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MECHANIZED THINNING OF NORTHERN HARDWOOD POLE STANDS methods and economics

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Professor Steinhilb received his B.S. degree in forest management from Michigan Technological University in 1940. His M.S. degree in forest management was obtained from Michigan State University in 1951. From 1940 through 1945, he worked as a forester for the Copper Range Mining Company. From 1946 to the present, with the exception of his 9 months graduate work, he has been employed in the Department of Forestry, Michigan Technological University. He is a registered Forester and a Registered Land Surveyor in the State of Michigan.

Richard M. Godman, Principal Silviculturist, earned Bachelor and Masters degrees from the University of Michigan. Since joining the Forest Service in 1946, he has been assigned to the Northeastern Forest Experiment Station (1946 to 1948) and the Alaska Forest Research Center (1948 to 1953) before being transferred to the North Central Station. His research at this Station has included studies of old-growth northern hardwoods (1953 to 1958), coniferous plantations (1958 to 1964), and second-growth northern hardwoods (1964 to the present). He is the author of more than 40 publications.

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THE PROBLEM

There are approximately 32 million acres of northern hardwood forest types in the eastern United States, or 9 percent of the forest land area (Quigley and Morgan 1968). Since the removal of the original northern hardwood forest by commercial clearcutting, most of this area has grown back into second-growth forests that are predominantly stocked with saplings and poles.

Although silviculturists have shown that early and repeated thinnings will increase both the future volume and quality of these dense pole stands, most landowners are discouraged from thinning because there is no immediate monetary return under the old thinning methods. If the thinnings and defective trees could be efficiently and economically harvested, then: (1) landowners would have a monetary incentive to thin; (2) their stands would produce more and better quality timber in the future; and (3) the increasing needs for more hardwood pulp could be met by thinnings and defective trees so that the better trees could be used for lumber and veneer.

Modern logging equipment has made it profitable to harvest smaller volumes of forest products. Smaller, more mobile field chippers make on-site chipping more feasible. Highly maneuverable, articulated feller-bunchers with accumulating shears permit rapid felling and bunching of trees for efficient pickup by grapple skidders. An incentive to utilizing logging residue is the progress made by the Forest Engineering Laboratory, Houghton, Michigan, in removing bark from whole-tree chips. This bark removal process makes it possible to utilize thinnings for producing high-grade pulp (Arola and Erickson 1973, Mattson 1975).

There has been limited research on both individual tree selection and strip thinning using mechanized equipment in natural forests. Zasada and Benzie (1970) worked with strip thinning and recovery of material, but they used chain saws and choker skidders. Morey (Bryan 1975) used mechanized equipment primarily in individual tree selection. Hooker (1955) did strip thinning without the aid of modern equipment. In the present study, previously tested methods were combined with modern equipment.

PURPOSE

In general, the purpose of this study was to determine the cost of thinning, chipping, and transporting second-growth, northern hardwood pole stands using a completely mechanized system.

The specific objectives were: (1) To determine ways of increasing the productivity of equipment for thinning that is normally used for clearcutting and whole-tree chipping. (2) To evaluate the damage to the residual stand caused by the harvesting equipment. (3) To determine the best thinning method. (4) To determine the cost of mechanized thinning in a northern hardwood stand when the cut material is recovered and utilized.

METHODS

Description of the Stand

A 50-acre, predominantly pole-size stand of mixed species containing a few holdover saw log trees (fig. 1), was selected in the Mishwabic State Forest[1] in Michigan's Upper Peninsula. The soil was a sandy loam. The topography was essentially flat with very minor changes in elevation.

[1]*Provided by the Michigan Department of Natural Resources on the NW ¼ of section 36, T51N, R37W, Ontonagon County. The State of Michigan and the Ahonen Lumber Company of Ironwood cooperated in this study with the North Central Forest Experiment Station.*

Figure 1.--*Typical view of stand as it appeared before thinning.*

The stand was bisected into two blocks by a dirt road that extended ½ mile south to a blacktop highway. Each block was 1,650 feet long parallel to the road and 660 feet deep perpendicular to the road. Each of these two blocks was then subdivided into five plots. Each plot was 330 feet wide and 660 feet deep perpendicular to the road and contained 5 acres. A landing was cleared at each end of the area, adjacent to the woods road (fig. 2).

A preliminary survey indicated 13 cords of hardwood pulpwood and 2,700 board feet of small saw logs per acre (table 1). Basal area was about 100 square feet per acre in trees 6 inches d.b.h. and larger. Ring counts made on a few of the larger trees revealed that the virgin hardwood timber had been heavily cut in the late 1920's and early 1930's. Tree diameters ranged from less than 2 inches d.b.h. through 28 inches.

Thinning Treatments

There were five thinning treatments:

(1) Strip thinning, mechanical felling, and skidding to landing (Plots A-1, A-2).

(2) Selection thinning[2], chain saw felling, and no skidding (Plots B-1, C-1).

(3) Selection thinning, mechanical felling, and skidding (Plots D-1, D-2).

(4) Strip thinning with selection thinning between strips, mechanical felling, and skidding to landing (Plots E-1, E-2).

(5) Shelterwood thinning, mechanical felling, and skidding to landing (Plots B-2, C-2). Thinning patterns were apparent both from the air (fig. 3) and on the ground (fig. 4).

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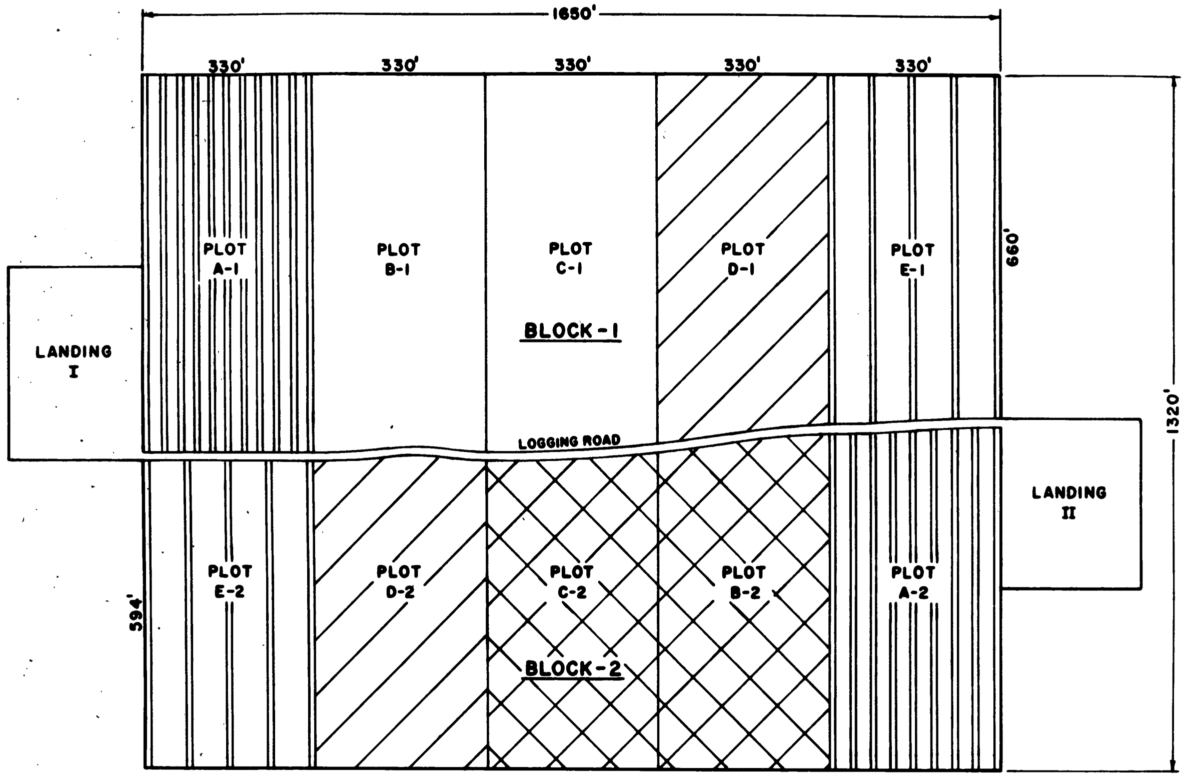
[2]*Selection thinning is also referred to as "individual tree selection."*



THINNING PATTERNS

SEC. 36, T51N, R37W
ONTONAGON COUNTY, MICHIGAN

LEGEND

PLOT A-1 MECHANICAL STRIP THINNING, SKID TO LANDING.
PLOT A-2 MECHANICAL STRIP THINNING, SKID TO LANDING.
PLOT B-1 SELECTION THINNING, CHAIN SAW FELL. TREES NOT SKIDDED.
PLOTS B-2+C-2 SHELTERWOOD THINNING, MECHANICAL FELLING AND SKID.
PLOT C-1 SELECTION THINNING, CHAINSAW FELLING, TREES NOT SKIDDED.
PLOTS D-1+D-2 SELECTION THINNING, MECHANICAL FELLING AND SKID.
PLOTS E-1+E-2 STRIP THINNING WITH SELECTION THINNING BETWEEN STRIPS, MECHANICAL FELLING, SKID TO LANDING.

Figure 2.--*Layout of plots and thinning patterns, Section 36, T51N, R37W, Ontonagon County, Michigan.*

Table 1.--*Stock and stand table (per acre) for entire 50 acres before thinning*

D.b.h. (inches)	Sugar maple			Red maple			Other species[1]			Totals			
	Trees	Volume	Volume (25 percent of trees)	Trees	Volume	Volume (55 percent of trees)	Trees	Volume	Volume (20 percent of trees)	Trees	Basal area	Volume	Volume
	No.	*Cords*	*Bd. ft.*	*No.*	*Cords*	*Bd. ft.*	*No.*	*Cords*	*Bd. ft.*	*No.*	*Ft.*[2]	*Cords*	*Bd. ft.*
5- 9	35.32	1.65	--	83.72	4.08	--	17.55	1.16	--	136.59	37.49	6.89	--
10-14	13.17	1.07	295	34.54	3.42	384	21.38	1.68	485	69.09	45.55	6.17	1,164
15-19	4.46	0.06	707	1.62	0.08	204	3.42	0.29	383	9.50	14.63	0.43	1,294
20+	0.55	--	125	0.10	--	23	0.32	--	66	0.97	2.29	--	214
Total	53.50	2.78	1,127	119.98	7.58	611	42.67	3.13	934	216.15	99.96	13.49	2,672

[1]In the western Upper Peninsula of Michigan these second growth hardwood stands are primarily composed of sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), and yellow birch (*Betula alleghaniensis*). There are lesser amounts of black ash (*Fraximus nigra*), American elm (*Ulmus americana*), black cherry (*Prunus serotina*), hemlock (*Tsuga canadensis*), balsam fir (*Abies balsamea*), and red oak (*Quercus rubra*). The maple, oak, birch, and cherry are valuable commercial species commanding a high price when saw log size.

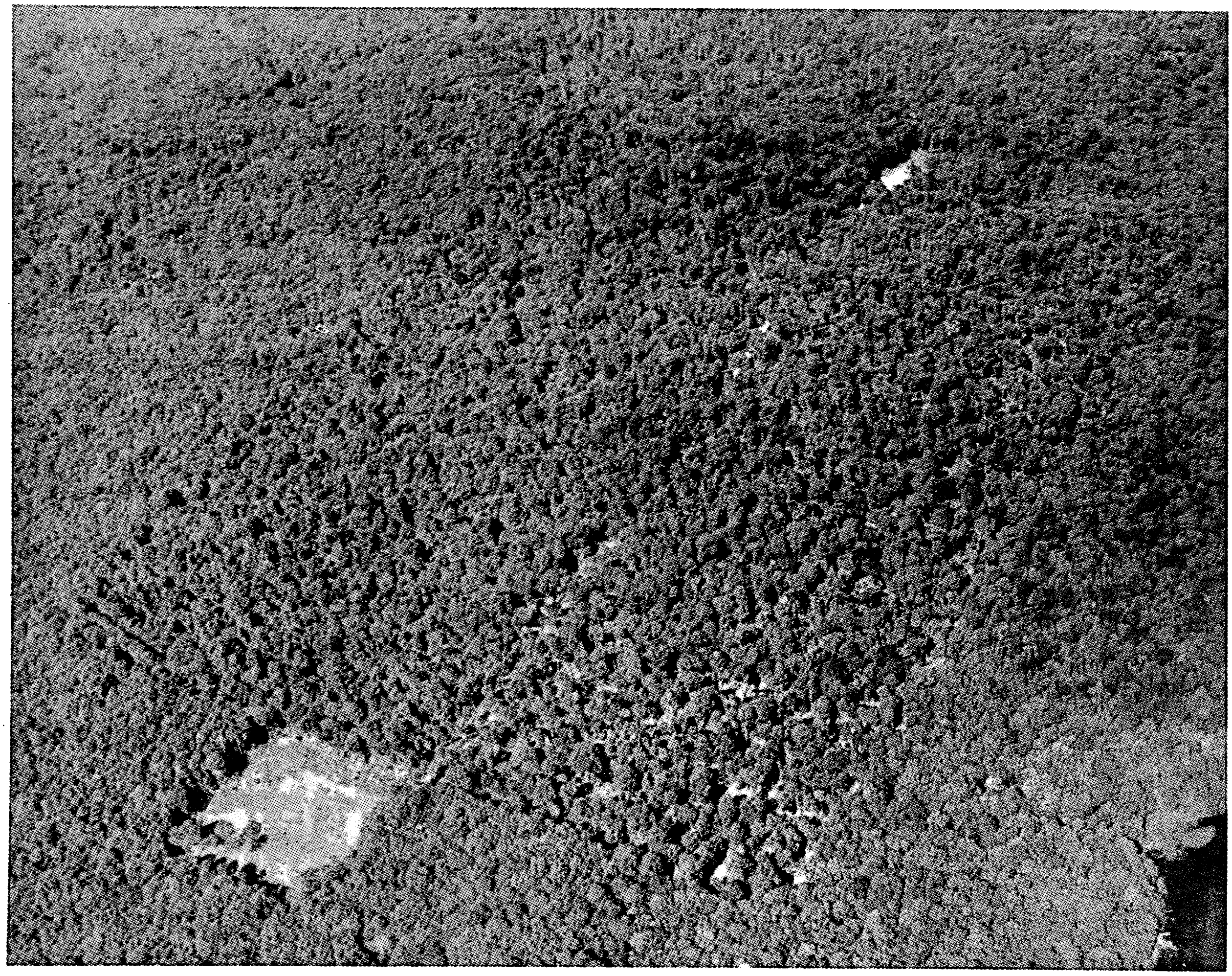


Figure 3.--*Aerial view of thinned site.*

Strip thinning.--Plot A-1 was strip-thinned with eleven 10-foot-wide strips located 32 feet apart from center line to center line. All trees within the 10-foot strips were paint-marked for cutting by including all trees within 5 feet of a compass-located center line. No cutting was done on the 22-foot areas between the 10-foot strips. The trees were cut by the feller-buncher, beginning at the end of the strips adjacent to the road. Felled trees were bunched with the butts facing the road to facilitate skidding the full trees to Landing I with the grapple skidder. Because the original basal area of A-1 was 111 square feet per acre in trees 6 inches and over, and because the clearcut strips occupied 33 percent of the area of plot A-1, the basal area of the stand after cutting was therefore assumed to be 74 square feet per acre in trees 6 inches and larger.

Plot A-2 was very similar to A-1 except that allowances were made for the slight difference in original basal area. A-2 was strip-thinned with nine 10-foot-wide strips located 40 feet apart from center line to center line. All trees within the 10-foot strips were paint-marked for cutting, and no cutting was done on the 30-foot areas between the cut strips. The strips were cut by the feller-buncher beginning at the ends of the strips adjacent to the road. Trees were bunched with butts facing the road and skidded to Landing II with the grapple skidder. The original stand had a basal area of 92 square feet per acre in

Figure 4.--*Ground view of thinned site.*

trees 6 inches d.b.h. and larger. The clearcut strips occupied 27.27 percent of the area of plot A-2, leaving a basal area after cutting of 67 square feet per acre.

Selection thinning.--Plots B-1 and C-1 were marked for selection thinning by painting "leave" trees to a residual basal area of 73 square feet per acre. The trees (including saplings) were felled by chain saw and were not removed from the area. This practice is similar to a commonly used timber stand improvement (tsi) procedure except that in tsi work trees are marked to fell, leaving most saplings uncut. During marking, plots were subdivided into marking units a chain square to assure uniformity in stand conditions and residual basal areas.

Selection thinning (Mechanical felling).--Plots D-1 and D-2 were marked for selection thinning by painting the residual trees to a basal area of 67 square feet per acre in trees 6 inches d.b.h. and larger. Trees to be cut were felled with the feller-buncher, placed with the butts facing the road, and moved to landings with the grapple skidder. Plot D-1 was skidded to Landing II and D-2 to Landing I.

Strip-thinning with selection between strips.--Plots E-1 and E-2 were strip-thinned with five 10-foot-wide cut strips. All trees within the 10-foot strips were paint-marked for cutting, and "leave" trees in the 70-foot areas between strips were paint-marked and tallied to 0.1-inch d.b.h. for a selection thinning. The residual basal area was 57 square feet per acre in trees 6 inches d.b.h. and larger. The trees were felled with the feller-buncher, placed in piles, and skidded to the landings by the grapple skidder. Trees from E-1 went to Landing II and from E-2 to Landing I.

Shelterwood thinning.--In Plots B-2 and C-2 "leave" trees were paint-marked for a two-cut shelterwood, leaving a residual stand with a crown cover of approximately 70 percent or 30,000 square feet per acre, and a basal area of 59 square feet per acre. Trees were cut by the feller-buncher and skidded to Landing II by the grapple skidder. The shelterwood cut was included in the study because it is a way of encouraging regeneration while the residual trees are increasing in size (Godman and Tubbs 1973).

Damage Survey

The extent of damage to the residual stand was determined in two ways: (1) by running a transect diagonally across each plot and describing the location and severity of each injury on damaged trees on the transect; and (2) sampling for presence or absence of injury during residual stand tallies of each plot.

Equipment and Manpower

The three major pieces of harvest equipment used in this operation were: a Rome Grapple Shear[3] with accumulator top clamp mounted on a John Deere 544 Loader, a Clark Ranger 667 GS Grapple Skidder, and the Trelan D-60 Whole-Tree Chipper (fig. 5).

For transporting the chips to the mill, two truck-tractor units were used in combination with four chip vans. Auxiliary equipment consisted of one Barko Loader to feed the chipper, one maintenance truck, one fuel truck, one chain saw, and a landing truck for spotting vans. Five men were required for the operation--four were equipment operators who alternated every 3 or 4 hours between machines to reduce operator fatigue. Table 2 lists the equipment including the purchase price and operating costs for each machine.

Time measurement and data collection.--All operations during the study were observed and total time and delay data were recorded for determining performance and operating costs. These data can be used for predicting results of similar operations in other stands, and for computer simulation studies (Bradley *et al.* 1976). Three stopwatches were used with a commercial timing board

[3]*Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

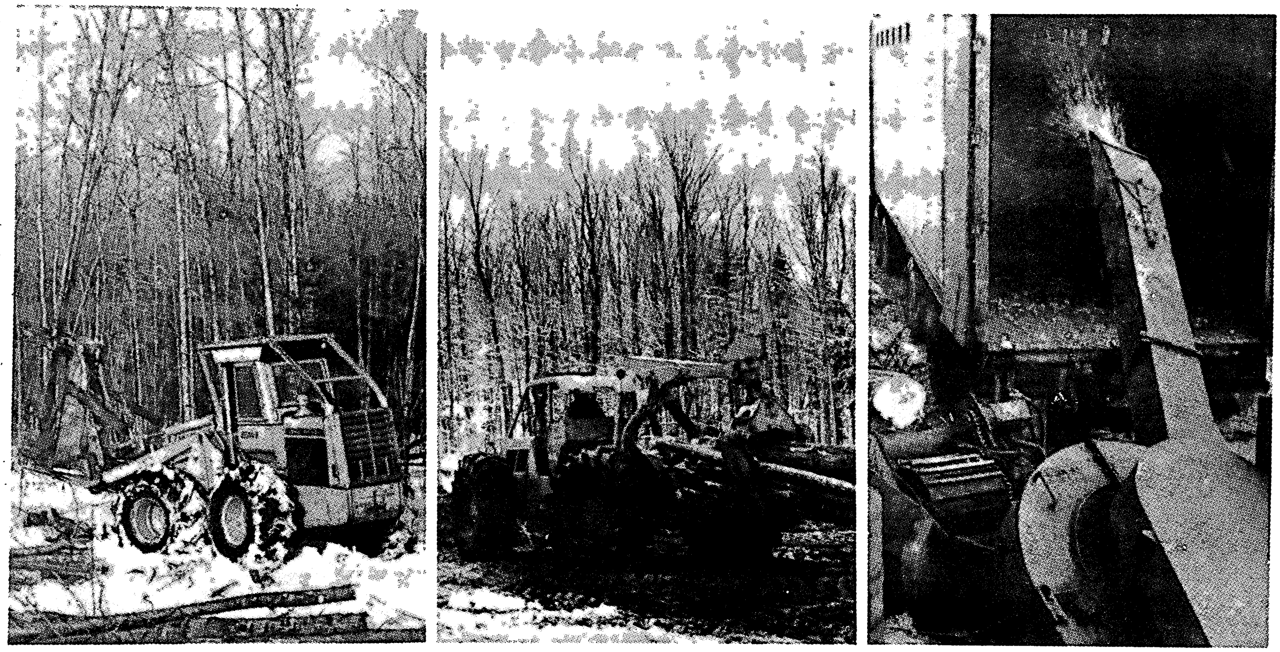


Figure 5.--*Major equipment used: (Left) John Deere 544 Feller-Buncher with Rome Accumulator Shear; (Center) Clark Ranger 667 Grapple Skidder; and (Right) Trelan D-60 Whole-Tree Chipper.*

Table 2.--*Itemized equipment cost*
(In dollars)

Machine	Initial cost	Cost/hour (without labor) Fixed	Operating
1 Clark Ranger 667 Grapple Skidder	$ 38,943	$ 6.72	$ 6.15
1 Trelan Chipper	34,000	5.86	6.75
1 Barko Loader	17,122	2.95	2.39
1 John Deere 544 with Rome Shear	39,900	6.88	7.55
Subtotal	$129,965	$22.41	$22.84
5 Chip vans	$25,980	$ 4.51	$ 8.26
2 Truck tractor units	56,100	10.72	20.62
Subtotal	$82,080	$15.23	$28.88
1 Maintenance and fuel truck	$3,990	$0.58	$0.42
1 Landing truck	2,500	.46	.85
1 Chain saw	280	.24	.70
Subtotal	$6,770	$1.28	$1.97
Total	$218,815	$38.92	$53.69

for continuous timing of events. A fourth independent watch was used to record delays. All distances were estimated.

Feller-buncher travel times, travel distances, shear and bunch times, and delays that occurred during each felling cycle were recorded. Because the feller-buncher had an accumulating head, a felling cycle started with the shearing of the first tree and continued until the accumulated bunch was laid down for the grapple skidder.

For convenience, the skidding data were recorded at two locations--in the woods and at the landing. Data for each turn included pick up time, number of trees, average d.b.h. (estimated), skidding distance, drop time, delays, and turnaround time.

Data recorded for each chipping cycle consisted of number of stems, average estimated d.b.h., delays, and total cycle time. A chipping cycle began with each grapple load.

All equipment data sheets recorded the operator's name, weather conditions, van load number, topography, soil conditions, brush conditions, and equipment used.

Separate data sheets were kept on the transportation of chips. These indicated the truck departure and arrival times, plot number, miles traveled, and the empty and full weights.

Upon completion of the study, all data were keypunched and computer programs written to compute costs, rates, and volumes.

RESULTS

System Productivity

The timing of machine operations resulted in construction of table 3, which lists the percent of productive time and percent of various delays for each machine used in thinning.

Table 3.--*Productive machine time and classification of delays*
(In percent)

Time category	Feller-buncher	Skidder	Chipper and loader
Productive time	67	62	49
Delays			
Lunch breaks	13	10	--
Wait for skidder	3	--	6
Miscellaneous	3	--	2
Discussion	3	1	--
Repair and maintenance	5	9	15
Help others	5	--	--
Change plots	1	--	--
Change vans	--	11	22
Wait for chipper	--	5	--
Bunching	--	2	--
Cut and stack saw logs	--	--	4
Clear branches	--	--	1
Change landings	--	--	1
Total time scheduled	100	100	100

Feller-buncher felling.--The feller-buncher (with accumulator shear) used in this study operated at an average felling rate of 85 stems per hour including delays (table 4). Differences in felling rates between treatments were not obvious because the treatment plots were felled by different operators who varied greatly in efficiency.

Table 4.--*Feller-buncher*[1] *operating rates by treatment*
(In numbers)

Treatment	Felling cycles	Stems per cycle	Stems per skidder bunch	Stems per hour: Without delays	Stems per hour: Actual
Strip	672	2.90	9.1	139.2	88.8
Shelterwood	858	2.90	11.1	133.8	87.0
Selective	709	2.95	11.2	137.4	80.0
Strip with selective	933	2.70	10.7	128.4	85.2

[1]John Deere 544 with Rome Shear.

Chain saw felling.--For comparison with feller-buncher plots, two 5-acre plots were selectively thinned with a chain saw by an experienced Michigan Department of Natural Resources (DNR) employee. The feller was instructed to fell the trees all in the same direction so they could be easily skidded to a landing and chipped or cut for saw logs. But he could not spend the time to carefully fell the closely spaced trees in the proper spot to facilitate skidding, and still be highly productive in felling. The attempt at skidding ended in failure. The felled trees, severely criss-crossed and entangled, were nearly impossible to skid with a choker skidder (fig. 6).

Total chain saw felling time was 2.24 minutes per tree or about 27 trees per hour (table 5). This included time to cut many saplings that were not counted in the "number of trees" column. The productivity of chain saw felling per man was more than 1.4 acres per 8-hour day.

Figure 6.--*Results of chain saw felling.*

Table 5.--*Time study data from chain saw felling*
(In minutes)

Plot and No. of trees[1]	Observation and walking	Brush	Felling	Delay	Total
B-1 (739)	608.54	33.97	431.4	326.21	1,796
C-1 (886)	883.72	35.49	461.90	461.27	1,849
Total 1,625	1,492.26	69.46	893.30	787.48	3,645
Average per tree	0.92	0.04	0.55	0.48	2.24

[1]Average d.b.h. for both plots was 7.1 inches.

Land treated (acres)	10.89
Trees per acre felled (no.)	149.2
Total trees felled (no.)	1,625
Average felling time per tree (min.)	2.24
Average felling time per acre (hr.)	5.57

Cost per acre

Labor (sawyer)	$22.28
Surveying and marking	5.75
Paint	.25
Chain saw and fuel cost	5.24
	$33.52 per acre

Skidding.--The skidder was most productive in the selectively thinned plot, equally productive in shelterwood and strip-with-selection thinning, and least productive in the strip thinning (table 6). The average weight per skid for all thinning treatments was 2.5 tons. Strip thinning was low in productivity because there were not enough trees within the operating limits of the machine on the 10-foot strips to make full-size bunches.

Chipping.--Without delays, the chipper produced 35 tons per hour; with all delays included, production dropped to about 17 tons per hour (table 7).

Material Removed and Costs

Material removed.--A total of 1,769 tons of chips (74 vans of 24-ton capacity) and 9,640 board feet of saw logs were removed from the study site in 22 partial days of operation. Total weight of both chips and saw logs was 1,829 tons (table 8).

Production costs.--Production costs are those incurred directly in cutting and removing the trees--felling, skidding, and transport. All production costs discussed include delays, avoidable and unavoidable, and should be regarded as conservative because proficiency will improve as loggers gain experience. Although these production costs are not excessive, nonproduction costs (tree marking, site preparation, and stumpage) are not included here because of their nature and variability. They are discussed

Table 6.--*Grapple skidder[1] operating rates by treatment*

Treatment	Skids	Average distance per skid: Road	Average distance per skid: Woods	Average stems per skid	Average weight per skid	Total time per skid: Without delay	Total time per skid: Actual
	No.	*feet*	*feet*	*No.*	*Tons*	*Minutes*	*Minutes*
Strip	214	517	638	9.1	1.67	4.5	6.25
Shelterwood	200	1,368	622	11.1	2.43	5.0	9.35
Selective	173	1,186	711	11.2	2.61	4.7	10.98
Strip with selective	219	518	625	10.7	2.42	4.5	8.56

[1]Clark Ranger 667.

Table 7.--*Chipper[1] operating rates for entire study*

Vans	Stems	Chipping cycles	Stems per cycles	Stems per van	Minutes per van: Without delays	Minutes per van: Actual	Tons per hour: Without delays	Tons per hour: Actual
- - -	- - -	*No.*	- - -	- - -				
73.75	8,570	5,336	1.6	116.2	41.35	83.82	34.82	17.18

[1]Trelan.

Table 8.--*Material removed*

Treatment and size (acres)	Chips removed	Saw logs removed	Total removed	Tons/acre	Stems/acre
	Tons	*Bd. ft.*	*Tons*		
Strip (10.5)	342	2,760	359	34.2	186.2
Shelterwood (9.61)	470	2,670	486	50.6	255.0
Selective (9.5)	444	1,380	453	47.7	219.2
Strip with selective (9.5)	513	2,830	531	55.9	263.9
Total	1,769	9,640	1,829		
Average				46.8	230.0

later. Felling, skidding, chipping, and transport account for over 80 percent of the $8.78 per ton required to produce the chips (table 9). Transport costs alone were $2.61 per ton or 30 percent of the total.

Table 9.--*Breakdown of costs*[1]

Item	Equipment	Labor	Total	Percent of total
	- - *Dollars/ton* - - - -			
Feller-buncher	$1.13	$0.68	$1.81	21
Skidder	0.94	.68	1.62	19
Chipper	1.29	.68	1.97	22
Chain saw	.03	.27	0.30	3
Maintenance and fuel truck	.06	.41	.47	5
Chip van	.48	.31	.79	9
Highway truck	1.40	.31	1.71	20
Landing truck	.04	.07	.11	1
Total	$5.37	$3.41	$8.78	100

[1]Average of all thinning treatments on 40 acres.

Break-even analysis.--A "break-even" chart was constructed from careful analysis of machine costs and rates (fig. 7). The fixed cost of thinning per day was $593.00. This included labor, depreciation, interest, insurance, taxes, licenses, and other miscellaneous fixed costs. For the break-even analysis, labor ($35.25 per hour[4]) was considered as a fixed cost because it was being charged whether or not the machines were operated. An additional $36.77 per hour is necessary to operate the equipment. Therefore, $887.00 of revenue must be realized for an 8-hour operating day in order to break even. When the system produced at the rate of 13 tons per hour, which was the average hourly rate for the lowest daily production during the study, a break-even point was achieved after 5 hours of production (fig. 7). This calculation is based on revenue of $11.85 per green ton delivered to the mill. When thinning produced 26 tons per hour, the average hourly rate for the best daily production during the study, it took slightly over 2 hours to break even.

Figure 8 displays a more realistic picture entailing both profit and loss based on the average rate of production for the duration of the study. Using the same logic as for figure 7, it took just over 3-½ hours of producing at the average rate of 17 tons per hour to reach the break-even point.

Costs by treatment.--Strip thinning--the most costly--was 40 percent more expensive than the shelterwood cut--the least costly (table 10). But for all practical purposes, differences in costs cannot be considered significant because factors that affected productivity (such as weather, operator ability, skidding distances, and unavoidable delays) were not constant from treatment to treatment. For example, among all treatments, feller-buncher operators varied as much as 25 percent in their productivity, other factors being equal.

Nonproduction costs.--Depending on the type of thinning, marking will cost from 5 cents per ton for strip thinning to 15 cents per ton for selective thinning.

Site preparation costs depend largely upon the size of the area to be logged. In this study an existing road was improved and two landings were cleared for only 40 acres of thinning. Therefore, for this study, site preparation and road improvements cost $1.00 per ton; it would have been possible to thin a much larger area utilizing the same roads and landings so that costs would have been less than 25 cents per ton. In addition, improved roads will service future logging operations, making site preparation costs negligible.

[4]*Labor costs calculated for five men totals $35.25 per hour: $4.50 per hour for four men and $5.50 per hour for one man, plus 50 percent of the hourly total for overhead.*

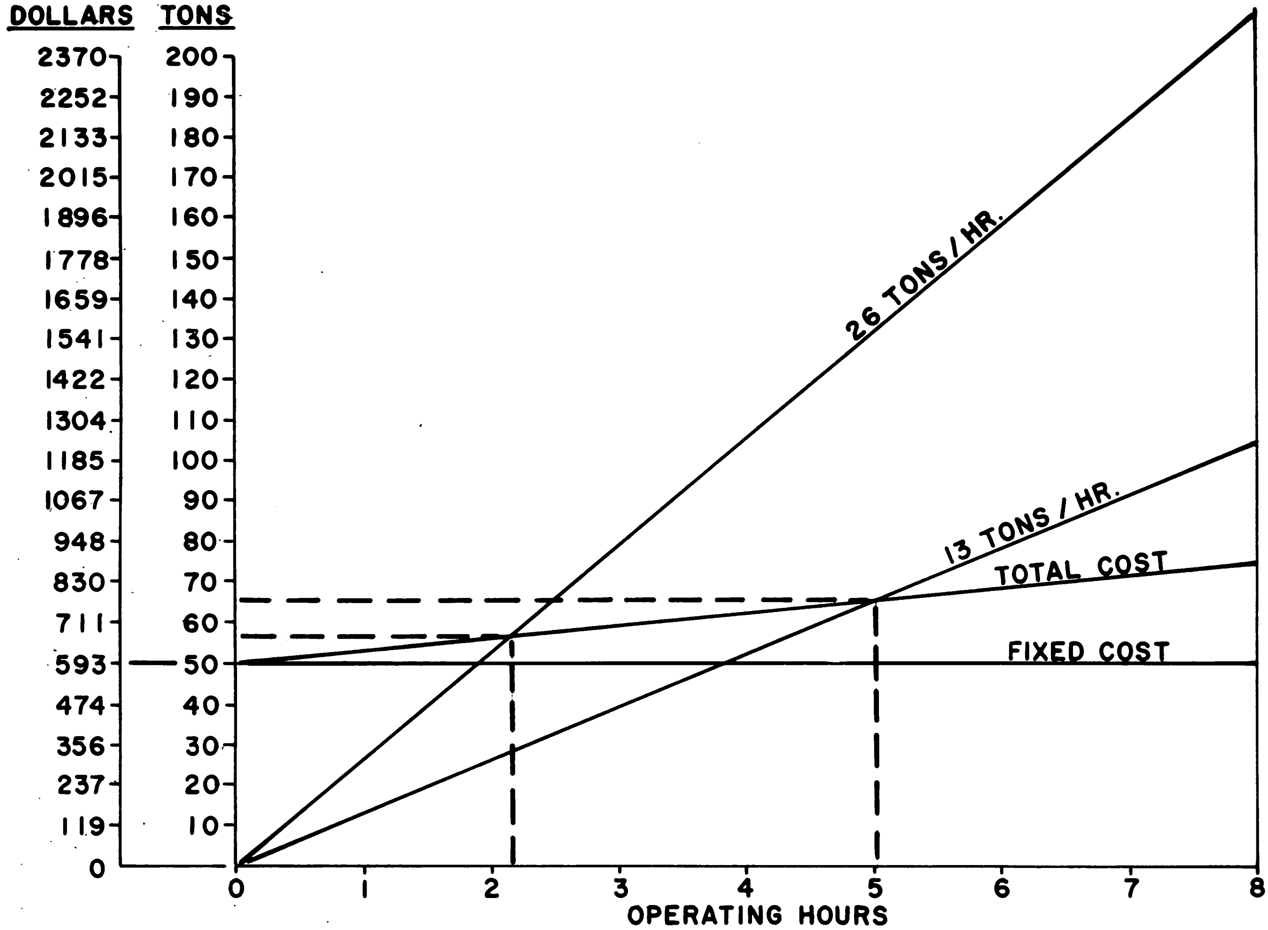


Figure 7.--*Maximum and minimum break-even points for entire thinning.*

Stumpage costs were ignored in this study because this stand was thinned as if it were being done by the Michigan Department of Natural Resources (DNR). Thinning in this manner by the DNR usually costs the State $25.00 per acre if the material is chain saw felled and left to decay.

If mechanized thinning should become a normal harvesting operation, cost calculations may have to include stumpage allowances. Table 11 illustrates the possibility of cost-benefit when applying the strip-with-selection thinning, including all costs. Based on the actual amount of product removed by this method (55.9 tons), a profit of $125.00 per acre was obtained.

Damage to Residual Stand

Kinds of injuries.--All plots harvested by the feller-buncher and skidder had significantly more bole and root injuries than the chain saw felled trees (table 12). Crown injuries were minor (they were most prevalent in stands thinned by chain saw) and consisted primarily of small and lower limb breakage that should not adversely influence crown development.

Bole injuries were the most common; an average of from 6 trees per acre in chain saw felling to 63 trees per acre in strip thinning had bole injuries. Fewer trees were injured (22 per acre) by the feller-buncher and grapple skidder during selection thinning between strips (table 13), but there were more injuries per tree (3.0), injuries were more severe, and they were higher up the bole than in other treatments.

Root injuries ranged from an average of 6 trees per acre in the shelterwood cutting to 39 trees per acre in strip cutting. Unexpectedly, the selection between strips had more major root injuries (67 percent were major) than other mechanized methods.

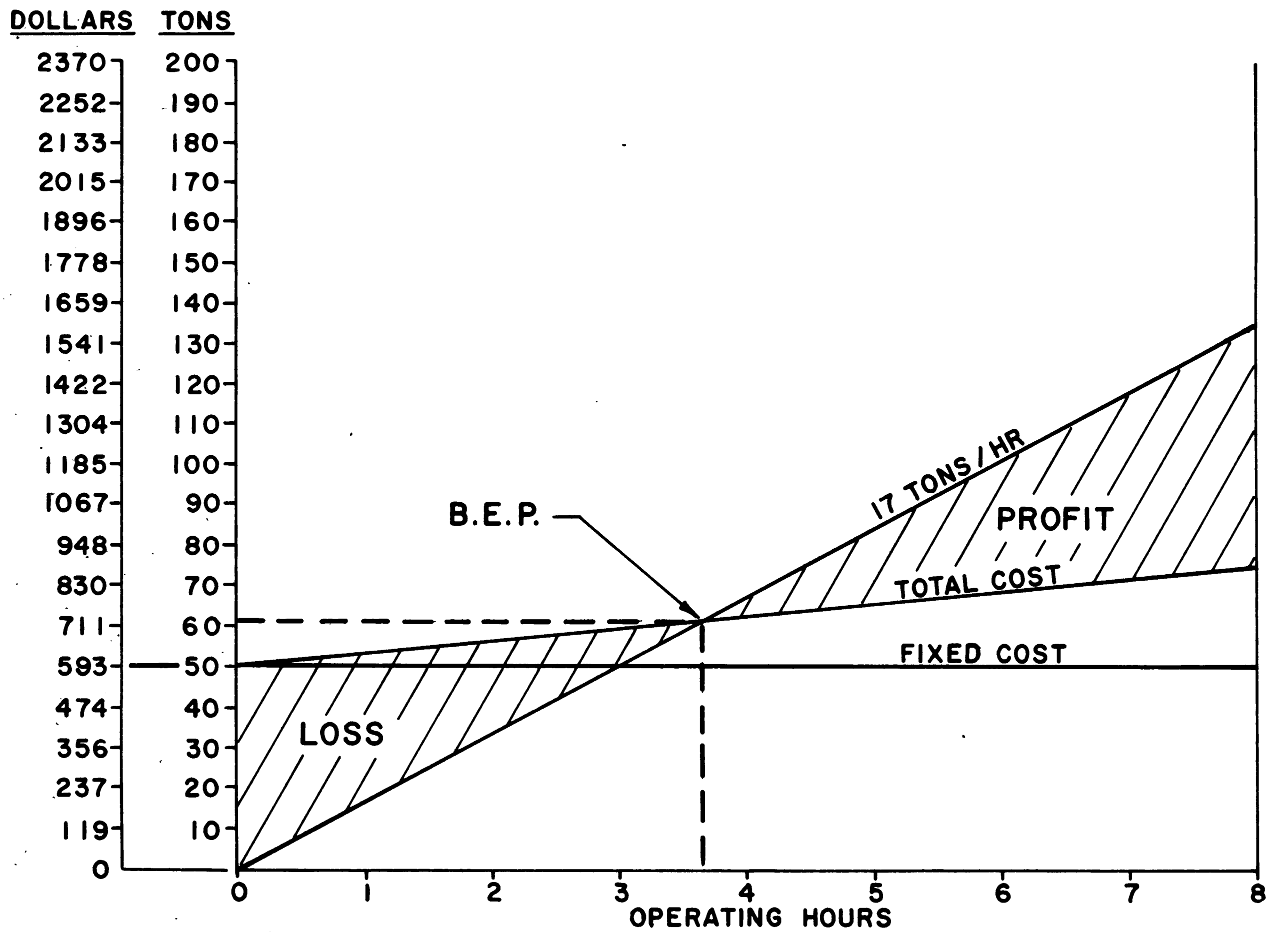


Figure 8.--*Profit and loss based on the mean productivity for entire thinning.*

Table 10.--*Cost of thinning treatments*
(In dollars/ton)

Treatment	Equipment	Labor	Total
Strip	$6.38	$4.49	$10.87
Shelterwood	5.04	2.74	7.78
Selective	5.12	3.47	8.59
Strip with selective	5.21	3.27	8.48
Average	$5.37	$3.41	$ 8.78

However, there was no consistent relation between root injuries and bole injuries on the same trees. Although root injuries were more frequent in the strip thinnings, they were just as severe far from the main haul road as close to it.

Strip thinning injuries.--The thinning patterns were a major factor in the frequency

Table 11.--*Projected return from strip thinning with selection between strips*

Cost		Delivered return	
	Dollars/ton		
Stumpage	$0.50	Revenue/green ton	$11.85
Marking	.10	Delivered cost/ton	9.60
Roads and landings	.22	Profit/green ton	$ 2.25[1]
Harvesting	6.18		
Transport	2.60		
Total	$9.60/green ton		

[1]Based on 55.9 tons removed per acre, a profit of $125.78 per acre may be realized.

Table 12.--*Frequency of tree injuries by cutting method and location on tree*

Marking and harvesting method	Residual trees per acre	Trees with one or more injuries: Per acre	Trees with one or more injuries: Per acre	Proportion with injuries to: Bole	Proportion with injuries to: Roots	Proportion with injuries to: Crown
	No.	*No.*	*Percent*	- - - - -	*Percent*	- - - - -
Chain saw						
Selection	155	16	10	39	0	58
Mechanized equipment						
Shelterwood	109	23	21	99	28	14
Selection	137	46	34	77	30	36
Selection between strips	156	31	20	70	45	30
Strips[1]	350	86	25	73	45	16

[1]Applies to area between strips.

Table 13.--*Severity of injuries by cutting method and location on tree*

Marking and harvesting method	Bole injuries: Trees per acre	Bole injuries: Major[1]	Bole injuries: Minor	Root injuries: Trees per acre	Root injuries: Major	Root injuries: Minor
	No.	*Percent*		*No.*	*Percent*	
Chain saw						
Selection	6	0	100	0	--	--
Mechanized equipment						
Shelterwood	23	29	71	6	50	50
Selection	35	9	91	14	50	50
Selection between strips	22	60	40	14	67	33
Strips[2]	63	40	60	39	33	67

[1]"Major" injuries had 50 square inches or more of stem or root cambium exposed. "Minor" injuries had less than 50 square inches of stem or root cambium exposed.
[2]Applies to area between strips.

of damage to residual trees. In the strip thinnings, which had the greatest number of injured trees per acre, the average spacing of trees was 11.2 feet. All of the trees cut from the strip had to be placed to the right of the operator into the uncut stand. This frequently involved repeated placement of small bunches and many reverse movements by the feller-buncher with trees in the accumulator head. Consequently, the repeated movements and placement of cut trees into closely spaced standing trees caused an increase in bole and root injuries. In conjunction with this, the productivity of felling and skidding equipment was the lowest of the several cutting methods.

Selection thinning (mechanical) injuries.--Selection cutting had the second highest injury rate. Because the feller-buncher meandered randomly within the plot, more trees were injured but most injuries were classified as minor.

Strip-thinning-with-selection-between-strips injuries.--This method resulted in the greatest percent of major bole and root injuries of all the mechanized thinning treatments because of the concentrated logging activity along the edge of the strips. Contributing to this was the relatively narrow spacing between trees in this plot (averaging 16.7 feet).

Mechanical thinning injuries compared to conventional harvesting injuries.--Injuries were more common than reported for conventional methods of harvesting (Benzie 1959, Engle 1947, Meyer *et al.* 1966). Factors contributing to the variation in injuries were differences in spacing within a plot, the difference between equipment operators, and weather conditions.

Although injuries occurred more frequently than in previously reported studies, most are expected to be relatively minor. Many of the damaged trees can be removed in future thinnings and, according to older studies, before significant volume or value losses occur in these young, vigorous stands (Hesterberg 1957, Ohman 1970).

DISCUSSION

System Productivity

Balance of equipment.--In order to optimize the efficiency of a thinning system, the operating rate of each major element of the system should be approximately equal (table 14). In the present study, the balance was generally good with the exception of the chipper, which had a production capability from 20 to 30 percent greater than the feller-buncher and skidder.

Felling.--When selecting a shear to operate in hardwoods, primary consideration must be given to maximum shearing force (approximately 6,600 pounds per inch width of cut when using a 3/4-inch blade in hard maple) (Arola 1972). Therefore, a 10-inch maple may take up to 66,000 pounds of shearing force to fell. It is also necessary to have a shear with accumulating capabilities in order to collect as many small stems as possible in the felling head before bunching. Figure 9 illustrates the difference in production volume between a single tree shear and an accumulator shear (Rome Industries 1972). The shear used in the present study had both capabilities.

Skidding.--The grapple skidder was an acceptable machine for this thinning operation. However, the feller-buncher operator must be familiar with the maximum size load the grapple skidder can handle in order to optimize the latter's productivity. As mentioned, too narrow a strip prevents the grapple skidder from attaining maximum productivity.

Chipping.--The chipper used on this operation was an efficient machine, however, a separate loader must be located adjacent to the chipper and placed so that the skidder can only drop its load at the feed end of the chipper. This was a major cause of skidder delays because the chipper must chip everything in the drop zone before the skidder can deposit another load.

Advantages and Disadvantages of Thinning Treatments

Selection thinning.--Silviculturally, selection thinning is superior to strip thinning but is more difficult to mechanize because:

1. The feller-buncher and skidder must both operate in the stand, creating a higher risk possibility for injury to the remaining trees.
2. A good felling and removal system is difficult to coordinate because both machines tend to interfere with one another--bunches felled in uncut areas must be removed before felling can be continued.
3. Skidder operators are often not experienced enough to decide the least damaging route out of the woods each time they pick up a load.

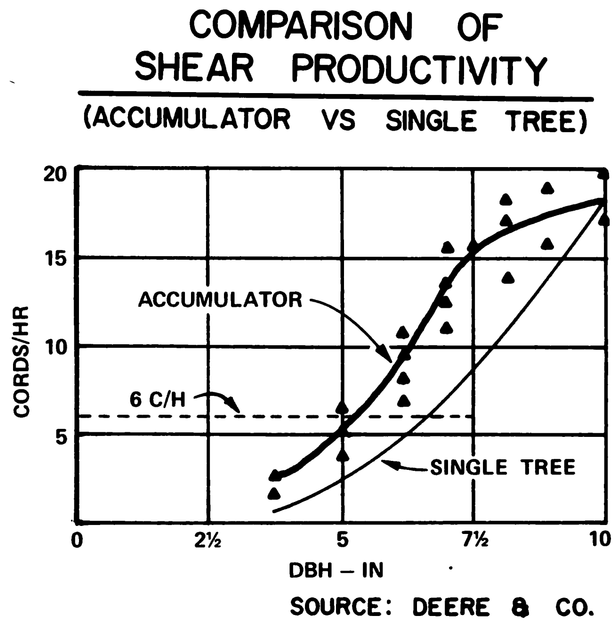


Figure 9.--*Production curves indicating the difference between a single tree feller-buncher and a feller-buncher with an accumulator shear.*

Table 14.--*Productivity of various operations by thinning treatment, with and without delays*

Treatment		Feller-buncher		Skidder		Chipper	
		Stems/hr	*Tons/hr*	*Stems/hr*	*Tons/hr*	*Stems/hr*	*Tons/hr*
Strip	(Without delays)	139.7	24.0	121.3	22.3	154.4	29.4
	(Actual)	89.6	16.4	87.4	16.0	93.7	18.2
Shelterwood	(Without delays)	133.8	25.0	133.2	28.8	185.2	36.1
	(Actual)	87.4	17.2	71.2	15.9	77.1	15.0
Selective	(Without delays)	137.2	29.7	143.0	36.9	174.9	37.6
	(Actual)	79.7	17.3	61.8	16.1	75.7	16.3
Strip with selective	(Without delays)	129.1	26.7	143.4	31.3	170.6	37.2
	(Actual)	85.7	21.5	75.2	17.0	88.2	19.3
Average (weighted)	(Without delays)	133.3	27.2	135.0	31.3	172.3	34.8
	(Actual)	88.8	17.5	72.5	16.8	82.2	17.2

Strip thinning.--Strip thinning is easy to mechanize but silviculturally less satisfactory because there is no possibility of choosing between individual trees. All trees within the strip should be cut. In addition, the 10-foot-wide strips were not adequate to maximize production as previously discussed. Residual stand damage was high because the feller-buncher must always place the cut material into the uncut stand.

Strip thinning with selection--the best method.--Strip thinning with individual tree selection between strips was a good compromise because it was reasonably productive and was acceptable silviculturally. It was also preferred by the equipment operators and adopted by the logger as the system to use on his own woodlands.

Figure 10 shows why the strip with selection system was preferred. Initially, the feller-buncher starts cutting a 10-foot-wide strip, laying all bunches to the right. As soon as the end of the strip (660 feet in this case) is reached, the operator would go to his left and begin selectively thinning the between-strip space up to where the next strip will be (70 feet). The trees from the selective area would be bunched in the previously cut strip, thereby minimizing damage and also concentrating all of the cut material either in the cut strip or adjacent to it. After the operator has finished the selective cutting, he is back at his starting point and has one cut strip and a 70-foot-wide band of selectively thinned area. He then moves 70 feet to the left and begins a new strip, again laying bunches to the right and into the thinned area he just finished cutting. As he progresses in this manner to his left, he can cut many acres of material and never interfere with the skidder. With all the material being concentrated on a strip, the skidder operator, experienced or not, can easily follow the cutting pattern without having to make any skidding route decisions.

Other Considerations

Landings.--The in-woods landing only occupied ½ acre but was adequate to efficiently service the operation (fig. 10).

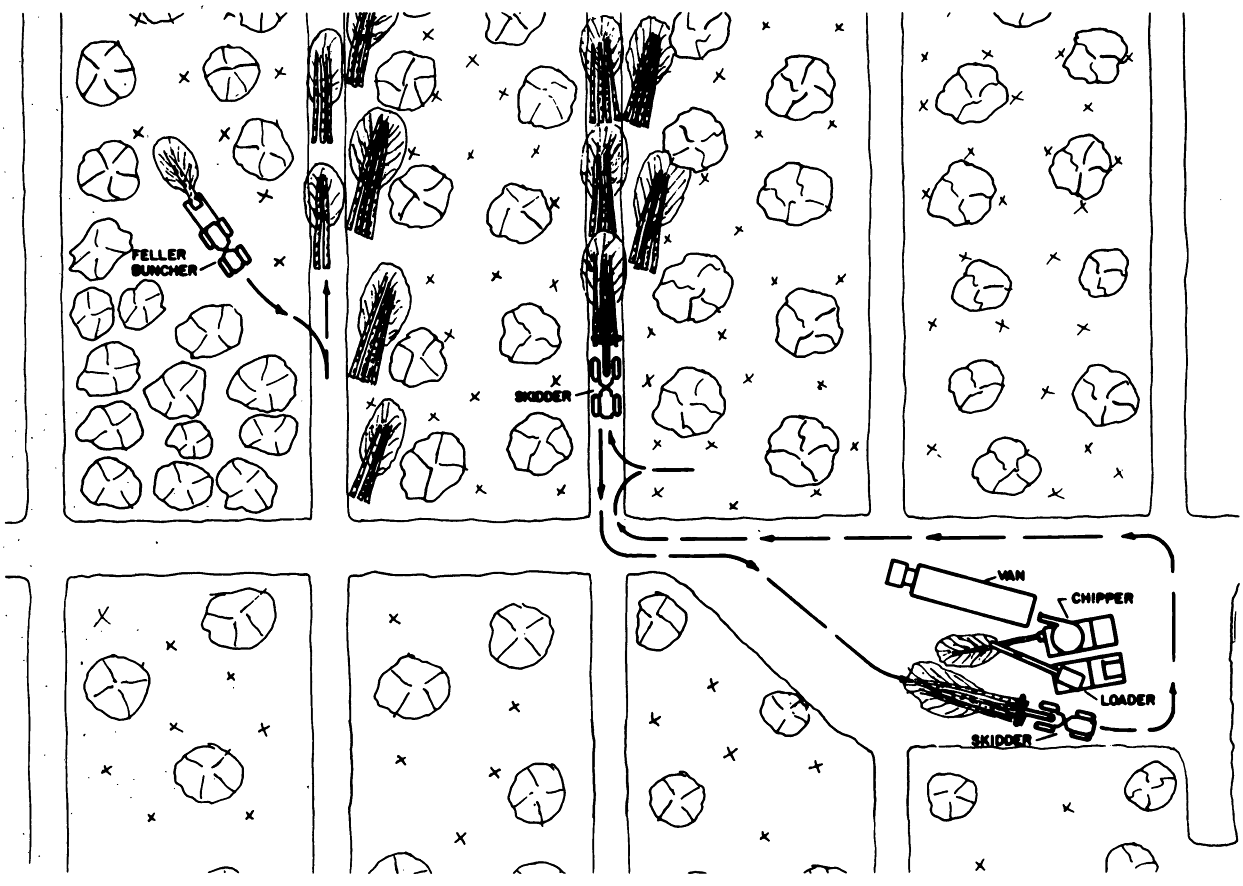


Figure 10.--*Strip with selective thinning system.*

Construction of this landing took approximately ½ day and began with the feller-buncher cutting and decking the entire area without intermediate handling by the skidder. This allowed the dozer to stump and level the area immediately after felling. The chipper was then placed next to the decked material (about one van load), which it started to chip while the feller-buncher got a head start on the rest of the operation. The landing was also designed with a small spur road on one end that was used as a van turnaround and van storage area.

Effects of weather.--This study began in the first days of November 1974 and ended 1 month later during the transition period between fall and winter. All types of weather were encountered--dry, rain and snow mixed, and heavy snow. Temperatures ranged from 75° F down to 10° F. The greatest problem associated with weather was chipper knife maintenance. Skidding during wet, snowy, and freezing conditions caused an accumulation of dirt and grit on the branches that dulled the chipper knives. They consequently had to be changed for every van load of chips. As soon as the ground became frozen and snow covered, the chipper knives lasted about 10 times longer. In winter there is greater ease of movement on the frozen ground and possibly less damage to the forest floor and root systems of the residual stand.

CONCLUSIONS AND RECOMMENDATIONS

1. Strip thinning with tree selection within the "leave" strip had some drawbacks, but it was the best of the treatments.

2. It is possible to realize a profit from mechanized thinning in pole stands but it will be less than from clearcutting and chipping whole trees.

3. Because operators have a large investment in equipment, mechanized thinning might be achieved by subsidizing any equipment owner willing to try thinning. A portion of the money now being spent on other thinning methods could be paid directly to him. The amount might be enough to encourage a logger to try it and perhaps, with experience, the need for a subsidy would diminish. Because we need to develop thinning specialists now, we hope this study will encourage capable operators to undertake thinning, and encourage others to support these operators until they become self-sufficient.

4. Further tests of these thinning treatments should be made on larger tracts giving the equipment operator freedom to operate within the constraints of the system and not be burdened with continual observation of every move. Larger areas will permit experimentation with tree marking, methods, strip widths, and landing sizes and locations. Tree marking could be minimized to reduce costs. A properly trained feller-buncher might be able to do an adequate thinning job with little or no tree marking.

5. Wider strips, resulting in greater productivity, could also reduce tree damage on strip edges, or damaged trees could be removed right after thinning. A study of the most economical landing sizes, road types, and locations of each would be beneficial.

6. Different equipment combinations might be more productive.

7. Computer simulation of mechanized thinning will reduce the cost of further research by solving problems that would otherwise have to be solved by field testing. Basic data collected in this study will be used as input in the GPSS[5] Whole-Tree Field Chipping Simulation System.

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[5] *The GPSS (General Purpose Simulation System) is an IBM computer language for simulating discrete systems (Bradley* et al. *1976).*

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