MANUAL FELLING TIME AND PRODUCTIVITY IN SOUTHERN PINE FORESTS

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ABSTRACT

Sixteen stands were harvested by either clearcut, shelterwood, group selection, or single-tree selection methods. Three of the stands had uneven-aged structure. The other 13 were typical, mature, even-aged stands. Harvest intensity (proportion of basal area removed) ranged from 0.27 to 1.00. Harvested sites were similar in slope, average diameter at breast height (DBH), and pre-harvest diameter distributions. Logging contractors used 1 to 3 sawyers with production chain saws on all 16 tracts. There was no difference in production rate between sawyers on the same stand. Factors affecting total felling time (in decreasing order of importance) were DBH of harvested stems, inter-tree distance, and harvest intensity. Total felling time (including walk, acquire, fell, and limb-top times) was inversely related to harvesting intensity and directly related to stem DBH and inter-tree distance. Felling productivity was found to be highest under high intensity harvests of large trees and lowest under low intensity harvests of small trees. Productivity was more sensitive to stem diameter than harvest intensity.

This is the first in a series of reports evaluating harvesting productivity and profitability as a function of harvest intensity. In this paper, manual felling operations are evaluated. The next installment evaluates skidding productivity. The final paper considers all harvesting phases and identifies key relationships between harvesting equipment and the stand, with an emphasis on harvesting profitability.

Comparisons of even-aged and uneven-aged forest management have recently attracted increased attention. Research in this area includes comparisons of the time required to perform various timber harvesting operations under differing management regimes. Manual tree felling is the most labor-intensive component of all harvesting operations, and frequently represents a "bottleneck" in production. While mechanical felling is typically more productive than manual felling, site disturbance and residual stand damage are increased by the additional machinery operating on the stand. This, combined with the fact that uneven-aged management requires more entries into the stand at shorter intervals than even-aged prescriptions, makes manual felling a less intrusive alternative to mechanical felling. Also, steep slopes may preclude the use of mechanical fellers. Manual felling is and will continue to be an important component in modern forest management.

Previous studies often addressed only a single harvest method, (i.e., clear cutting or single-tree selection) (5,6) with differences among stands or harvesting crews and equipment confounded with treatment effects (2,7,9). Studies have been needed that cover both even-aged and uneven-aged silviculture and contain a data set large enough to identify trends common to all manual felling operations. The results of felling time studies conducted over 4 years are presented here.

METHODS

STAND TREATMENT

A wide range of harvest intensities was examined. Clearcutting and single-tree selection methods represented extremes in harvest intensity, while shelterwood and group selection harvests represented intermediate treatments. **Table 1** shows the method of harvest, harvest date, and harvest intensity. The proportion of basal area removed was used as an index of harvesting intensity for each stand. Basal area removed was chosen because it is sensitive to both number of trees removed from the stand and average tree size. The stands were located in western Arkansas (13 on the Ouachita National Forest and 3 on privately owned industry land).

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TABLE 1. — Descriptive information for the 16 stands studied.

Stand (year - no.)	Harvest method	Proportion of BA[a] removed	Avg. DBH removed
			(in.)
91-01	Clearcut	1.00	11.4
92-04	Clearcut	1.00	10.4
92-05	Shelterwood	0.71	10.6
91-02	Shelterwood	0.57	10.4
93-08	Group selection	0.62	10.9
93-07	Group selection	0.48	11.7
93-09	Single-tree	0.45	13.5
92-06	Single-tree	0.43	13.7
93-10	Single-tree	0.32	13.9
91-03	Single-tree	0.31	10.7
93-11	Single-tree	0.31	11.8
93-12	Single-tree	0.30	12.2
93-13	Single-tree	0.27	12.3
94-14[b]	Single-tree, uneven-age	0.36	15.5
94-15[b]	Single-tree, uneven-age	0.32	15.5
94-16[b]	Single-tree, uneven-age	0.27	16.0

[a] BA = basal area.
[b] These three stands were well-balanced uneven-aged stands. All others were even-aged.

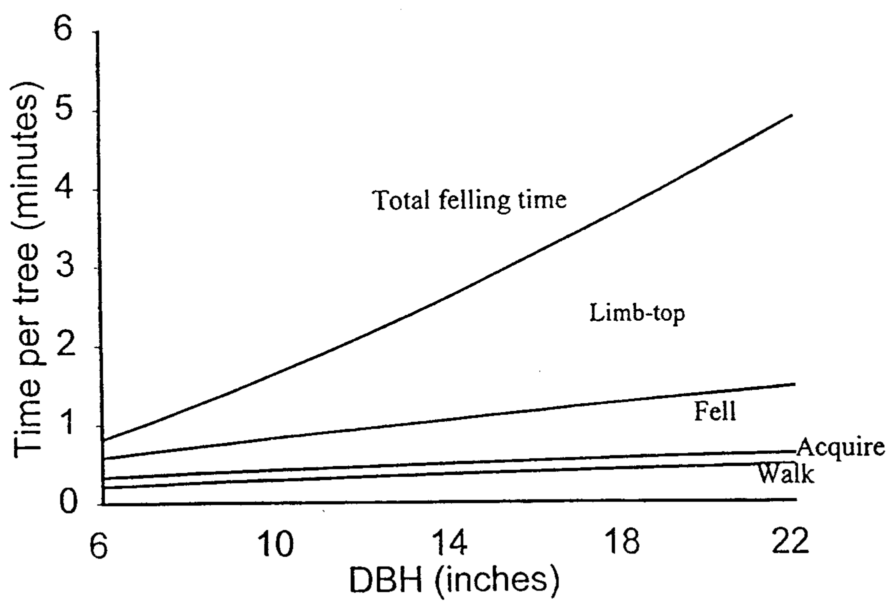

Figure 1. — Predicted felling time by operation per tree based on DBH.

The stands were composed primarily of shortleaf pine (*Pinus echinata* Mill.) and loblolly pine (*Pinus taeda* L.). There was a small hardwood component in all stands. The 3 stands harvested in 1994 were of uneven-aged structure, while the other 13 were even-aged.

All stands were cruised before and after harvest to determine the harvest intensities and diameter distributions. Diameter distributions from pre-harvest cruises were compared using a Kolmogorov-Smirnov distribution test (10) to insure that all stands could be grouped into a single data set for later analysis.

The sawyers felled all marked trees within the stand boundaries according to felling ease and safety. Directional felling to optimize skidding was not a consideration, nor was it practiced. Trees were processed into tree-length logs by manually limbing and topping immediately after felling. Data were collected during the summer; heat occasionally affected worker utilization percentages.

A felling observation consisted of the time required for the sawyer to walk to a tree (walk), clear the brush for a safe exit path and plumb the tree (acquire), cut the tree down (fell), and remove the limbs and top the tree (limb and top). Not every felling cycle was observed. Observed felling cycles were randomly chosen as work progressed through the stand. Field research team members timed and recorded each event in the cycle. After a tree was limbed and topped and it was safe to approach, researchers measured the diameter at breast height (DBH) and merchantable length (most stems were cut to a 5-in. top) of the felled tree. Individual tree volumes were calculated by a formula developed by Clark and Saucier (3). This volume estimating equation was tested and found to be reliable for the trees harvested. Total time per tree (excluding delays) was calculated for each observation.

Means for walk-time, acquire-time, cut, limb and top-time, and delay-time were computed by tract and the overall study. Differences in mean times by sawyer and harvest year were tested at the 0.05 level.

Total felling time was analyzed in two stages. First, each phase of the felling operation was fit to an exponential equation ($Y = a \times X^b$) using DBH as the independent variable. This was done to determine whether or not the results of the current study were consistent with classic relationships defined in the literature and to identify the expected felling time for an individual tree apart from influences of surrounding trees (4). Second, characteristics of the stand and harvest prescription were added to the model to show how these factors influence the felling time and to give a more realistic model of the felling operation.

A step-wise linear regression process was initially used to determine independent variables that were significant in estimating total felling time ($p = 0.01$) for the analysis that included stand characteristics and harvesting prescription. A simple exponential equation ($Y = a \times X^b$) was then modeled to capture the relationship between the dependent variable (total time) and the significant independent variables. The same variables that were significant in the linear model were significant in the nonlinear form. The nonlinear model was combined with a volume equation (based on DBH) to give a nonlinear function estimating felling productivity.

RESULTS

STANDS

The pre-harvest diameter distributions were compared using a Kolmogorov-Smirnov distribution test that showed that they were from the same parent distribution. The even-aged stands were characterized by a normal bell-shaped distribution of tree size. The diameter distributions for the three uneven-aged stands harvested in 1994, while not statistically different from the parent population, were approaching a "reverse-j" distribution indicative of uneven-aged stands. The average DBH of *harvested* stems was larger in these stands. This is a function of the uneven-aged management prescription where the harvested trees are concentrated in the larger DBH classes. In the seven even-aged stands harvested by single-tree selection, the distribution of removed stems was similar to a mixed thinning, with cutting concentrated in the 6- to 10-inch classes (low thinning) and in the 14- to 18-inch classes (thinning from above). The goal of this thinning was to move these stands toward uneven-aged structure.

Delay times were found to be highly variable for all sawyers. Every felling cycle was not recorded and thus every delay was not recorded. When a delay interrupted a cycle, the sawyer often did not return to the same tree after the delay. Information that was gathered on delay time did not add to the predictive capability of the felling equations. Without the delays, there was no statistical difference in the rate sawyers worked on the same stand (ANOVA, alpha = 0.05). Thus, a variable for different sawyers was not included in this analysis. However, there were differences in utilization rates (productive hours/scheduled hours) among sawyers.

DBH AS A PREDICTOR OF FELLING

Inter-tree distance was inversely related to harvesting intensity and directly related to tree size. The sawyer had to walk further to find marked trees in the single-tree selection stands than in the clearcut stands where he could move directly to the next nearest tree; walk time

TABLE 2. — Summary of the felling data variables used in the stand level felling regression equation, n = 1,154 observations.

Variable	Minimum	Mean	Maximum
Harvest intensity (proportion of BA)[a]	0.27	0.49	1.00
DBH removed (in.)	5.2	13.7	26.1
Intertree distance (ft.)	1.1	43.2	408

[a] BA = basal area.

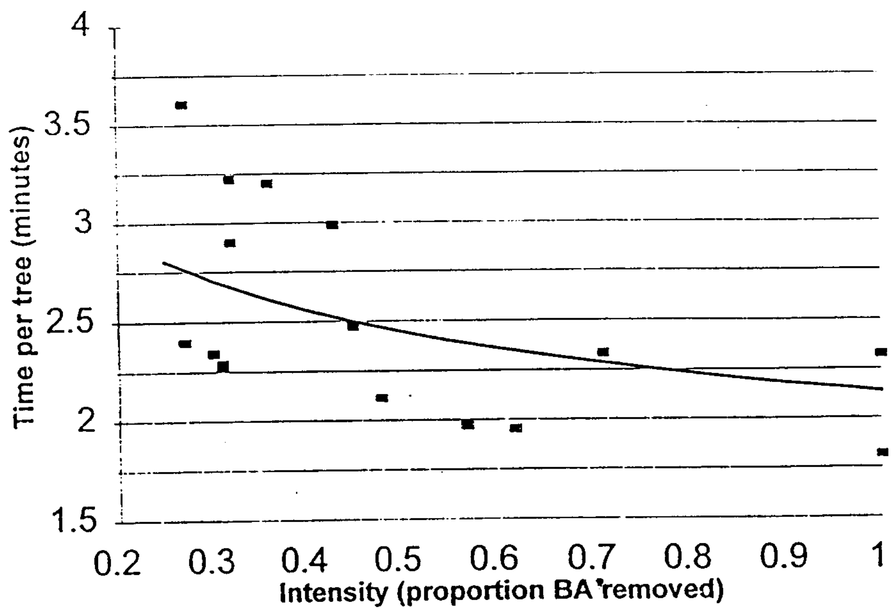

Figure 2. — Predicted average felling time per tree within a stand.

decreased as harvesting intensity increased. The number of trees marked on a per-acre basis was influenced by the size of the trees. The distance between trees may be approximated by the square root of the area per tree. Thus, a square root relationship between walk time and DBH, as found (the exponent coefficient approaching 0.5), is consistent with the expected relationship.

$$Walk\ Time = 0.079 \times DBH^{0.591} \quad [1]$$

There was no identifiable trend in acquire time. The amount of time to plan the fall and to clear brush from around a 10-inch tree would be about the same as that of a 20-inch tree. Only in the extreme diameter classes would DBH have an influence on acquire time. The low power coefficient shows that this value was essentially constant. An exponent of zero would mean that acquire time is constant and independent of the size of the tree:

$$Acquire\ Time = 0.080 \times DBH^{0.200} \quad [2]$$

Fell time approached a linear relationship with the DBH (the exponent coefficient approaching one). This is consistent with studies evaluating production chain saws (8).

$$Fell\ Time = 0.047 \times DBH^{0.937} \quad [3]$$

Limb and top time was a function of crown size. The ratio of crown diameter to stem diameter is essentially constant; therefore stem volume may be estimated as a function of crown diameter (1). It is reasonable that the time to remove the limbs and top (a function of crown size) would be estimated using the best single proxy for stem volume, which is DBH^2. Limb and top time constituted the largest portion of the felling operation.

$$Limb\ and\ Top\ Time = 0.006 \times DBH^{2.129} \quad [4]$$

Figure 1 shows total felling time broken into each component. The vertical distance between the lines is the average time required for the identified activity. The top line is the average total felling time based solely on DBH. This equation gives a baseline to compare with models that include the stand information when predicting felling time.

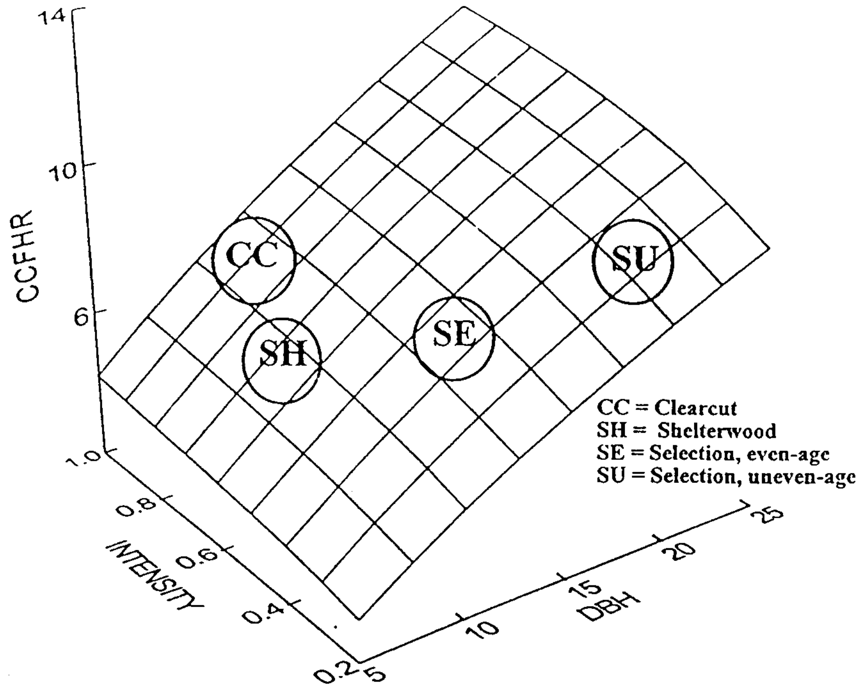

Figure 3. — Felling productivity by harvest intensity and stem diameter.

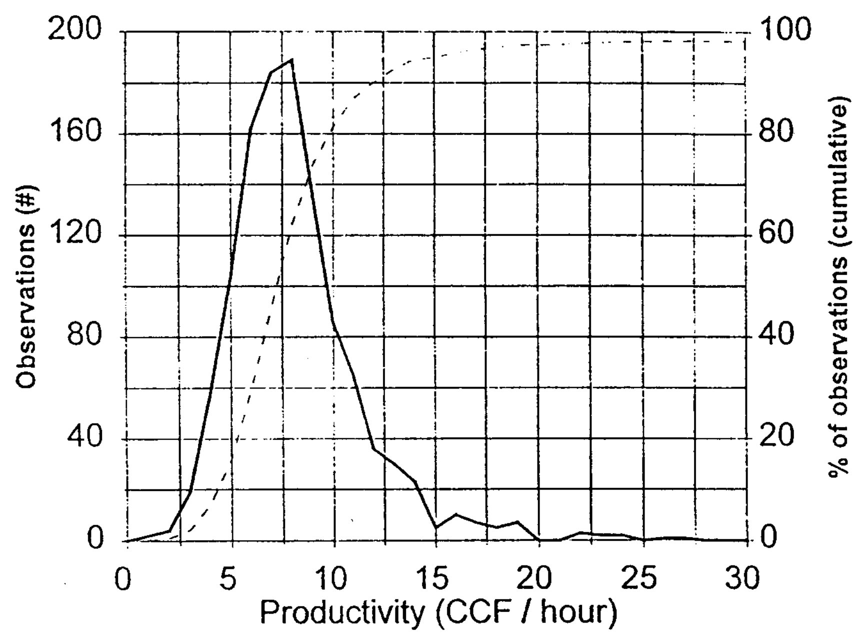

Figure 4. — Felling productivity frequency and cumulative distribution.

$$\mathit{Total\ Time} = 0.069 \times DBH^{1.379} \qquad [5]$$
$$r^2 = 0.49 \quad n = 1150$$

Stand factors

While tree diameter proved to be the best single variable when estimating felling time of a tree, additional information regarding the stand's characteristics and harvesting prescription improved the prediction of felling time. Including the stand level factors in the mathematical equation produced a more realistic model of the felling operation.

When estimating the felling time of a tree within a stand, the distance from the previous felled tree (DIST), the proportion of basal area removed (INTENSITY), and stem diameter DBH proved to be significant at the 0.01 level. **Table 2** gives the range of values for harvest intensity, inter-tree distance, and DBH. Other factors were tested as potential independent variables but were not significant at the 0.01 level. The predictive capability of this equation is significantly better than when using only DBH.

$$\mathit{Total\ Time} = 0.049 \times DBH^{1.338} \times DIST^{0.083} \times INTENSITY^{-0.196} \qquad [6]$$
$$r^2 = 0.55 \quad n = 1145$$

The expected total time for the average tree in each stand is plotted in **Figure 2** using individual stand averages for DBH, inter-tree distance, and measured harvest intensity (points). The regression line in **Figure 2** shows the expected total felling time across all harvest intensities using total averages (all stands combined) for DBH and inter-tree distance.

Productivity

Productivity in hundred cubic feet per hour (CCF/hr.) was calculated using measured total time and estimated stem volume. An estimator for productivity was derived by combining the nonlinear total time model with a single-entry volume equation (based on DBH)[1].

$$\frac{CCF}{hr.} = 1.959 \times DBH^{0.668} \times DIST^{-0.083} \times INTENSITY^{0.196} \qquad [7]$$
$$r^2 = 0.55 \quad n = 1145$$

This equation was used to create a three-dimensional response surface (**Fig. 3**) holding inter-tree distance at its average of 43 feet. Productivity was more sensitive to changes in DBH than to changes in harvest intensity.

If an even-aged stand with an average DBH of 12 inches was harvested under typical single-tree selection, shelterwood, or clearcut harvesting prescriptions, the expected felling productivity would fall on the response surface at regions SE (selection, even-aged), SH (shelterwood), and CC (clearcut), respectively. The average DBH of removed stems for a shelterwood (SH) prescription will be slightly less than the stand average because a number of the larger trees are left standing. A stand with simi-

[1] The single-entry volume estimation equation used was developed from data by Clark and Saucier and was of the form: CCF = .096 DBH.$^{2.0[illegible]}$

lar characteristics (e.g., an average DBH of 12 in.) but having uneven-aged structure harvested with single-tree selection would fall on the response surface at region SU. While the average stand diameter is the same as that for the even-aged stand, the average removed stem diameter will be larger (in this case it is 16 in.) because typical uneven-aged management focuses harvest on the larger trees.

The mean productivity level was 7.6 CCF/hr. (**Fig. 4**). However, the majority of the productivity observations were between 4 and 11 CCF/hr. (±1 standard deviation). The steep rise in the cumulative percentage curve between 3 and 15 implies that this range captures the typical productivity rates, and observations outside this range are aberrations.

Discussion

Manual timber felling is a highly variable operation. There are a multitude of factors that influence the felling productivity. Many of these factors are difficult to identify and even more difficult to quantify. This paper identifies the variables that are most significant and that may be identified prior to harvest.

Each sawyer observed developed his own techniques and style of working. While some did cut more timber than others during a day, differences in daily productivity were a function of the number of breaks taken during the day. When delays were removed from the analysis, there was no statistical difference attributable to the sawyers.

The most important factors in felling time per tree were DBH, inter-tree distance, and harvest intensity. In the structural regression analysis, intensity acted as a harvest variable to collect variation in felling time. The extra time spent finding marked trees, planning the cut, and working around residual stand components slowed production for the partial harvest methods.

Individual tree size had the greatest influence on felling productivity. The felling operation was most productive in stands where large trees were being removed under high harvest intensities. The average DBH removed from the even-aged stands tended to be lower than those from the uneven-aged stands. Trees removed from these stands tended toward the stand average tree size.

In the uneven-aged stands, the tree size distributions approached a "reverse-j" with many more stems in the smaller diameter classes than in the larger classes. However, at harvest, only the larger diameter classes were removed (this is typical of uneven-aged forest management). This had the effect of increasing productivity (CCF/hr.) even at the observed lower harvesting intensities.

The discussion surrounding even-aged versus uneven-aged management and their associated silvicultural methods will continue, especially for public land management. For many proponents of uneven-aged management, harvesting cost and economic efficiency are a distant third consideration after maintaining stand visual quality and minimizing individual stand disturbance. Even-aged management advocates focus on harvesting and capital efficiency as preeminent concerns.

Literature Cited

1. Avery, T.E. and H.A. Burkhart. 1983. Forest Measurements. McGraw-Hill Book Company, New York. 331 pp.
2. Bell, R.D. 1989. Influences of varying stand harvest methods on timber harvesting costs in southwestern Virginia hardwoods. M.S. thesis. Industrial Forestry Operations Program, Virginia Tech., Blacksburg, Va. 69 pp.
3. Clark, A.C. and J.R. Saucier. 1990. Tables for estimating total-tree weights, stem weights and volumes of planted and natural southern pines in the southeast. Res. Div., Georgia Forestry Commission, Macon, Ga. 23 pp.
4. Conway, S. 1976. Logging Practices. Miller-Freeman Pub., San Francisco, Calif. 416 pp.
5. Kellogg, L.D., S.J. Pilkerton, and R.M. Edwards. 1991. Logging requirements to meet new forestry prescriptions. *In*: Proc. COFE 1991 Annual Meeting. Council of Forest Engineering, Corvallis, Oreg. pp. 43-49.
6. Miller, G.W. and R.L. Sarles. 1986. Costs, yields and revenues associated with thinning and clear cutting sixty year old cherry-maple stands. Res. Pap. NE-582. USDA Northeastern Forest Expt. Sta., Radnor, Pa. 6 pp.
7. ________ and H.C. Smith. 1991. Applying group selection in upland hardwoods. *In*: Proc. Uneven-aged silviculture of upland hardwood stands workshop. Virginia Tech. Cooperative Ext. Serv., Blacksburg, Va. p. 6.
8. Lanford, B.L., T. Cunia, and G.F. Haver. 1972. Handbook of Production Tables. Harvesting Res. Project., Am. Pulpwood Assoc., Atlanta, Ga. 791 pp.
9. Sloan, H. 1991. Uneven-aged silviculture: impacts on loggers. *In*: Proc. Uneven-aged silviculture of upland hardwood stands workshop. Virginia Tech. Cooperative Ext. Serv., Blacksburg, Va. p. 4.
10. Wilkinson, L. 1990. SYSTAT: the system for statistics. SYSTAT, Inc., Evanston, Ill. 677 pp.