to 5 logs per turn. This adjustment in skidding strategy increases the estimated production rate from 2.7 to 3.1 cunits per hour. The regression equations can be used to evaluate similar adjustments in all treatments.

To illustrate the procedure for estimating felling, bucking, and skidding costs for the 60% residual stocking treatment, a nomogram is provided (Fig. 2). The nomogram is a graphical representation of the three basic steps required to compute the cost of merchantable material at the landing. Loading, hauling, and road construction are not included.

The first graph in Fig. 2, upper right, determines the production rate in cunits per hour, excluding coffee breaks, personal time, and other nonproductive time. This graph was derived from the skidding time equation for the 60% residual stocking treatment. Since skidding was the weak link in the logging system, production rates and costs are determined by the skidding operation. Production rates were computed for three skidding distances and a range of average turn volumes, while the average number of logs was held constant at 4 logs per turn.

To determine the production rate, enter the first graph (upper right) at the appropriate average turn volume and draw a vertical line down to the appropriate skidding distance. At this point (A), the production rate, excluding nonproductive time, is found at the left. In this example, the estimated production rate for 81 ft^3 per turn in 4 logs per turn and a skidding distance of 500 ft is 3.5 cunits per hour.

The second graph in Fig. 2, upper left, computes the production rate per scheduled hour by accounting for nonproductive time. This graph includes three adjustment factor lines to allow for a range in crew efficiency. To account for nonproductive time, move horizontally from point A to the left, stopping at the appropriate adjustment factor line. At this point (B), the production rate per scheduled hour, including all delays and nonproductive time, is read at the bottom. In this example, the delay adjustment factor is 0.90 and the estimated production rate per scheduled hour is 3.2 cunits.

The third graph in Fig. 2, lower left, computes the cost per cunit from the production rate per scheduled hour and the total labor and machine cost (for both felling and skidding) per hour. Because labor and machine costs can vary, four cost curves are provided. To compute felling and skidding costs per cunit, draw a vertical line from point B down to the appropriate cost curve. At this point (C), the predicted cost per cunit is found at the right. In this example, costs were assumed to be $30 per hour and the predicted cost is $9.50 per cunit, point D. If solved algebraically, the predicted cost is $9.41 per cunit.

Merchantable volume from all 45 treated acres sold for $13,264. The total yield from all treatments combined was 770 cunits. The average yield was 17.1 cunits per acre, similar to the average yield in the 60% residual stocking treatment, 18.3 cunits per acre. Based on the average stumpage price observed in this sale, i.e., $17.23 per cunit, the 60% treatment would provide a revenue equal to $315 per acre. So even in a small tract of immature timber, there is an opportunity for owners to undertake commercial thinnings, thereby leaving their timber in a more productive condition for future earnings. □

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