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ABSTRACT

Manual felling and limbing may be cost effective for early thinning of northeastern softwoods. Using regression analysis with observations of 695 trees, models are presented for predicting cutting time based on stem diameter and basal area. When trees were limbed in groups of 2-7 stems, limbing time was reduced by 15% to 40%. The results of other studies of alternative, more efficient chainsaw limbing techniques are discussed.

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Harvesting small trees - 4-8 inches in diameter at breast height -has not been common in North America, but as average tree size declines, loggers must cut smaller stems. Many softwood stands in the Northeast contain 2000-4000 stems per acre with mean stand diameters of six inches or less (see Fig. 1). If diameter averages ten inches, there may be 6-7 trees per cord, but if it declines to six inches, loggers may handle four times as many trees for the same volume. Handling this increased number of pieces per unit requires changes in operating techniques.

LITERATURE REVIEW

Despite the trend toward mechanization of woods operations, probably 90% of cutting performed in the woods utilizes the chainsaw (1). Continued use of the chainsaw is especially appropriate on non-industrial private lands because of the high cost of moving heavy machinery and its unsuitability for small woodlots.

Since cutting with chainsaws is labor intensive as well as dangerous, mechanized feller-bunchers have been developed to reduce both labor requirements and safety risks. Mechanical felling is probably as costly as manual methods, with the savings, if any, coming mainly from lower bunching costs. However, as stand density increases, limiting machine maneuverability and increasing the number of cycles per unit of volume, feller-bunchers may become more expensive than manual methods (2), (3), (4).

Limbing is one of the most time-consuming elements of cutting, requiring up to 65-70% of total cutting time in Norwegian softwood (5). As a result, mechanization of limbing has become common in softwoods, though not in hardwoods. Folkema (6) reported that chainsaw limbing costs averaging \$6.00 per cunit compared favorably with chain flails (\$2-10) and sophisticated machines such as the Logma (\$7-12). Chainsaw limbing is of consistently higher quality, as branches are cut flush with the bole. This is important with electronic scaling and merchandising equipment, as branch stubs produce false diameter readings. Simple gates such as those

used with southern pines are not satisfactory with the persistent branches of most northeastern conifers.

Because of the high cost of manual limbing in softwoods, several simplified methods have been tried in Norway. Samset et al. (7) reported that "overlimbing", the cutting of limbs only on the upper side of downed trees, required 53-66% of the time needed for normal limbing. Egner (8) and Sellaeg (9) experimented with "crown cutting" (tree is topped below the lowest whorl of green branches) and "green limbing" (remove live branches only to upper limit of merchantability), producing 30-55% reductions in limbing time. All three methods rely upon skidding to break off the remaining limbs.

Although full-tree cutting is less expensive than methods which involve limbing, transport costs may be higher. Garlicki and Calvert (10) reported that full-tree skidding required 51% more power than treelength, hence the extra wood is not totally "free" as some proponents would suggest. Also, full-tree forwarding of small trees prevents complete utilization of vehicle capacity because of the space required for branches (2). Thus all implications of cutting techniques on transport must be considered when weighing alternatives.

METHODS

In order to evaluate the cost of feasibility of cutting small trees, a tree-length thinning operation was conducted in a softwood stand in eastern Maine. The stand was marked to remove overtopped and intermediate crown classes and poor-quality codominants. Diameters ranged from 4 to 16 inches and volume averaged 25 cords per acre before cut. The cut removed 10 cords per acre; each tree averaged 6.4 inches d.b.h. and 3.3 cubic feet (26 trees per cord). An experienced two-man crew equipped with a chainsaw and skidder conducted the operation, but because of the small tree size, payment was based on hourly rates rather than the conventional piece-rate.

Harvesting operations were timed for six days by two observers using conventional time-study methods. Tree diameters were measured when possible but most were estimated ocularly. Effective cutting time was

divided into three elements: preparation, felling and limbing.

Preparation included (1) walking to the tree to be cut, (2) clearing brush and lower limbs, (3) planning the fall and (4) starting the saw. Preparation thus incorporated all time from the completion of topping one tree until the beginning of cutting the next.

Felling included the actual sawing time from the beginning of the undercut until the trees began to fall and the saw was removed from the back cut. Limbing included removal of limbs, topping and occasional slash lopping, and incorporated all activities from the time the cutter began walking toward the first limb until the completion of topping.

Non-productive activities were recorded as delays and the cause of each was noted. To sharpen the measurement of felling and limbing work, an element termed "wait" was timed for each tree to account for the period between the end of felling and the beginning of limbing. Delays included time for rest, saw repair and maintenance, other cutting-related delays and interference caused by skidder operations. Since most "wait" time was the result of hung trees, it was considered as a delay.

Field data were edited each night and transcribed onto summary sheets for entry into the computer. Statistical analysis utilized the Statistical Package for Social Sciences (SPSS).

Cutting data were recorded for a total of 695 trees. Normally, trees were felled, limbed and topped singly, then skidded to the landing. However, 178 trees were felled individually but limbed and topped in groups of 2 to 7. Limbing data for these trees were analyzed separately.

Regression analysis was used to examine relationships of cutting production with species, dbh, basal area and volume for seven individual species and five combinations of species. Regression equations for felling and limbing by individual species, major species groups and all species combined were tested for differences in slope and intercept using the procedure outlined by Freese (11).

To examine the relative efficiency for multiple-stem limbing, data for stems limbed in groups were segregated by group size (the number of trees in the group). For each group, predicted limbing times were computed from regression equations and summed for all trees in the group. These values, which represent the time required to delimb all trees

separately, were then compared with the observed times for each group.

RESULTS AND DISCUSSION

Production statistics are summarized in Table 1 for 695 observations of preparation and felling and 517 observations of limbing and topping individual trees.

Table 1
Cutting Production Analysis

EFFECTIVE CUTTING TIME IN MINUTES (695 trees)					DELAY TIME ¹ (MIN)	TOTAL TIME (MIN)
ELEMENT	PREPARE	FELLING	LIMBING	TOTAL		
Total	389.50	165.59	294.75	858.84	1086.13	1944.97
Mean	.57	.24	.42	1.23	1.57	2.80
Percent	46.4	19.3	34.3	100.0	--	--
Percent of Total	20.5	8.5	15.2	44.2	55.8	100.0

¹Includes time waiting for tree to fall.

Simple regression equations showing correlations between cutting production time (dependent variables) and tree d.b.h., basal area and volume (independent variables) are presented in Table 2.

Preparation (see Table 1) averaged 46% of effective cutting time but was totally unrelated to tree size. The smallest (4 inch) birch tree required the most preparation (3.8 minutes) and the largest (8 inches) required the least (0.8 minutes). This element of effective time is most closely related to site conditions immediately adjacent to the tree (stand density, terrain, obstacles, brush), factors which were not measured in this study. As a result, average preparation time was considered to be the best indicator of this element of work and was incorporated in the model as a constant.

Table 2
Regression coefficients for productive elements of cutting,
Brookton, ME, 1978

ELEMENT		NUMBER OF OBSERVATIONS	CONSTANT	COEFFICIENT	R ²	PREDICTOR
C	PREPARATION	695	0.564 ¹	--		
U T	FELLING	695	-0.0283	0.04168	.21	DBH (inches)
T I N G	L HARDWOOD	135	0.027	1.21	.60	Basal area (sq. ft.)
	B SPRUCE/ I HEMLOCK	108	0.008	3.02	.56	
	N G FIR/CEDAR	108	0.239	1.32	.28	

¹Mean value \pm 0.618.

The best predictor for felling time was d.b.h., and for limbing, basal area was best. Felling took only 19% of total effective cutting time, but it must be pointed out that this was actual sawing time. The time required for the tree to fall to the ground was classified as "wait", which was relatively independent of tree size, and was incorporated in the model as a constant (delay).

Felling time was influenced only slightly by diameter; and wood density, as reflected by species, had negligible and insignificant effects. It is likely that sawing speed and time in small diameters is directly affected by the depth of chain raker teeth, rather than wood cross-section or density. This might well change in larger diameter ranges. Separate equations were calculated for each species for felling time, but the differences were insignificant within the diameter range observed in this study. As a result, one equation was deemed suitable for predicting felling times for all species (see Table 2). Although the r² is low (0.21), the equation is better than the mean.

Limbing required 34% of effective time, a small percentage when contrasted with the 65-70% cited by Taruldrud (op. cit.) in Norwegian

softwoods. This is logical when thinning from below, as understory trees have shorter live crowns and smaller branch sizes than overstory trees of the same diameter. Further, approximately one-third of the trees were hardwoods, species with significantly fewer branches.

Equations for limbing time showed significant differences between hardwoods and softwoods, with spruce and hemlock requiring more than twice as much limbing effort as hardwoods. Differences were also noted between spruce/hemlock and fir/cedar, but the fir/cedar equation is less reliable, having an r^2 of only 0.28. Although fir data were inadequate for analyzing that species alone, they confirm that it can be limbed easily, an important consideration in spruce budworm salvage where fir is a substantial portion of the stand.

The results of multiple-stem limbing of trees in groups of 2-7 stems (Table 3) indicate that "group-limbing" of 2-5 trees offers significant reductions (15-50%) in limbing time (Figs. 2 and 3). For groups of five or more trees, the data are unreliable, but logic suggests that reaching limbs in large bunches will reduce productivity. Applying this technique requires the faller to drop the trees sufficiently close, and parallel, to permit limbing 2 or more trees at once, or to bunch one or more trees (manually or with the skidder) to facilitate the procedure.

Table 3
Comparison of single-tree and group limbing times,
in centiminutes.

NUMBER OF TREES/GROUP	NUMBER OF GROUPS	OBSERVED GROUP LIMBING TIME PER TREE	CALCULATED LIMBING TIME PER TREE	RELATIVE EFFICIENCY OF GROUP LIMBING
2	30	41.1	48.1	1.17
3	13	36.4	47.2	1.30
4	7	23.5	38.8	1.65
5	5	26.3	45.0	1.71
6-7	4	25.8	46.0	1.78

Delays totalled 55.8% of total time (Table 4), considerably more than the 40% reported by Gabriel and Nissen (12) and 25% reported by Samset et al. (7). Some of this difference could be the result of measurement techniques, but a major factor is probably the system used by the crew. In the Gabriel and Nissen study, the trees were felled only, and in the Norwegian operations (Samset), cutting is normally performed well in advance of skidding. It is customary in New England for the timber faller and the skidder to work close to each other. As practiced on this study, the faller often assists the skidder operator with choking or swamping roads, and the skidder assists the faller by pulling down hung trees.

In this study 38% of delay time (21% of total time) was caused by the skidder. Such delays included the faller helping the skidder operator with choking, pulling cable, finding trees and swamping trails. Also, due to the close proximity of the two operations, the cutter was often prevented from falling timber because the skidder strayed into the area. Most of these problems could be eliminated by better trail planning, in advance of cutting, and physical separation of the two activities. No doubt the large number of small trees also had an effect, as the faller could easily keep ahead of the skidding operation. The large number of trees per cord, compounded by the difficulty of locating sufficient convenient trees for an optimum load, resulted in greatly increased unit bunching time for the skidder.

Table 4
Analysis of delays associated with cutting tree lengths.

CUTTING DELAY TIME, MINUTES (670 trees)						
ELEMENT	SAW	PERSONAL	SKIDDER RELATED	WAIT	OTHER	TOTAL
Total	107.30	392.76	402.88	64.53	79.59	1047.06
Mean	.16	.59	.60	.10	.12	1.57
Percent	10.2	37.6	38.2	6.4	7.6	100.0
Percent of total	5.7	21.0	21.3	3.6	4.2	55.8

Prediction models are influenced by factors of a specific study which cannot be accurately quantified, hence they have limited utility outside of the case in question. However, such equations do express relationships which are helpful in analyzing other situations. Because of wide fluctuations in preparation times, multiple correlations were poor. Further, felling was best related to tree diameter, and limbing with basal area. The best model expressing stand/work relationships is the algebraic sum of the prediction constants and coefficients of the work elements listed in Table 2, expressed as follows:

Effective Cutting Time in Minutes per Stem

$$\text{Hardwoods} = 0.563 + 0.042 D + 1.21 \text{ BA}$$

$$\text{Spruce/Hemlock} = 0.544 + 0.042 D + 3.02 \text{ BA}$$

$$\text{Fir/Cedar} = 0.775 + 0.042 D + 1.32 \text{ BA}$$

Where: D = d.b.h. in inches

BA = basal area in square feet

Theoretically, from a stand table, effective cutting time for a thinning operation similar to this case could be estimated with these equations. Table 5 shows the relative time and cost of cutting spruce trees of different sizes, based on the model, not including delays.

The major benefit of studying such an operation is to identify areas in which efficiency can be improved. From Table 1, the work elements comprising the major portions of time are delays (56%), preparation (20%) and limbing (15%). Felling is a minor part of total time (8%); aside from designing faster, more powerful or sharper saws, there is little opportunity to improve this phase of cutting, and improvements would have minor effects on overall productivity. Similarly, improved limbing techniques may reduce limbing costs by half, but would reduce total costs only by 7-8%. However, as major problems are solved, minor ones become relatively more important, hence all factors should be considered.

Among the productive time elements, preparation requires nearly half of the working time, hence deserves serious consideration for improvement in technique. However, preparation time is related to stand and site

conditions, and options for altering them are few. Reduction of brush and unmerchantable trees is often performed in Sweden before a harvest cut, and precommercial thinning makes subsequent harvesting less costly, but these alternatives merely transfer the time and cost of work and very likely do not substantially reduce it.

Table 5.
Comparison of chainsaw production rates in spruce, by stem dbh (from regression analysis), excluding delays.

STEM DBH, INCHES	6	8	10	12	14	16
Number of trees per cord	26.7	11.9	6.4	4.1	2.9	2.2
Prepare time per tree, minutes	.56	.56	.56	.56	.56	.56
Felling time per tree, minutes	.22	.31	.39	.47	.58	.64
Limbing time per tree, minutes	.60	1.06	1.65	2.38	3.24	4.22
Total time per tree, minutes	1.38	1.93	2.60	3.41	4.38	5.42
Total time per cord, minutes	36.85	22.97	16.64	13.98	12.70	11.92
Cost/cord (\$12.05/hour for labor, overhead, saw)	7.40	4.61	3.34	2.81	2.55	2.39

The obvious culprit in this operation was delays which comprised 56% of total time at the work site. Major delays resulted from interactions between cutting and skidding which could be largely eliminated through better planning and/or separation of the cutting and skidding operations. Elimination of the skidder interference may create other problems, such as delays in getting hung trees to the ground.

The next largest factor was personal delay, which accounted for 21% of total time. No doubt this can be improved, but rest is important to the cutter and cannot be totally eliminated. Ergonomic studies offer an opportunity to improve this aspect of delay. Although the cutter on this operation cut 206 trees per day, which is respectable in spruce-fir pulpwood operations, crew productivity was about half that of similarly equipped and organized crews in tree-length harvests reported for Maine by Jacobs et al. (13). This illustrates the effect of increasing the number of trees from 6 to 26 per unit which greatly reduces productivity on a unit basis.

Results from this study suggest many opportunities to improve the efficiency and productivity of manual felling and limbing. With high capital and energy costs of mechanization and the social costs of underemployment and unemployment, coupled with the need for increased utilization of non-industrial private forests which are less suitable for mechanization, manual cutting operations are not likely to be supplanted in the foreseeable future.

CONCLUSIONS

When labor is expensive compared to capital and energy, mechanization becomes a solution to reducing unit costs in logging. However, changes in the relative costs of labor, energy and capital, and anticipated needs for more extensive and more careful partial cutting may not favor mechanization. Residual trees prevent the rapid operating cycles of machines from being used to best advantage in partial cutting, and unit costs of mechanized harvesting may become higher than manual costs as tree size declines.

The relatively high density of northeastern stands impedes the operation of machinery in early thinnings, hence cutting operations may best be performed by a man and chainsaw. The chainsaw is still relatively cost effective when compared to mechanical methods. If thinning concentrates on removing the lower canopy levels, in effect pre-salvaging mortality and leaving trees with the best crowns to continue growing, limbing may not be the significant cost that it has proven to be in

dealing with trees of greater diameters. The results of this study suggest that to be true, but further efficiencies can still be attained by applying more efficient limbing techniques.

The greatest gains from simplified limbing will likely be realized in partial cutting of stands from 4-10 inches d.b.h. to remove intermediate and overtopped trees. When cutting small trees, it is essential that all possible efficiencies be developed to improve the economic margin. Full-tree harvesting and utilization offer even greater potential benefits for cost reduction in small trees.

Space shuttles notwithstanding, the man and chainsaw still have a place in modern thinning operations.

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Figure 1. A typical northeastern softwood stand containing 2000 trees/acre ranging from 2-10 inches in diameter breast high.



Figure 2. Felling two or more trees together permits multiple stem limbing as shown in Figure 3.



Figure 3. Limbing two or more trees at a time significantly reduces operating costs.