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Skyline Thinning a Western Hemlock-Sitka Spruce Stand: Harvesting Costs and Stand Damage

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Contents

Introduction

A multidisciplinary research study was conducted to study the management of young forests containing western hemlock (Tsuga heterophylla (Raf.) Sarg.) and Sitka spruce (Picea sitchensis (Borg.) Carr.). This research bulletin summarizes the sections of the study that examined harvesting cost and stand damage during logging. Objectives of the harvesting cost study were (1) to develop predictive production models for felling and yarding, (2) to compare felling and yarding production and cost rates between thinning treatments, and (3) to determine total stump-to-mill harvesting cost. Objectives of the stand damage study were (1) to describe characteristics of tree scars caused by logging, (2) to compare stand damage between thinning treatments, and (3) to identify harvesting variables correlated with stand damage during thinning. All log volumes are reported in cubic feet; to convert to board feet, multiply by 3.4.

The thinning prescription (tree size, volume per acre, and pattern of removal) is an important variable, affecting cost (LeDoux and Brodie 1982) and residual stand conditions (Caccavano 1982). Nearly all thinning prescriptions in the Pacific Northwest have followed selective systems, which are based on density management methods (e.g., basal area per acre, spacing rule-of-thumb, or stand-density index).

In strip thinning, an alternative method to selection thinning, trees are removed in adjacent clearcut strips spaced a set distance apart. This method results in alternate cut and leave strips. Herringbone thinning is another form of strip thinning, in which additional cut and leave strips are created at an angle to the main corridor. Density management methods are still required with this treatment; however, the prescription is based primarily on strip spacing.

Cost of unit layout may be lower with strip thinning than with selection thinning because tree marking can be eliminated (Hamilton 1980). Cost of commercial thinning also can be reduced. Various studies have shown increased felling and yarding production and lower harvesting cost with strip thinning than with selection thinning (Kramer 1974, Aulerich 1975, Twaddle 1977).

The potential effects from scarring residual trees in commercial thinnings include loss of growth, volume, and quality; increased susceptibility to disease or insect attack; and negative aesthetic impacts. These effects vary considerably between stand types, harvest planning practices, and logging methods. Hargrave (1985) summarized logging variables, identified in past thinning studies, that influence residual tree damage. Some studies have shown less stand damage with strip thinning than with selection thinning (Hamilton 1980, Caccavano 1982). Tree scarring in western hemlock-Sitka spruce stands is of particular concern to managers because of these species' thin bark and susceptibility to a root disease, Fomes annosus.

Most studies of damage produced by cable logging have documented tree scarring without specifying the cause. To identify techniques that minimize damage, it is necessary to analyze damage as it occurs during operations. A few studies have been conducted on stands of large timber during partial removal (Fieber et al. 1982, Miles and Burk 1984), and similar work on smallwood thinnings is needed.

Clearly, decisions about young-growth stand management must involve silvicultural, harvesting, and economic considerations. To make well-founded decisions, more information is needed about the silvicultural effects and financial returns from different thinning prescriptions. These data are particularly important for management of western hemlock-Sitka spruce forests, which are among the world's most productive. Careful and intensive management of these stands will maintain their productivity and increase financial yields.

This logging analysis and stand damage study, together with later silvicultural and economic analyses, will provide information for management of young western hemlock-Sitka spruce forests.

Project Description

Study Site and Treatments

The study site was northeast of Lincoln City, Oregon, in the Cascade Head Experimental Forest, Siuslaw National Forest. The site is highly productive, with good soil and abundant moisture throughout the year. The timber stand, which resulted from natural regeneration, was precommercially thinned at age 15 and was 32 years old during this study. Three conifer species were present: western hemlock, 72 percent of total trees per acre; Sitka spruce, 21 percent; and Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), 7 percent.

The 45-acre study area was divided into two parts. The first, larger area contained 12 treatment compartments that were designated by the U.S. Department of Agriculture Forest Service research group (Greene and Emmingham, in press); the second area contained four compartments. The Oregon State University (OSU) Forest Engineering research group planned and laid out skyline roads for harvesting within each thinning treatment (Figs. A1 and A2, Appendix A). For each skyline road, a payload analysis was completed by using the Hewlett-Packard model 86 computer and the "Logger" program.

Thinning treatments included two selection methods, one resulting in narrow spacing and one in wide spacing of residual trees. The third treatment, a herringbone design, created 20-foot-wide lateral cut strips, with 30-foot-wide uncut strips between them, placed at a 45-degree angle to the main corridor. The fourth treatment was an unthinned control. The four treatments were replicated four times. Forest Service sales-layout personnel completed tree marking in all treatments. After logging, a detailed timber cruise was conducted with a variable plot program based on the tarif concept (Tappeiner et al. 1984). Stand data results are summarized in Table A1, Appendix A.

Volume removal for all thinning treatments ranged from 50 to 66 percent. For each treatment, the number of thinned and unthinned trees per acre by diameter class is shown in Figure 1. The average stand diameter at breast height before thinning was 13.4 inches; average total tree height was 74 feet.

Harvesting Procedure and Equipment

During this study, the smallwood-log market was insufficient to recover harvesting costs and required adding a portion of larger, higher-valued timber to offset an appraised thinning sale deficit. The project also required close cooperation between the logging contractor, the Forest Service sales administrator, and the research project leader. During the study, some modifications were agreed upon. In particular, these included changes caused by a mill closure: before

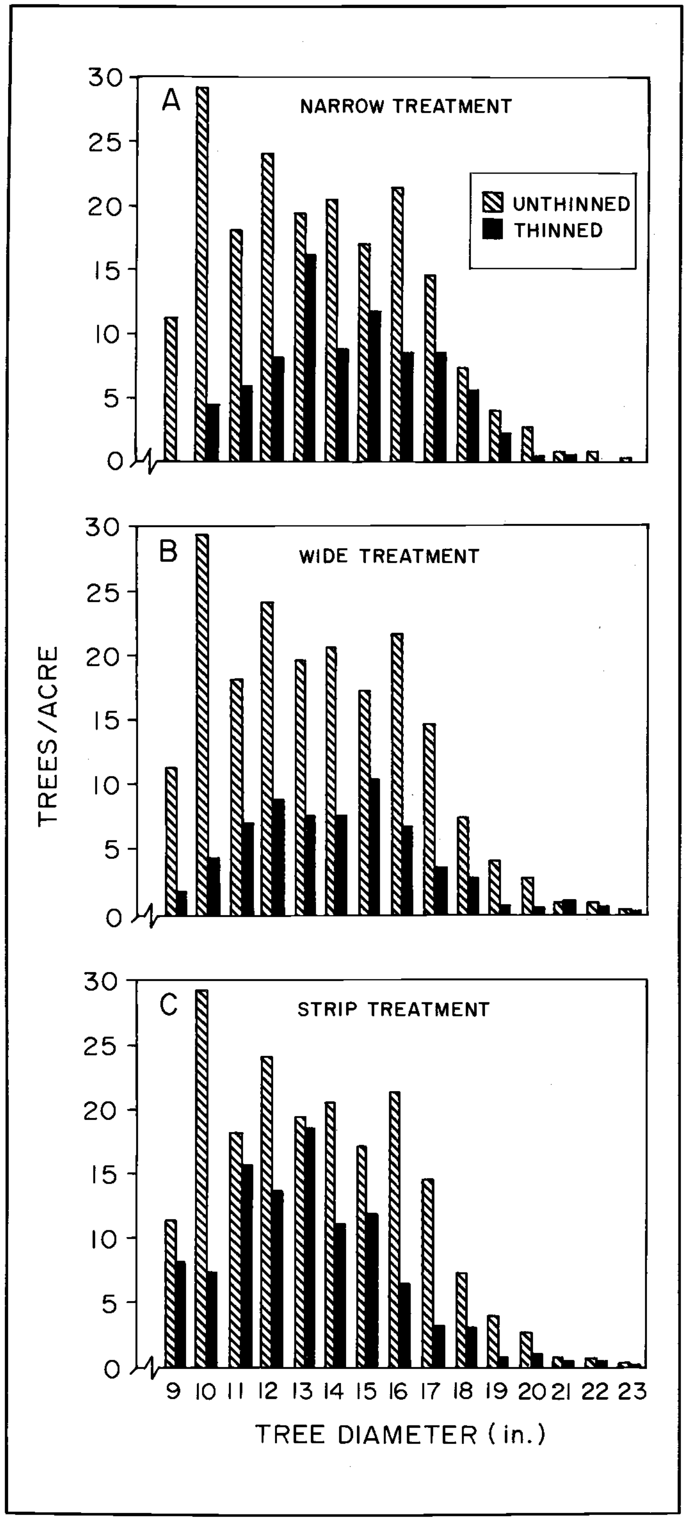

FIGURE 1.

PROPORTION OF THINNED AND UNTHINNED TREES BY DIAMETER CLASS (a) WITH NARROW SPACING TREATMENT, (b) WITH WIDE SPACING TREATMENT, AND (c) WITH HERRINGBONE STRIP TREATMENT.

the closure, logs were loaded and hauled to the mill during yarding; afterwards, they were cold-decked and later hauled. Landing delays were separated from the yarding cycle; thus, any differences between decking and loading methods were eliminated.

The felling operation was subcontracted to four experienced cutters. Trees were felled, limbed on three sides, and bucked in the woods before yarding. All cutters were highly productive but had varying degrees of ability in commercial thinning (e.g., felling to lead). The productivity of two cutters was measured for the three thinning treatments.

Experienced and highly productive crew members yarded and loaded the logs with a Madill 071 yarder and a Danebo MSP carriage (Figs. 2 and 3), along with a Bantam C-366 hydraulic heel boom loader. A slackline system was rigged with the MSP carriage (Fig. 4). Tailtrees were used on three corridors and an intermediate support was needed on one. Adequate deflection was obtained in the remaining corridors by taking advantage of the topography. The hooktender prerigged skyline corridors for most of the project. An excessive amount of limbing on the landing made two chasers necessary, and the hooktender filled in when a second chaser was unavailable.

FIGURE 2.

LANDING AREA WITH MADILL 071 YARDER AND BANTAM LOADER.

FIGURE 3.

DANEBO MSP CARRIAGE WITH INTERMEDIATE SUPPORT TRUCK.

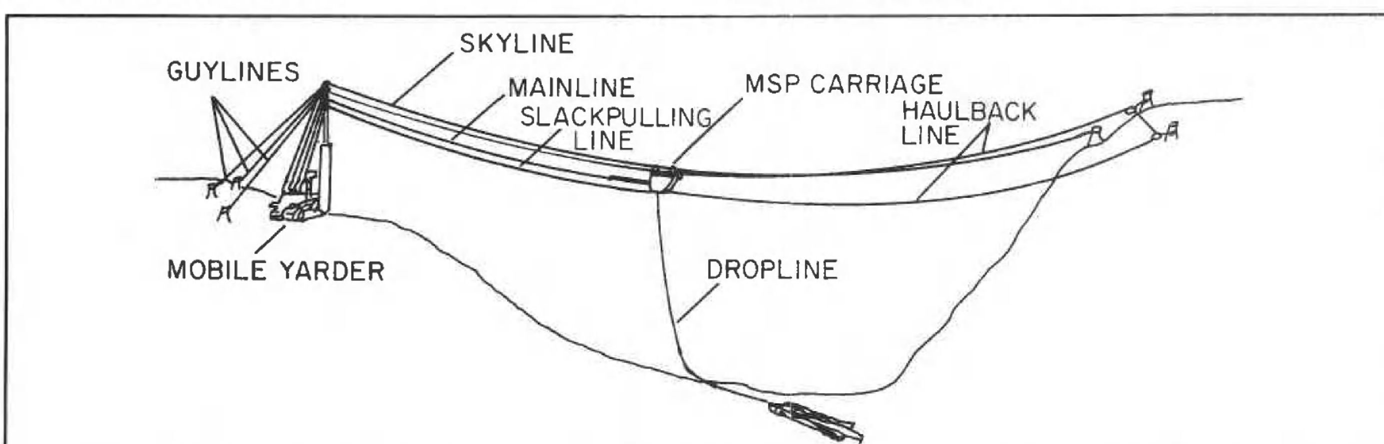

FIGURE 4.

SLACKLINE YARDING SYSTEM.

Methods

Production Study

A detailed time-and-motion study on the felling and yarding operations was the basis for the production analysis. For this study, total cycle times were divided into (1) basic elements that contributed directly to output during the cycle and (2) minor, nonproductive elements. Other interruptions in the main cycle were classified as delays and recorded separately. The time required to change skyline roads was also recorded. In addition to cycle time-elements, independent variables, upon which time was expected to be dependent, were recorded.

The cycle time-elements within the total felling and bucking time were move and select, cut and wedge, limb and buck. The cycle time-elements within the total yarding turn time were outhaul, lateral outhaul, hook, lateral inhaul, inhaul and unhook. In addition, yarding resets and carriage repositions were timed but were not considered part of the total cycle time; rather, they were analyzed as delays. Independent variables measured for felling and bucking were move distance, number of buck cuts, number of limbs, slope, species, and tree volume. Independent variables measured for yarding were carriage repositions, crew size, cutter, ground clearance, lateral distance, lead angle, log angle, log length, logs per turn, rigging slinger, slope, slope distance, turn volume, and yarding resets. Definitions of the independent variables for felling and yarding are given in the Glossary.

Most harvesting time studies have modeled the work cycle (e.g., felling a tree) as a first step in determining production rates and costs (Aubuchon 1982). Production rates are then obtained by the following calculation:

$$\frac{\dfrac{\text{Volume of wood}}{\text{cycle}}}{\left(\dfrac{\text{minutes}}{\text{cycle}}\right)\left(\dfrac{\text{hours}}{\text{minute}}\right) + \begin{array}{l}\text{delays and other}\\ \text{nonproductive}\\ \text{time per cycle}\end{array}}$$

Many harvesting treatment comparisons and analyses have been completed by using the cycle time variable, which often means less to harvest planners than production rates do. As an alternative, production rate can be used directly as the dependent variable in the regression model. Then the regression model and statistical analysis would be more directly applicable by forest managers.

In this study, multiple linear regression techniques were completed to develop models for predicting cycle times and production rates for both the felling and yarding operations. A random 20 percent of the time-study data was withheld from the regression analysis in order to validate the models. A t-test (0.05 probability level) compared predicted versus actual cycle time and production rate. This validation does not imply that the models can be used for appraisal purposes on any smallwood-thinning operation. The models are valid only for the given range of conditions shown in the data set and should be used with discretion elsewhere. The validation does, however, show that the production comparisons made in this study are statistically sound.

Stand Damage Study

During yarding, stand damage was measured on nine skyline roads (three per thinning treatment). The variables measured were type of damage (tree scarring or breakage), cause of damage (logs, skyline, or carriage) and location of the damaged tree in the stand. In addition, the following scar measurements were made: height of scar above ground line; length, width, and surface area of the scar; and depth of wound. A multiple regression analysis was then completed by correlating the variable scar area per cycle with 12 possible independent yarding variables. These were the same variables that were used in the yarding production study; they are defined in the Glossary. The purpose of this analysis was to identify the harvesting variables that influence stand damage, not to develop a predictive model. Scar area per turn reflects the total amount (ft^2) of residual tree damage per yarding cycle (all tree scars per cycle).

In addition to the detailed study, stand damage measurements were made after logging on 18 additional skyline roads to determine differences in damage between thinning treatments.

Results

Production Study

Felling and Bucking

The average time and relative frequency of felling cycle elements for all treatments combined are shown in Figure 5. Limbing and bucking required 59 percent of the total time because of the many limbs on hemlock and spruce. Even with a complete job of limbing after felling, logs with limbs attached caused significant congestion at the landing and two chasers had to complete limbing after yarding.

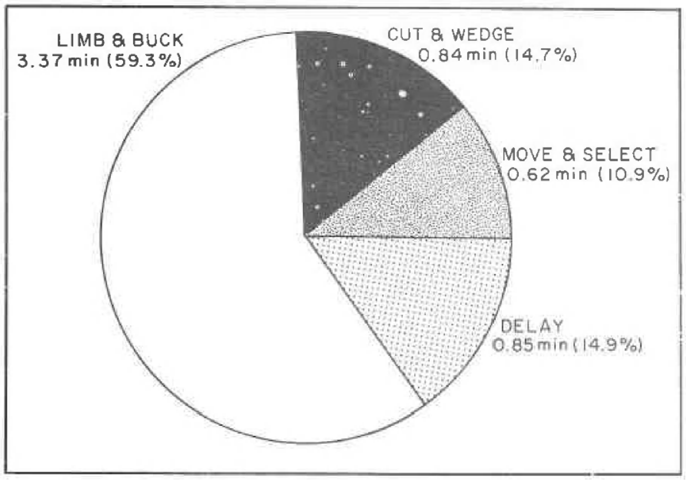

FIGURE 5.

FELLING CYCLE ELEMENTS. VALUES ARE FOR ALL TREATMENTS; PERCENTAGES ARE OF TOTAL FELLING CYCLE TIME.

Regression Models

Felling regression models are shown in Table 1. The production rate model includes the average delay time per cycle of 0.85 minutes. Thinning treatment was a significant variable. Felling cycle times for the wide spacing and strip treatments were significantly different from the narrow spacing treatment at the 99 percent confidence level. However, the coefficients for the wide and strip treatments are similar, thus indicating little difference in felling cycle time between these two methods. Relative frequencies for the indicator variables are as follows:

Indicator variable	Relative frequency
Cutter	
0 variable	0.56
1 variable	0.44
Treatment	
Strip	0.38
Wide	0.31
Narrow	0.31

Descriptive statistics for other felling cycle variables are summarized in Table 2.

Felling delays by categories are shown in Figure 6. Operating delays occurred most frequently; felling hangups, cutting nonmerchantable trees, and walking in or out of the unit consumed most of this time. The category named "other" included one excessively long cut-and-wedge time plus miscellaneous delays.

TABLE 1.

FELLING REGRESSION MODELS.[a]

Dependent variable	Intercept	Move distance[b] (ft)	Slope (%)	Tree volume (ft^3)	DBH (in.)	Species[c]	Cutter[d]	Wide treatment[e]	Strip treatment[f]	$\bar{R}^2$[g]	Sample size
Time/felling cycle (min.)	1.3286	+0.0187	+0.0143	+0.09868		+0.3541	+0.9019	−0.7820	−0.6575	0.59	1,293
Production rate (ft^3/hr, includes delays)	4.3583	−0.6572	−0.7497		+22.8116	−31.7431	−29.4183	+34.4381	+20.7497	0.55	1,293

[a] All values in the table are regression model coefficients.
[b] All variables are significant at the 0.01 level, except species, which is significant at the 0.05 level.
[c] 1 = Hemlock or spruce, 0 = Douglas-fir.
[d] 1 = Least experience, 0 = most experience.
[e] 1 = Wide treatment, 0 = otherwise.
[f] 1 = Strip treatment, 0 = otherwise.
[g] $\bar{R}^2$ = Adjusted coefficient of determination.

TABLE 2.

INDEPENDENT VARIABLES FOR FELLING CYCLE.

Independent variable and statistic	Treatment			
	All	Narrow	Wide	Strip
Move distance (ft)				
Average	24.61	27.48	19.12	26.36
Maximum	236	210	101	236
Minimum	0	0	0	0
Standard deviation	21.94	22.09	15.14	25.11
Sample size	1,859	585	539	735
Slope (%)				
Average	30.80	29.01	27.42	35.81
Maximum	90	78	90	80
Minimum	0	0	0	0
Standard deviation	14.87	13.69	13.32	15.63
Sample size	2,032	636	623	773
Tree volume (ft^3)				
Average	24.20	25.34	21.59	25.43
Maximum	91.33	91.33	67.80	82.03
Minimum	2.33	2.91	3.14	2.33
Standard deviation	13.35	13.23	10.97	14.87
Sample size	2,020	624	635	761
Diameter breast height (in.)				
Average	13.58	14.01	12.98	13.73
Maximum	27.00	27.00	23.00	24.00
Minimum	6.00	7.00	7.00	6.00
Standard deviation	3.15	3.04	2.74	3.48
Sample size	1,968	607	612	748

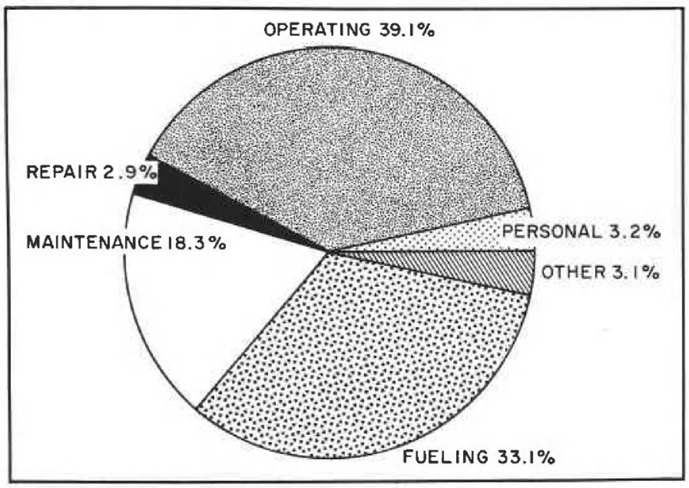

FIGURE 6.
FELLING DELAYS. PERCENTAGES OF TOTAL FELLING CYCLE TIME.

Production Rates and Costs

Details of the hourly owning and operating rates are shown in Appendix B. Costs are based on August 1983 values (when the study was conducted). Felling and bucking production and cost values are summarized in Table 3. Delay-free cycle time was obtained by substituting average values for the independent variables (Table 2) into the appropriate regression model.

The wide-spacing treatment was the most productive and the least costly. Strip thinning had similar results to wide spacing; narrow spacing was the least productive and the most costly. Hourly cubic-foot production increased 12.8 percent with strip thinning over selective narrow spacing and 15.4 percent with selective wide spacing over narrow spacing. Felling and bucking cost per cunit were reduced 11.4 percent with strip thinning over selective narrow spacing and 13.4 percent with selective wide spacing over narrow spacing.

Felling production rate differences as influenced by tree diameter are shown in Figure 7.

TABLE 3.

PRODUCTION AND COST FOR FELLING AND BUCKING.

Item	Treatment		
	Narrow	Wide	Strip
Felling cycle time (min)			
Delay free	4.97	4.19	4.31
Delay time/cycle	0.85	0.85	0.85
Total time/cycle	5.82	5.04	5.16
Hourly production[a]			
Number of trees	10.31	11.90	11.63
Volume (ft^3)	249.50	287.98	281.45
Cost			
$/cunit	11.23	9.73	9.95
$/M bd ft[b]	33.03	28.62	29.26

[a] Based on cycle time model
[b] 3.4 bd ft per ft^3

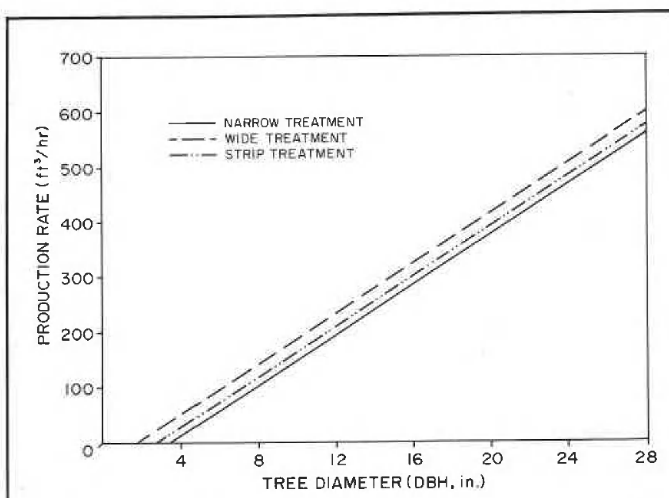

FIGURE 7.

FELLING PRODUCTION RATES BY DIAMETER CLASS.

Yarding

The average time and relative frequency of the yarding cycle elements for all treatments combined are shown in Figure 8. Hook is the most time-consuming of the yarding cycle elements (road changes and delays excluded); lateral outhaul, hook, and lateral inhaul consumed 59 percent of the total yarding cycle time. Road changes and delays added a significant amount of time to each yarding cycle: 1.64 and 1.57 minutes, respectively.

Skyline road change times are summarized in Table 4. Major road change delays took only 25 minutes during the entire project; these delays were caused by waiting on loading at a landing and by a lost shackle. Most of the road changes required moving the yarder short distances to a new landing and rerigging (Figs. A1 and A2, Appendix A). A landing change to a multispan road occurred once and was not prerigged, thus increasing the time (an intermediate support jack was rigged 40 feet above the ground). Most of the skyline roads did not require tailtrees; average landing and road change times were similar between tailtrees (average tailtree rigging height was 20 feet) and stump tailholds.

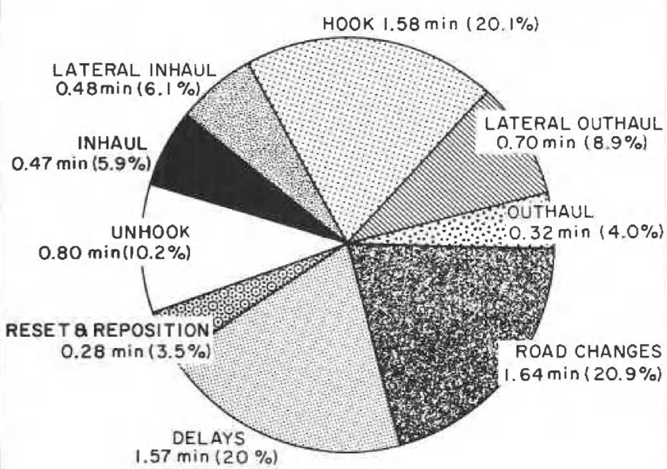

FIGURE 8.

YARDING CYCLE ELEMENTS. VALUES ARE FOR ALL TREATMENTS; PERCENTAGES ARE OF TOTAL YARDING CYCLE TIME.

TABLE 4.

SKYLINE ROAD CHANGES.

Statistic	All corridors	Landing change[a]	Road change only[b]	Landing change with intermediate support
Sample size	24	20	3	1
Total (hrs)	34.91	29.49	1.92	3.50
Average (hrs)	1.45	1.47	0.64	3.50
Maximum (hrs)	3.50	2.15	0.70	3.50
Minimum (hrs)	0.55	0.83	0.55	3.50
Standard deviation (hrs)	0.60	0.33	0.08	0.00

[a] Yarder moved and skyline road changed.
[b] Only skyline road changed; yarder remained in same location.

Regression Models

Yarding regression models are shown in Table 5. Note that in the cycle time equation, lateral distance is squared. The production rate model includes resets and carriage reposition delay times of 0.28 minutes per cycle and other delays of 1.57 minutes per cycle; rigging time, however, is not included. The following formula can be used for determining average production per hour including rigging time (yarder setup and road changes):

$$\bar{V} = \frac{V_1}{(V_1/V + R)}$$

where:
- $\bar{V}$ = average production including rigging time (ft^3/hr)
- V = average production excluding rigging time (ft^3/hr)
- V_1 = volume per landing (ft^3)
- R = rigging time (hrs).

Descriptive statistics for significant yarding variables are summarized in Table 6. Indicator variables for thinning treatments are not included in these models because they were not significant; several explanations are offered. First, the large number of trees being removed in all treatments may have caused similar optimal yarding conditions for each treatment. The range of stand conditions (tree removal) between these treatments may not have been wide enough to noticeably affect turn time or production rate. Second, if turn time or production rate differed between treatments, some of this difference may have been lost because of long delay times at the landing. These were attributed mainly to limbing and sorting. We tried to account for this by separating delays from the yarding time study but this was sometimes difficult to accurately observe and measure. Our time-study crew worked next to the choker setters and could not always

TABLE 5.

YARDING REGRESSION MODELS.[a]

Dependent variable	Intercept	Slope distance[b] (ft)	Lateral distance (ft)	Lateral distance squared (ft^2)	Turn volume (ft^3)	Log angle (°)	Slope (%)	$\bar{R}^2$ [c]	Sample size
Time/yarding cycle (min)	1.8202	+0.0024		+0.00021	+0.0125	+0.0024	+0.0151	0.31	846
Production rate (ft^3/hr)	255.7603	−0.2263	−1.93185		+8.8050	−0.2056	−1.2914	0.84	846

[a] All values in the table are regression model coefficients.
[b] All variables are significant at the 0.01 level.
[c] $\bar{R}^2$ = Adjusted coefficient of determination.

TABLE 6.

INDEPENDENT VARIABLES FOR YARDING CYCLE.

Independent variable and statistic	Treatment: All	Narrow	Wide	Strip
Slope distance (ft)				
Average	255.78	230.76	244.03	296.94
Maximum	795	694	679	795
Minimum	0	0	15	5
Standard deviation	166.35	139.17	150.05	200.73
Sample size	1,314	344	578	387
Lateral distance (ft)				
Average	36.20	36.77	35.04	37.23
Maximum	140	100	140	120
Minimum	0	0	0	0
Standard deviation	46.16	45.85	44.18	48.28
Sample size	1,301	341	575	385
Log angle (°)				
Average	69.27	68.62	74.78	61.61
Maximum	180	180	180	180
Minimum	0	0	0	0
Standard deviation	46.16	45.85	44.18	48.28
Sample size	1,301	341	575	385
Slope (%)				
Average	29.52	29.35	29.29	30.31
Maximum	95	85	95	85
Minimum	0	0	0	0
Standard deviation	14.57	13.85	14.19	15.62
Sample size	1,357	360	584	402
Turn volume (ft^3)				
Average	64.93	56.30	65.48	71.69
Maximum	198.93	148.11	198.94	184.11
Minimum	2.78	2.78	5.69	3.82
Standard deviation	28.99	26.19	26.05	33.21
Sample size	1,281	336	547	386

see activities at the landing. The third explanation centers around turn volume as a highly significant variable in both models. There was a difference of approximately one additional log per turn in the strip treatment compared with the narrow treatment. Thus, the turn volume variable may reflect some of the treatment differences. When turn volume was removed as a candidate independent variable, the treatment indicator variables entered the model but the adjusted coefficient of determination was much lower.

The adjusted coefficients of determination differed significantly between the two regression models. To verify the correctness of the production model, several tests were conducted. A frequency distribution of cycle time showed variation around the mean, which indicates that cycle time was not constant. If this were the case, there would be a strong one-to-one relation between the dependent variable, production rate, and the independent variable, turn volume. Second, a scatter plot of production rate with turn volume showed a linear relation, as expected. Also, the plot did not show a distribution of outliers that would cause unequal weighting of data points and result in a model that did not reflect most of the data. The models were also compared by substituting appropriate values for the independent variables, and each model produced a similar cycle time or production rate.

Turn volume should have an effect on production rate. For this study, the results may be exaggerated between the two models (difference in $\bar{R}^2$) because of the relatively large machine being used with small logs. Cycle time was not highly variable with the measured independent variables because of machine characteristics (high power and fast line-speeds). For instance, the machine could yard logs a distance of 1,500 feet and handle logs 20 times the size of those in this study. Thus, there should not be much difference in cycle time over a narrow range of conditions within the wide capability of a large yarder. Production rate is a better dependent variable than cycle time; more variation is explained by turn volume and other measured independent variables in the production model than in the cycle time model.

During yarding, operating delays occurred most frequently (Fig. 9); fifteen specific delays were coded as operating delays. The longest operating delay (52 percent of the occurrences and 20 percent of total operating delay time) was caused by landing delays from limbing and clearing logs from the landing chute. Other frequently occurring and time-consuming operational delays were felling and bucking during yarding (e.g., those caused by a pulled skyline corridor tree), inspection or repair of the slack pulling line, and pulled anchor stumps or tailtrees. Delays associated with pulled stumps or tailtrees occurred 10 times; average time per delay was 27 minutes. The category named "other" mainly involved picking-up lost logs from previous turns before finishing a skyline road.

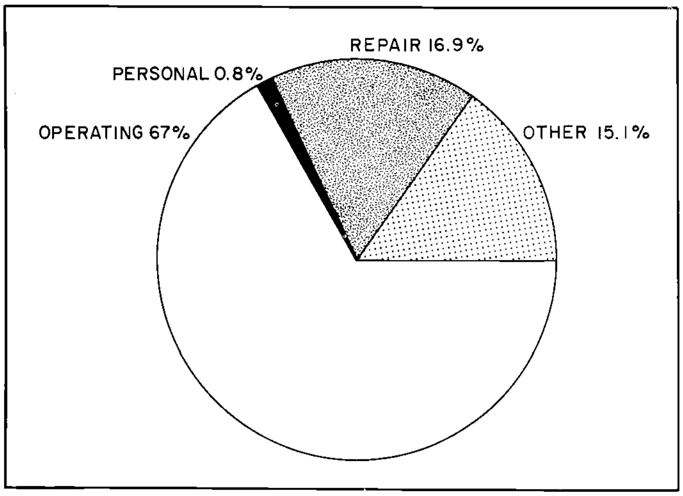

FIGURE 9.

YARDING DELAYS. PERCENTAGES ARE OF TOTAL YARDING CYCLE TIME.

Production Rates and Costs

Details of the hourly owning and operating rates for yarding are shown in Appendix B. Yarding production and cost values are summarized in Table 7. The delay-free cycle time was obtained by substituting average values for the independent variables (Table 6) in the appropriate regression model. The average value for all treatments was used for slope distance, lateral distance squared, and slope; however, treatment averages were used for log angle and turn volume. There is a significant difference (95 percent confidence level or higher) between treatment averages for log angle and turn volume, because of treatment effects.

The strip thinning treatment was the most productive and the least costly. Results for selective wide and narrow spacing were similar. Hourly cubic-foot production increased 24.3 percent, and costs were reduced 19.6 percent with strip thinning over selective narrow thinning. The main contributing factor was turn volume. Approximately one additional log (15.4 ft^3) was yarded per cycle for strip thinning over selective narrow thinning.

TABLE 7.

PRODUCTION AND COST FOR YARDING.

Item	Treatment Narrow	Wide	Strip
Yarding cycle time (min)			
Delay-free	4.03	4.16	4.21
Resets and carriage reposition delays/cycle	0.28	0.28	0.28
Other delays/cycle	1.57	1.57	1.57
Road change time/cycle	1.64	1.64	1.64
Total time/cycle	7.52	7.65	7.70
Hourly production[a]			
Number of logs	27.4	31.3	34.1
Volume (ft^3)	449.20	513.36	558.47
Cost			
$/cunit	64.27	56.22	51.68
$/M bd ft[b]	188.97	165.35	152.00

[a] Based on cycle time model
[b] 3.4 bd ft per ft^3

Yarding production rate differences as influenced by turn volume and slope yarding distance are shown in Figures 10 and 11.

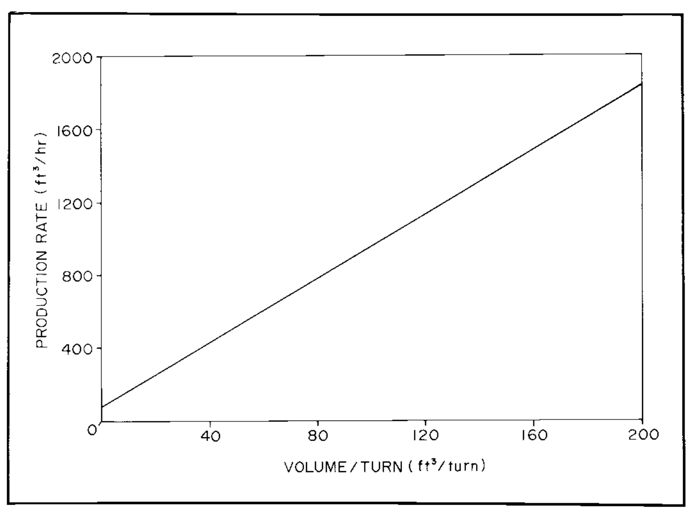

FIGURE 10.

YARDING PRODUCTION RATE BY AVERAGE TURN VOLUME.

Loading and hauling data is summarized in Table 8. The hourly yarding production rate translates to approximately 4.5 truck loads per 8-hour day.

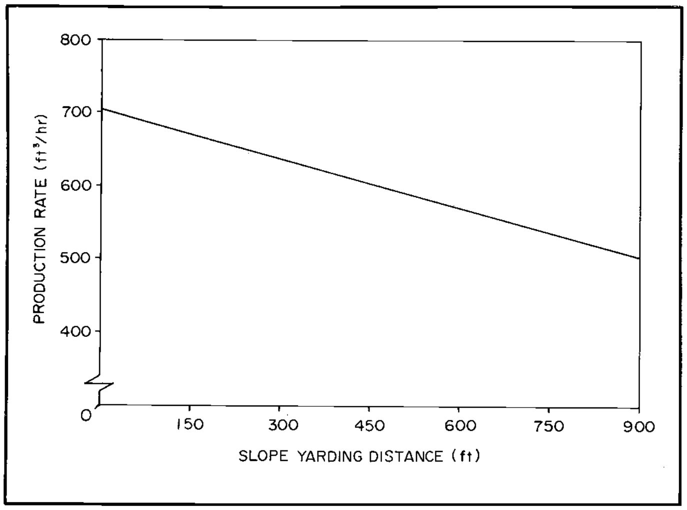

FIGURE 11.

YARDING PRODUCTION RATE BY SLOPE YARDING DISTANCE.

TABLE 8.

LOADING AND HAULING DATA.

Statistic	Loading time (min)	Hauling time[a] (hr)	Volume per load[b] (net ft^3)	Logs per load (number)
Average	24.5	2.64	892.06	56.8
Maximum	45	3.50	1,010.00	62.7
Minimum	14	1.62	753.53	45
Standard deviation	0.11	0.40	88.85	4.96
Sample size	78	53	112	112

[a] Approximate round trip distance = 50 miles.
[b] Log scaling loss from gross to net = 0.006%.

Total Harvesting Cost

Total harvesting costs are summarized in Table 9 for the strip thinning treatment (lowest harvest cost). These costs exclude a profit-and-risk factor and costs for sale layout and administration. In addition, there were no major road construction requirements for this project. Logs were sold to three mills either per thousand board feet or by weight; approximately one-third of the sale volume was delivered to each mill. Delivered mill log prices varied considerably; summer 1983 prices per thousand board feet were $165 for spruce, $185 for hemlock, and $215 for Douglas-fir; a camp-run price was $17 per ton. The overall mill price (pond value) for this study was $168.33 per thousand board feet. A deficit amount results when total harvesting cost is compared with the pond value. To break even, logging cost would need to be reduced 20 percent or the pond value increased 25.5 percent.

TABLE 9.

HARVESTING COST FOR STRIP TREATMENT VERSUS POND VALUE.

Item	$/cunit	$/M bd ft[a]
Felling	9.95	29.26
Yarding and loading	51.68	152.00
Hauling[b]	10.20	30.00
Total harvesting cost	71.83	211.26
Pond value	57.24	168.33
Deficit	14.59	42.93

[a] Based on a conversion of 3.4 bd ft = 1 ft^3
[b] Contractor's estimate

Stand Damage Study

The selective thinning operation caused more residual stand damage than the strip treatment. Yarding damage sustained in the nine detailed-study corridors was 84.78 ft^2 scars per acre for narrow spacing, 91.64 ft^2 scars per acre for wide spacing, and 17.57 ft^2 scars per acre for the strip treatment. For the entire project (27 skyline roads), only 12 percent of the residual trees were damaged from yarding in the strip treatment; narrow and wide treatments were damaged 47 and 61 percent, respectively. The majority of stand damage occurred during yarding; only 3.1 percent of the scars measured were caused by felling, 7.9 percent from loading activities around the landing, and 5.4 percent from line damage outside the logging units.

Incidence of decay from logging scars is related to both scar size and location on the tree (Wright and Isaac 1956, Wallis et al. 1971). Small scars are less likely to become decayed than large scars. Also, as the height of the scar above ground increases, the frequency of infection decreases. Characteristics of stand damage from this study are summarized in Table 10. For all treatments, scar height above ground ranged from zero to 38 feet; 23.2 percent were located within one foot of the ground, 59.2 percent between 1 and 7 feet,

TABLE 10.

CHARACTERISTICS OF STAND DAMAGE FROM YARDING.

Treatment	Statistic	Scar characteristics: Height above ground (ft)	Length (ft)	Width (ft)	Area (ft^2)
All	Average	4.51	1.37	0.38	0.57
	Maximum	38.00	19.00	2.80	14.00
	Minimum	0.00	0.10	0.10	0.02
	Standard deviation	4.93	1.67	0.27	1.04
Narrow	Average	4.08	1.47	0.40	0.65
	Maximum	24.00	15.00	2.10	13.01
	Minimum	0.00	0.10	0.10	0.02
	Standard deviation	4.20	1.81	0.27	1.20
Wide	Average	4.58	1.28	0.37	0.51
	Maximum	30.00	14.00	2.30	14.00
	Minimum	0.00	0.10	0.10	0.02
	Standard deviation	4.78	1.41	0.27	0.92
Strip	Average	4.69	1.29	0.36	0.50
	Maximum	38.00	12.00	2.80	9.10
	Minimum	0.00	0.10	0.10	0.02
	Standard deviation	5.88	1.50	0.27	0.84

and 17.6 percent over 7 feet. Scar length ranged from 0.10 to 19 feet, scar width from 0.10 to 2.8 feet, and scar area from 0.02 to 14.00 square feet.

Deep scars can result in higher wood loss than surface wounds (Wallis and Morrison 1975). We categorized logging scars into four sapwood damage classes (amount of sapwood removed over the surface area) and three wound depth classes (Table 11). Most of the wounds had the bark removed but the sapwood was undamaged.

Most of the yarding damage (66.6 percent of total scar area) occurred within 20 feet of the skyline corridor centerline; beyond 10 feet, occurrence of damage dropped dramatically. Skyline corridors were felled to a width of 10–15 feet before yarding. During yarding, several corridor rub trees were felled because of severe damage, or they were pulled over. We measured nine corridors and found that an average of 2.2 trees were removed during yarding per corridor (a range of 0 to 5 trees). After yarding, the average corridor width was 21.9 feet; the range was 15 to 31 feet. The distribution of damaged trees varied between treatments. Most of the damage in the strip treatment was limited to a rub tree at the edge of the lateral strip and main corridor. In the narrow and wide treatments, all skyline corridor boundary trees had a higher potential of being rub trees. Also, there was a greater risk of damaging trees away from the corridor in the narrow and wide treatments compared to the strip treatment.

Using regression analysis, we identified five significant operational variables from 12 measured variables that influenced scar area per turn. Only a small amount of the total variation in residual damage (21 percent) was explained by the five variables. Significant (95 percent confidence level) variables were the number of times the carriage was repositioned during lateral yarding, carriage clearance above the ground, angle of the log with respect to the mainline, rigging slinger, and cutter.

A skyline carriage is often repositioned to a new location along the skyline during lateral yarding. This yarding technique can be used to avoid hangups and tree damage or as a corrective measure to free logs hung up during lateral yarding. In this study, scar damage per turn increased as the number of carriage repositions increased, which indicated that the technique was used mainly as a corrective procedure once hangups occurred.

Scar area per turn increased as carriage clearance above the ground increased. This result is contrary to some part studies (Fieber et al. 1982). However, it does suggest that, in thinning,

TABLE 11.

FREQUENCY (%) OF SCARS BY DAMAGE CLASS.

Treatment	Wound depth class[a]	Sapwood damage class[b]: 1	2	3	4	Total
All	1	63.2	—	—	—	63.2
	2	16.6	0.9	1.1	10.4	29.0
	3	5.5	1.0	0.5	0.8	7.8
	Total	85.2	2.0	1.6	11.2	100.0
Narrow	1	77.2	—	—	—	77.2
	2	17.3	0.3	0.8	—	18.4
	3	3.6	—	0.8	—	4.4
	Total	98.1	0.3	1.6	—	100.0
Wide	1	52.0	—	—	—	52.0
	2	13.6	0.9	1.6	19.2	35.3
	3	8.1	2.3	0.5	1.8	12.7
	Total	73.7	3.2	2.1	21.0	100.0
Strip	1	62.8	—	—	—	62.8
	2	22.7	2.3	0.6	9.3	34.9
	3	2.3	—	—	—	2.3
	Total	87.8	2.3	0.6	9.3	100.0

[a] Wound depth classes:
1 = bark removed but sapwood undamaged
2 = ≤ 1/4 inch
3 = > 1/4 inch

[b] Sapwood damage classes:
1 = 0–25% sapwood removed
2 = 26–50% sapwood removed
3 = 51–75% sapwood removed
4 = 76–100% sapwood removed

log control is improved when only one end is lifted above the ground. As ground clearance increases and logs become fully suspended above the ground, log control may be reduced.

Log angle, with respect to the mainline, reflects the degree of turning into lead that a log must achieve during lateral inhaul; when the angle is small, there is less chance for tree scarring.

The rigging slinger and cutter variables identified in the regression analysis show how crew members influence logging damage levels. Two rigging slingers were used during this study. One had considerable experience in both clearcut and thinning operations, while the second had experience as a chaser and choker setter but limited experience as a rigging slinger. Scar area per turn was lower for the more experienced rigging slinger. Similar results occurred with the cutters. During the study, we recorded the areas felled by each cutter and the experience of the cutters in felling and yarding both old-growth clearcuts and smallwood thinnings. Scar area per turn during yarding was different depending on which cutter felled the particular area. While the experience level did not correlate directly with the amount of damage, there was a general trend towards lower damage levels with the cutters that had more years of experience in smallwood felling and yarding.

Discussion

This study documented the negative stumpage associated with thinning western hemlock-Sitka spruce stands. Commercial thinning in the Pacific Northwest often has a low profit margin. A variety of factors affect this margin, such as harvesting efficiency and small-log values. Small gains in harvesting production can significantly reduce costs (Kellogg 1980, Kellogg and Olsen 1984). In this study, thinning treatment had a significant effect on harvesting cost. For removal of a similar volume, stump-to-truck logging costs were 31 percent lower for strip thinning than for selective narrow spacing. With removal of a greater volume, selective wide spacing had costs in between those of the strip and narrow treatments. These savings are slightly higher than those reported by Aulerich (1975) but similar to those in other studies (Kramer 1974, Twaddle 1977, Terlesk and Twaddle 1979, Hamilton 1980).

Additional gains are needed to reduce harvesting cost with thinning of western hemlock-Sitka spruce stands. In this study, delays and road changes occupied a significant amount of the yarding operation. An excess number of limbs and their toughness caused yarding delays and slowed the felling operation. In a previous study with whole-tree yarding of Douglas-fir,[1] we did not experience delays with limbs because they simply broke off during the yarding operation. Perhaps increased mechanization would improve logging efficiency in hemlock-spruce stands. Feller-bunchers and delimbers with whole-tree yarding systems have been successful on gentle slopes and may also be beneficial on steep terrain.

Much of the residual stand damage can be attributed to logging during early summer, when the tree cambium was growing and the bark was loose. Also, there were different damage levels between thinning treatments and operational variables. Damage was considerably less with strip thinning than with selective narrow and wide thinning. Both selective thinning treatments had similar levels of damage.

This study revealed the difficulty in identifying and quantifying operational variables causing stand damage when thinning with a skyline system. Many of these variables are interrelated with specific stand conditions and crew factors that vary with each turn and hour of operation. Even with these limitations, the study demonstrated that good planning and logging practices can minimize damage.

Similar research studies on stand damage levels and operational techniques related to damage are needed to study cost versus benefits. Studies have indicated that at final harvest there may be a relatively small impact from volume loss caused by decay from an earlier entry (Parker and Johnson 1960, Shea 1960, 1961, Hunt and Krueger 1962, Wallis and Morrison 1975, Chavez et al. 1980, Goheen et al. 1980). Most future forest-management practices in the Northwest will be concerned with smallwood and short rotations. Other potential negative impacts, caused by reduced growth, decreased value of forest products,

[1] Burrows, J.O., E.D. Olsen, and L.D. Kellogg. Swinging and processing whole trees in a Douglas-fir thinning. Submitted for publication in ASAE Transactions.

and aesthetic impacts, need to be considered. However, these effects may not be significant in all areas and may vary by forest type. We need to know what are the significant benefits from reducing stand damage during thinning entries, and how these benefits compare with the additional harvesting costs incurred.

Management goals for young forests involve more than minimizing harvesting cost and stand damage during thinning. Future blowdown, thinning shock, tree growth, stand yields, and management economics are additional important considerations. Future studies will evaluate all of these factors for this study area.

Recommended Practices to Minimize Stand Damage

In many cases, conscientious planning and logging can reduce damage but this requires well-trained people given appropriate incentives. The following recommendations are the result of our experiences with this study. A list of logging guidelines aimed at minimizing stand damage and logging cost, along with obtaining accurate research data, is included in Appendix C. They served as a basis for discussion during a pre-work meeting with the logging contractor, Forest Service sales administrator, and research project leader. Primary contract enforcement and logging administration was the responsibility of the Forest Service.

Harvest-unit planning and layout should occur simultaneously. A feasible and cost-effective logging plan must be developed in regard to such factors as volume removal and logging system requirements. When skyline systems are used, it is important that corridors be laid out before felling and that they "fit the terrain" (e.g., by taking advantage of the topography for obtaining adequate skyline deflection). Parallel skyline corridors help minimize damage by reducing the amount of sidehill yarding; however, fan-shaped corridors may be appropriate when yarding around ridges or with limited availability of adequate landings. When corridors are laid out before felling, trees can be cut and directed to lead toward the skyline. Long log lengths (greater than 32 feet) may not cause greater stand damage than short lengths when trees are felled to lead. Corridors must be straight and the skyline should be placed in the center. Offsetting the yarder on the landing or using tailtrees other than those planned for can result in the skyline being skewed to either side of the corridor and in excessive damage to trees on the corridor boundary. Initial narrow corridor widths (10-15 feet depending on the logging system and volume removal) and the use of rub trees along the corridor (removed after yarding when severely damaged) can aid in obtaining acceptable final results.

Much of the residual stand damage sustained during logging is dependent on skills and decisions made by logging personnel. For example, proper carriage location during lateral yarding and the selection of logs in a turn can influence stand damage. Crews working in thinnings must be knowledgeable in regard to felling and yarding techniques that minimize stand damage; often training is necessary. When minimizing stand damage is a management objective, this must be communicated to the logging crews after adequate planning and layout. Sometimes logging operators may be selected and maintained based on a conscientious accomplishment of management objectives with minimal supervision and contract enforcement; other situations may require strict contract requirements and enforcement. In any case, close cooperation between the landowner and logger is needed to meet both parties' objectives.

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Glossary of Cycle Time Variables

Independent Variables of Felling and Bucking

MOVE DISTANCE
Distance in feet that the cutter travels from the work area to the next tree to be cut.

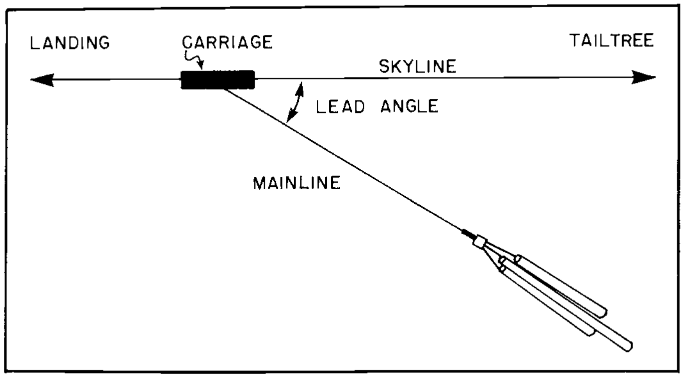
NUMBER OF BUCK CUTS
Number of bucking cuts during the limbing and bucking process, including the top cut.

NUMBER OF LIMBS
Number of limbs removed during the limbing and bucking process that require sawing.

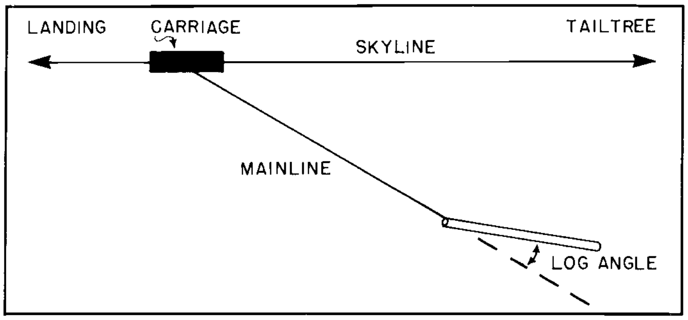
SLOPE
Ground steepness (percent) measured perpendicularly to the contour at the tree being cut.

SPECIES
Type of tree cut: hemlock, spruce, or Douglas-fir.

TREE VOLUME
Volume of tree in cubic feet from stump to merchantable top (5 inches).



LOG ANGLE
Angle in degrees between the log axis and the projection of the skidding line at the log for the most critical log per turn. Critical log is defined as the log that had the greatest opposition to being moved because of its position.



Independent Variables of Yarding

CARRIAGE REPOSITIONS
The number of times the carriage was moved to a new place on the skyline during lateral inhaul.

CREW SIZE
Total number of people (from six to eight) on the yarding and loading crews.

CUTTER
An indicator variable that identifies the cutter for the turn being yarded.

GROUND CLEARANCE
Distance in feet from the carriage bottom to the ground during lateral inhaul.

LATERAL DISTANCE
Perpendicular distance in feet from the corridor center line to the point of choker attachment on the furthest log in each turn.

LEAD ANGLE
Angle in degrees between the skyline and the path of the logs during lateral inhaul

LOG LENGTH
Longest log (feet) in a yarding cycle.

LOGS PER TURN
Total number of logs yarded in a cycle.

RIGGING SLINGER
An indicator variable that identifies the specific rigging slinger: 0 = rigging slinger A; 1 = rigging slinger B.

SLOPE
See INDEPENDENT VARIABLES OF FELLING AND BUCKING.

SLOPE DISTANCE
Distance in feet along the skyline corridor from the landing to the carriage position during lateral outhaul.

TURN VOLUME
Total volume in cubic feet of the logs in each turn.

YARDING RESETS
The number of times a turn of logs was stopped during lateral inhaul for resetting the chokers.

Appendix A: Study Site Maps and Timber Stand Data

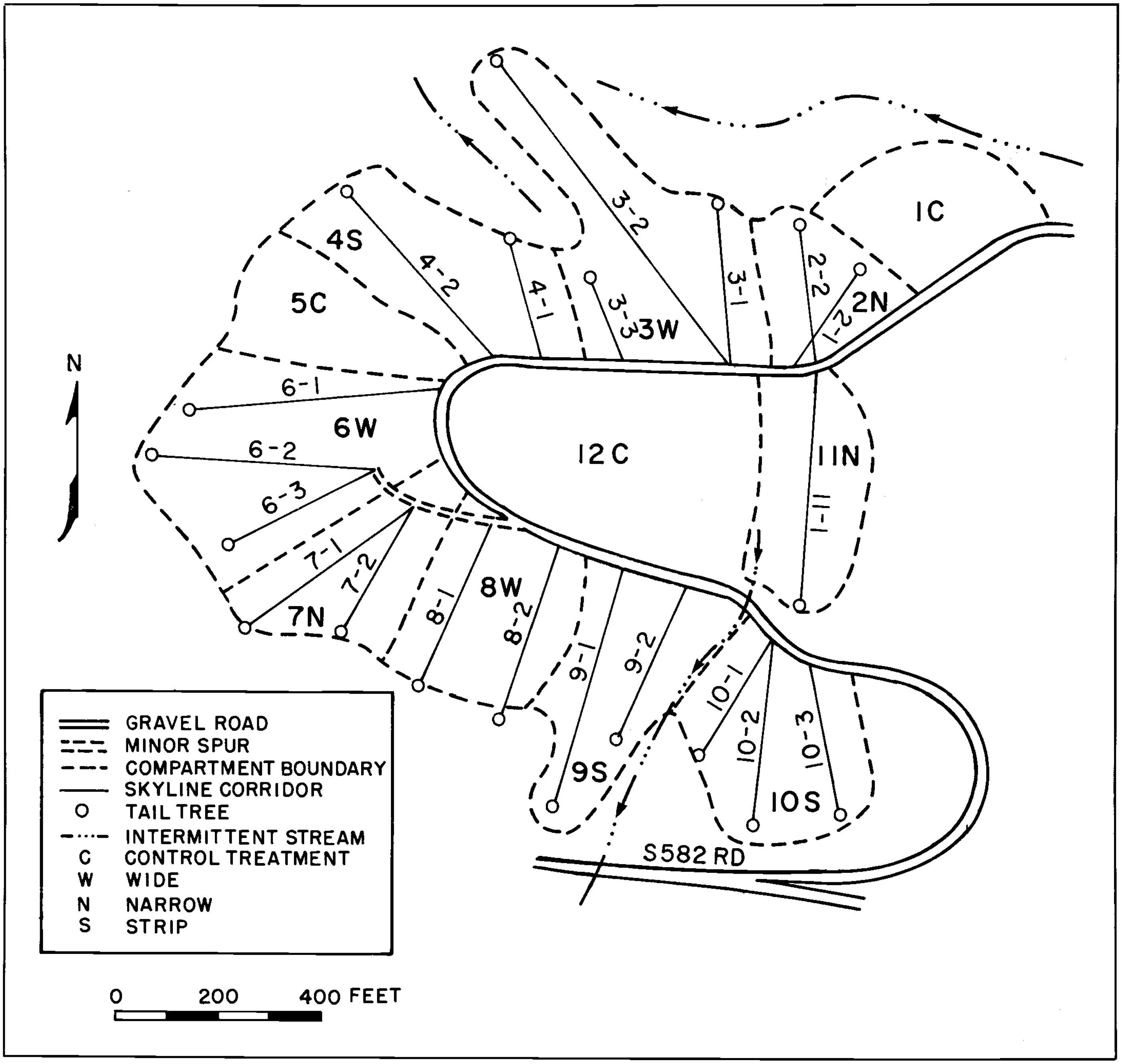


FIGURE A1.

CASCADE HEAD THINNING AREA I. T.6S., R.10W., W.M. SECTION 9.

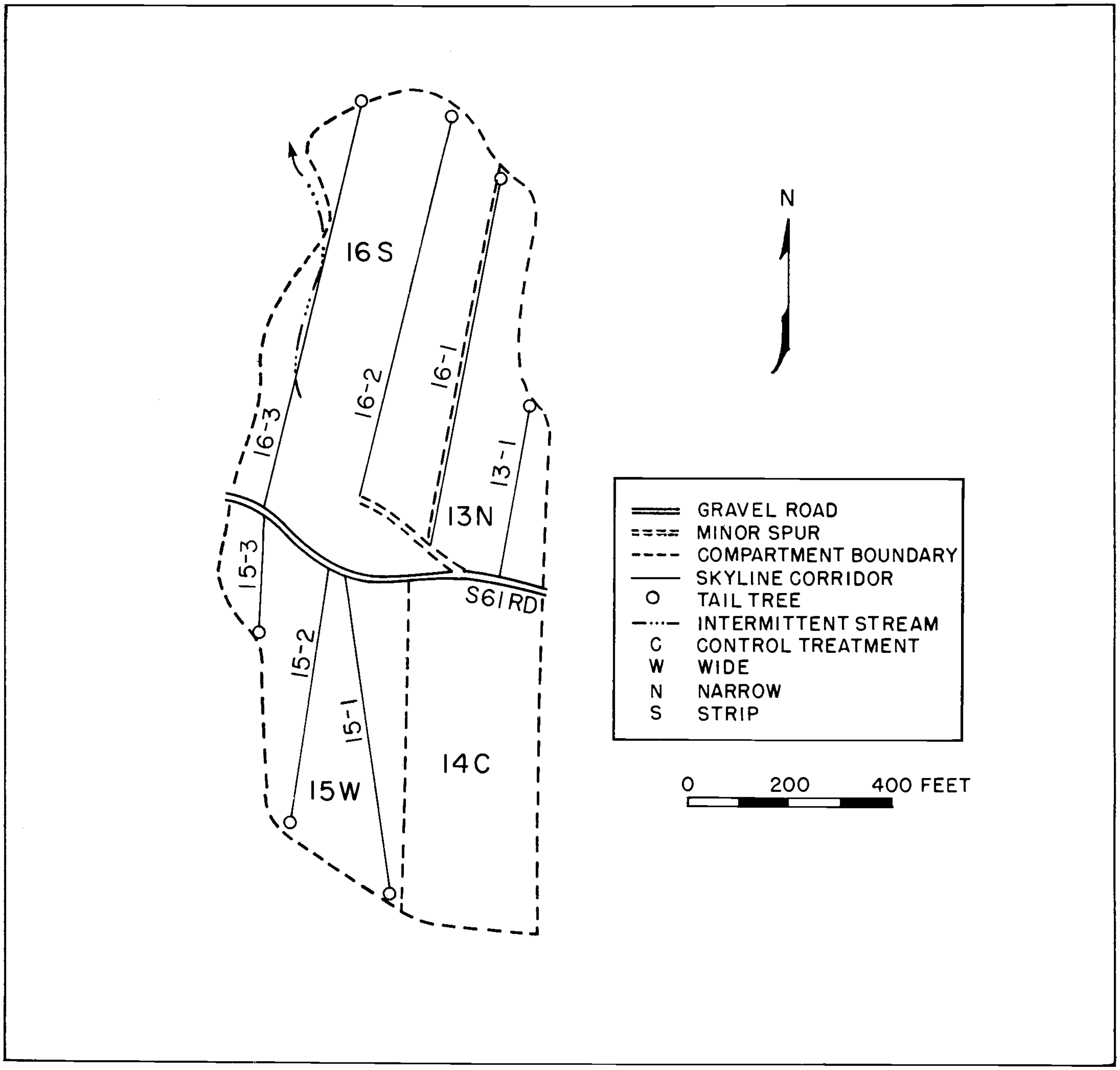


FIGURE A2.

CASCADE HEAD THINNING AREA II. T.6S., R.10W., W.M. SECTION 16.

TABLE A.1.

TIMBER STAND DATA.

Variable	Treatments			
	Control	Narrow	Wide	Strip
Residual stand				
Trees per acre	192	83	63	104
Volume per acre, ft^3	6,215	3,084	2,137	3,044
Basal area per acre, ft^2	198	95	66	100
Prescribed tree spacing, ft	—	18 x 18	24 x 24	—
Actual tree spacing, ft	14.5 x 14.5	22 x 22	25.5 x 25.5	—
Thinning removal				
Trees per acre (%)	—	109(57%)	129(67%)	88(46%)
Basal area per acre, ft^2 (%)	—	103(52%)	132(67%)	98(49%)
Volume per acre, ft^3 (%)	—	3,131(50%)	4,078(66%)	3,171(51%)

Appendix B: Costs of Felling and Bucking, Yarding, and Loading

FELLING AND BUCKING COSTS

EQUIPMENT OWNERSHIP COST — $/hr

1. Depreciation

Straight line method = $\frac{P - R}{N}$

Average annual investment (AAI) =

$$\frac{(P-R)\ (\text{Depreciable value})\ (N+1)\ (\text{depreciation period} + 1)}{2\ (\text{depreciation period})\ (N)} + (R)\ \text{residual value}$$

Chainsaw
Purchase price (P) = $698
Residual value (R) = 10% x P
Estimated life (N) = 2 yrs 0.20
Average annual investment (AAI) = $384

Crew truck, 3/4-ton pickup
P = $12,362
R = 10% x P
N = 8 yrs 0.87
AAI = $7,494

2. Interest, Taxes, License Fees

Interest rate = 14.5%
Taxes = 1.5%
License fees = 1.0%
Total 17.0%

(17%) (average annual investment)
(17%) ($384 + $7,494) ÷ 1,600 hrs/yr 0.84

EQUIPMENT OPERATING COST — $/hr

3. Direct Labor

(Includes a fringe and burden factor of 40% and a travel allowance of $0.80/hr) 19.91

4. Supervision

(15%) (direct labor cost) 2.99

5. Maintenance and Repair

Chainsaw
(90%) (depreciation) 0.18

Crew truck
(50%) (depreciation) 0.44

6. Chainsaw Operation

Fuel
(0.25 gal/hr) ($1.28/gal) 0.32

Oil
(50%) (fuel cost) 0.16

Chain
P = $30
N = 130 hrs 0.23

Miscellaneous supplies
Axe and shovel
Wedges
Logger's tape
Safety gear
P = $253
N = 1,600 hrs 0.16

EQUIPMENT OPERATING COST (continued) $/hr

7. Crew Truck Operation

Fuel
(100 mi/day) ($1.28/gal) / (10 mpg) (8 hrs/day) 1.60

Oil and lube
(7%) (fuel cost) 0.11

TOTAL COST PER SCHEDULED HOUR $28.01

YARDING COSTS

EQUIPMENT OWNERSHIP COST $/hr

1. Depreciation

Equipment	P($)	R(%)	N(yrs)	AAI($)	
New yarder (Madill 071)	336,000	30	8	228,806	18.38
Radio (Talkie Tooter with three transmitters)	7,835	20	8	5,093	0.49
Used landing cat (International TD12)	30,500	20	4	21,350	3.81
Crew truck (six-passenger, 3/4-ton pickup)	12,362	10	8	7,494	0.87

2. Interest, Insurance, Taxes

Interest rate = 14.5%
Insurance = 3.0%
Taxes = 1.5%
Total 19.0%

(19%) (average annual investment)
(0.19) ($228,806 + $5,093 + $21,350 + $7,494) ÷ 1,600 hr/yr 31.20

EQUIPMENT OPERATING COST

3. Direct Labor

(Includes a fringe and burden factor of 40% and a travel allowance of $0.80/hr)

Yarder engineer 17.46
Hooktender 19.56
Rigging slinger 16.48
Choker setter 15.29
Chaser 15.54

4. Supervision

(15%) (direct labor cost) 12.65

5. Maintenance and Repair

Yarder
(50%) (depreciation) 9.19

Radio
(60%) (depreciation)
+ one transmitter every 4 yrs @ $1,217 . . . . 0.48

Landing cat
(65%) (depreciation) 2.47

Crew truck
(50%) (depreciation) 0.44

EQUIPMENT OPERATING COST (continued) $/hr

6. Equipment Operation

Yarder
(10 gal/hr) ($1.00/gal) x 1.07 (lube and oil adj.) 10.70

Landing cat
(4.0 gal/hr) (4 hrs/day) ($1.00/gal) / 8 hrs/day x 1.07 (lube and oil adj.) . . 2.14

Crew truck
(100 mi/day) ($1.28/gal) / (10 mpg) (8 hrs/day) x 1.07 (lube and oil adj.) 1.71

7. Wire Rope and Rigging

Skyline
1" x 1,900' @ $1.97/ft ÷ 1,600 hrs 2.34

Mainline
3/4" x 2,200' @ $1.57/ft ÷ 1,600 hrs 2.16

Haulback
5/8" x 4,400' @ $0.88/ft ÷ 1,600 hrs 2.42

Slackpulling line
7/16" x 2,600' @ $0.73/ft ÷ 1,600 hrs 1.19

Skidding line (for MSP carriage)
5/8" x 150' @ $0.88/ft ÷ 800 hrs 0.17

Strawline
3/8" x 3,340' @ $0.57/ft ÷ 1,600 hrs 1.19

Guylines
[1" x 225' @ $1.97/ft + 15.22] x 3 ÷ 1,600 hrs 0.86

MSP carriage
$5,275 ÷ 3,200 hrs 1.65

Multispan truck and jack
$4,000 ÷ 3,200 hrs 1.25

Intermediate support line
[7/8" x 200' @ $0.73/ft] x 2 ÷ 1,600 hrs 0.18

Tailtree guylines
[3/4" x 200' @ $1.57/ft] x 4 ÷ 1,600 hrs 0.78

Haulback blocks (for 5/8" wire rope)
$315 ea x 3 ÷ 3,200 hrs 0.30

Rigging blocks (int. support and tailtree)
$420 ea x 6 ÷ 3,200 hrs 0.79

Straps and chokers

Haulback line
[3/4" x 15' @ $47.30 ea] x 3 ÷ 3,200 . . . . 0.04

Skyline
[1" x 12' @ $47.00 ea] x 2 ÷ 3,200 . . . . 0.03

Intermediate support line
[7/8" x 12' @ $47.00 ea] x 4 ÷ 3,200 . . . . 0.06

Saws
$698 x 2 ÷ 3,200 hrs 0.44

Saw operating cost 1.06

Chokers
[5/8" x 12' @ $26.50 ea] x 14 ÷ 1,600 hrs 0.25

EQUIPMENT OPERATING COST (continued) — $/hr

Miscellaneous rigging
- Pass line blocks
- Shackles
- Line clamps
- Splicing needles
- Riggers maul
- Riggers chain
- Wedges
- Axe
- Other

$2,400 ÷ 3,200 hrs 0.75

8. Equipment Move In and Out

Yarder	$ 800
Cat	500
Total	$1,300

$1,300 ÷ 200 hrs 6.50

(This rate reflects transporting equipment approximately 100 total miles and a logging sale time of 200 scheduled hours.)

TOTAL COST PER SCHEDULED HOUR $203.27

LOADING COSTS

EQUIPMENT OWNERSHIP COST — $/hr

1. Depreciation

(Average for self-propelled crawler mount, operating range in small-to-medium timber)

P = $276,000
R = 30%
N = 8 yrs 15.09
AAI = $191,475

Pickup truck (3/4 ton) — $/hr

P = $10,300
R = 10%
N = 8 yrs 0.72
AAI = $6,244

2. Interest, Insurance, Taxes

(19%) (average annual investment)
(0.19) ($191,475 + $6,244) / 1,600 hr/yr 23.48

EQUIPMENT OPERATING COST

3. Direct Labor

(Includes a fringe and burden factor of 40% and a travel allowance of $0.80/hr) 17.87

4. Supervision

(15%) (direct labor) 2.68

5. Maintenance and Repair

Loader
(65%) (depreciation) 9.81

Pickup truck
(50%) (depreciation) 0.36

6. Fuel, Oil, and Lube

Loader
(9 gal/hr) ($1.00/gal) x 1.07 (lube and oil adj.) 9.63

Truck
$\frac{(100 \text{ mi/day}) (\$1.28/\text{gal})}{(10 \text{ mpg}) (8 \text{ hrs/day})}$ x 1.07 (lube and oil adj.) . . . 1.71

7. Equipment Move In and Out

$800 ÷ 200 hrs

(This rate reflects transporting loader approximately 100 total miles and a logging sale time of 200 scheduled hours.) 4.00

TOTAL COST PER SCHEDULED HOUR $85.35

Appendix C: Guidelines for Experimental Logging

A. Felling methods and direction of fall
   1. Conventional felling. Cut-designated trees will be directionally felled at a 45° ± 15° angle to lead toward the skyline corridor during yarding. Skyline corridor width will be 10 feet (measured from bole of the tree).
   2. Strip felling (herringbone pattern). Trees within the clearcut strips will be directionally felled to the strip layout. To reduce lateral yarding distance, felling trees with the top end toward the skyline corridor is preferred. Skyline corridor width will be 10 feet and lateral strip width 20 feet.

B. Yarding equipment
   1. Medium-size yarder, Madill 071
   2. Multispan, slackpulling carriage, Danebo MSP

C. Rigging methods, including tailholds, intermediate supports, and number of chokers
   1. Skyline corridors, needed tailtrees, and intermediate support trees have been located (flagged) and are to be used. Changes may be made by mutual agreement with contractor, sale administrator, and research project leader.
   2. Turn size (number of chokers used and number of pieces yarded each turn) needs to be a maximum payload for the conditions of each skyline road (considering log distribution, thinning intensity, ground slope, line sizes, and deflection).
   3. Proper rigging height in all predesignated tailtrees and intermediate support trees is required to achieve adequate deflection.
   4. Ground profile analysis, rigging heights, and payload determination have been determined for each skyline road. Use this information, provided by the project leader, with your own experiences to aid in meeting the requirements of this section.

D. Yarding crew composition and assignments
   1. Both felling and yarding crews will be experienced in cable thinning.
   2. The same cutting and yarding crew will be used throughout the study with provisions for emergency situations or unavoidable changes in key personnel (yarder operator and rigging slinger). Crew members will not change job assignments during the study.

E. The sequence of felling and yarding operations within each subdivision will follow a designated schedule.

F. Stand damage
   1. Minimize stand damage during yarding with the use of rub trees and other practices, such as careful carriage spotting on the skyline for an adequate lead during lateral yarding.
   2. Trees excessively scarred (more than 50% of the bark removed) or pulled over will be removed during yarding except in designated study areas.

G. Changes in the logging plan for experimental logging subdivisions may be made by mutual agreement with the research project leader, logging contractor, and Forest Service sales administrator.

British/Metric Conversions

1 foot (ft) = 0.3048 meter (m)
1 inch (in.) = 2.54 centimeters (cm)
1 acre = 0.4047 hectares (ha)
1 ft^3 = 0.02832 m^3

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