Research Contribution 21 August 1999

Skyline Thinning Production and Costs: Experience from the Willamette Young Stand Project

By

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Abstract

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Production rates and costs for skyline harvesting were examined over a range of residual thinning intensities, operational methods, and sites. The sites included three stands of 40- to 50-yr-old Douglas-fir on the Willamette National Forest in the Cascade Mountains of Oregon. Three silvicultural treatments were studied at two sites, and one silvicultural treatment at the third site. Detailed time studies were conducted on manual felling and uphill skyline yarding with small or mid-size yarders. Separate regression equations were developed to predict delay-free felling cycle time and delay-free yarding cycle time at each site. The three silvicultural treatments had no consistent influence on production rates and costs, because the initial stocking levels varied among treatments and the volume harvested did not necessarily correspond to the silvicultural treatment. Cost differences within sites, where operational methods were uniform, were small. Cost differences among sites for each activity, such as felling or yarding, were larger because of differences in operational methods. Total harvesting costs among the three sites were similar, ranging from \$58 to \$64/100 ft^3.

Unit Conversions

1 foot (ft) = 0.305 meter (m)

1 inch (in.) = 2.54 centimeters (cm)

1 ft^2 = 0.093 m^2

1 ac = 4046.86 m^2

1 ft^3 = 2.83 x 10^{-2} m^3

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Introduction

Federal forest policy and land use management objectives in the Pacific Northwest have changed in emphasis from timber production to ecosystem management. Ecosystem management recognizes that natural systems must be sustained to meet the social and economic needs of future generations. A better understanding of ecological processes has highlighted the role of biological diversity in sustaining the health and productivity of ecosystems (Kaiser 1997).

Evaluation of the harvesting methods and the costs associated with alternative silvicultural prescriptions is important to land managers needing to make sound economic and environmental decisions. In western Oregon and Washington, hundreds of thousands of forested acres are in early seral stages (0–50 yr old). Management objectives for these stands vary, but, whether managers want to maximize wood fiber yield or to conserve biodiversity, commercial thinning may help them achieve their goals (Hayes et al. 1997). Further evaluation of existing information and large-scale trials of radical thinning regimes are needed (Curtis and Carey 1996).

The Willamette Young Stand Project is a long-term, multi-disciplinary research effort designed to monitor the effects of managing young stands for ecosystem diversity. The primary silvicultural goals are to determine whether thinning, underplanting, and snag creation accelerate the development of late-successional habitat and increase plant and wildlife habitat diversity in 40- to 50-yr-old plantations of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco]. Major aspects of the Project include evaluating harvesting economics and resource implications, monitoring wildlife impacts and vegetation response, evaluating tree growth and yield, assessing mushroom productivity, and analyzing social perceptions of three residual thinning intensities and a control. In addition, the effects of three different logging systems used to complete the thinnings are being studied: small to mid-size skyline yarding, tractor skidding, and a cut-to-length (harvester/forwarder) system.

Studies of harvesting economics and resource implications were divided into four parts: planning and layout costs, logging production and costs, soil compaction, and stand damage. This paper summarizes detailed production and cost information for the skyline logging portion of the Project. Planning and layout for the Project are described by Kellogg et al. (1998); soil compaction is described by Allen (1997); and stand damage, by Han (1997) and Han and Kellogg (1997).

Total skyline harvesting costs for alternative silvicultural methods can range from approximately 7% to 32% more than those for conventional clearcut methods (Kellogg et al. 1996a). Previous comparisons of production rates and costs of thinning intensities found that yarding production increased and costs decreased as thinning intensity increased (Hochrein and Kellogg 1988; Kellogg et al. 1996b). This was related partly to an increase in the average number of logs per turn as thinning intensity increased. Hochrein and Kellogg (1988) also determined that yarding with a mid-size yarder (Madill 071) increased costs 11%–12%, depending on thinning intensities, over those with a small yarder (Koller K300). LeDoux and Butler (1982), however, showed that thinning intensity did not influence costs when harvest levels were above 80 stems/ac and a mid-size yarder was used.

This report on the study of skyline logging examines production rates and costs over a range of residual thinning intensities, operational methods, and sites. Because this was an operational, rather than a strictly controlled, study, variations existed within and among sites as detailed in the Project Description below. The objectives of the study were the following:

- to obtain information on cycle times and delays for felling and yarding on each site
- to create regression equations that predict delay-free cycle times from significant independent variables
- to determine production rates and costs for felling, yarding, and total harvesting
- to compare the effects of silvicultural treatments on production and costs within and among sites
- to compare costs among the three sites given differences in site conditions, crew size, equipment, and logging methods.

Project Description

Study Sites and Treatments

The study sites are located in the western Cascade Mountains of Oregon, on the Willamette National Forest. The study areas involved three timber sales, each administered by a different ranger district of the USDA Forest Service (Table 1).

Table 1. Physical environment and site characteristics before commercial thinning of the light thin (LT), light thin with openings (LTO), and heavy thin (HT) treatment areas at each site.[a]

					Stand characteristics				
Site (Ranger District)	Treatment	Study area (acres)	Slope (%)	Season logged	Age (yr)	DBH (in.)	Tree height (ft)	Density (tpa)	Basal area (ft^2/ac)
Walk Thin (Oakridge)	All	177	0-80		45	10.1	72	205	118
	LT	55	5-80	Summer	45	9.8	71	233	118
	LTO	75	0-80	Fall/Summer	45	10.6	73	212	126
	HT	47	0-70	Winter	45	10.0	73	169	109
Tap Thin (Blue River)	All	111	0-70		46	10.8	72	223	146
	LT	60	5-60	Spring/Summer	46	10.7	78	260	171
	LTO	32	0-40	Summer	46	10.9	68	230	149
	HT	19	0-70	Summer/Fall	46	10.9	70	180	117
Mill Thin (McKenzie)	HT	69	0-50	Fall/Winter	44	11.8	75	195	149

[a]The stand characteristics of the study treatments were determined by cruising conifer trees >5 in. DBH.

All three sites were second-growth stands of Douglas-fir that had been clearcut during the mid-1940s or early 1950s. After logging, the sites had been broadcast burned and allowed to regenerate naturally for 2–4 yr before being interplanted with Douglas-fir. All stands consisted almost entirely of Douglas-fir with some scattered western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] and western redcedar (*Thuja plicata* Donn ex D. Don). Elevations ranged from 2000–2900 ft.

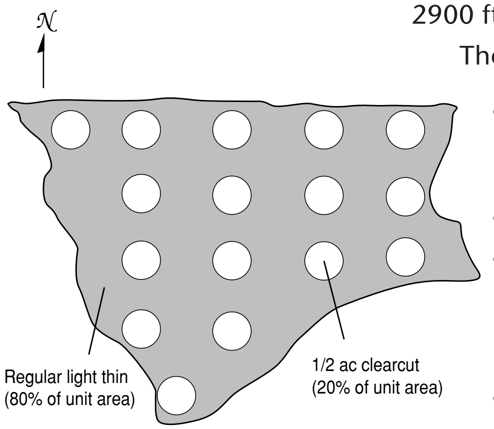

Figure 1. Example of a light thin with openings (LTO) treatment.

The silvicultural treatments at each site were designed as follows:

- *Control*—no thinning (This treatment was evaluated in other segments of the Willamette Young Stand Project, but is not treated in this report.)
- *Light thin (LT)*—residual stocking 110–120 trees per acre (tpa)
- *Light thin with openings (LTO)*—residual tpa the same as in the LT treatment, but with additional 0.5-ac openings dispersed systematically throughout the unit to encompass 20% of the total unit area (Figure 1). The average residual stocking was 92 tpa.
- *Heavy thin (HT)*—residual stocking of 50–55 tpa.

The Walk Thin and the Tap Thin sites each had one replication of each of the three silvicultural treatments. This allowed us to compare production and costs of the treatments within and between the sites. The Mill Thin site replicated only the HT treatment because of limitations in time and resources available for the study. However, this allowed us to see the range of costs that might be expected among three sites when different, but appropriate, harvesting systems are used. Detailed stand characteristics and the physical environment before harvest for each site and treatment are listed in Table 1.

Forest Service staff planned the sales, designated the treatment boundaries, and marked the residual leave trees. The timber sales were thinned from below, leaving the dominant and co-dominant trees after harvest. The initial stocking levels and specific treatment prescription determined the total volume removed for each treatment (Table 2); thus, the silvicultural treatment

Table 2. Stand density before and after thinning and volume harvested in the light thin (LT), light thin with openings (LTO), and heavy thin (HT) treatments at each site.

Site	Treatment	Stand density (tpa)		Trees thinned	Volume harvested	
		Preharvest	Postharvest	(tpa)	MBF/ac	CCF/ac[a]
Walk Thin						
	LT	233	115	118	7.16	22.49
	LTO	212	92	120	8.81	27.68
	HT	169	53	116	9.47	29.72
Tap Thin						
	LT	260	115	145	9.67	30.35
	LTO	230	92	138	8.44	26.50
	HT	180	53	127	6.74	21.16
Mill Thin	HT	195	53	142	11.19	35.13

[a]Derived from conversion factor of (3.14)(MBF) = CCF, obtained from scale ticket information.

did not necessarily correspond to the volume removed. At Tap Thin, for example, more volume was removed in the LT treatment than in the HT treatment. Volume removed ranged from 50% to 75% of the pre-harvest stand volume.

Forest Operations

Overview

Each study site was purchased by a private timber company as a "lump sum" thinning sale (i.e., the purchaser paid for the option to remove all timber not designated as a residual tree). In general, this allowed the purchaser the flexibility of either leaving the pulpwood in the woods or using it, depending on the volatile pulp market at the time of harvest. However, contractual requirements ensured utilization to at least a 4-in. top diameter.

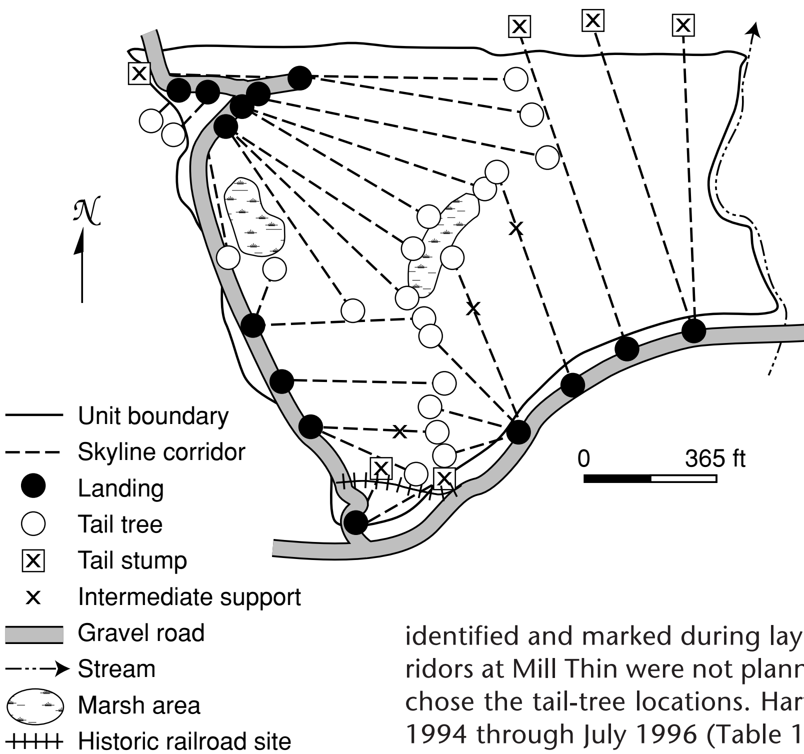

Figure 2. Example of skyline corridor layout.

The Forest Service planned the preliminary locations of the landings and spur roads, but allowed the contractors the flexibility to develop their own harvesting plans within the scope of the study. Each timber sale had a different logging contractor. On Walk Thin and Tap Thin, the logging contractors planned and flagged the skyline corridors. Figure 2 illustrates a typical layout for landings and corridors. After the corridors were flagged, the sale administrator adjusted and approved the corridors as needed before harvesting began. Tail trees and intermediate support trees were identified and marked during layout to prevent their being felled. Skyline corridors at Mill Thin were not planned or flagged; rather, the logging contractor chose the tail-tree locations. Harvesting on all sites occurred from November 1994 through July 1996 (Table 1).

Trees were felled and bucked into logs manually. Cable yarding was done with small to mid-sized yarders. A standing skyline configuration with partial log suspension was used to yard logs uphill to the landings.

Felling

Walk Thin and Tap Thin

Both sites were subcontracted to fallers with commercial thinning experience ranging from 6 mo to over 10 yr. Typically, the fallers started at the far boundary of the unit, used the skyline corridor as the center line, and cut towards the landing, 50–70 ft on either side. The corridors were cut at the same time as the rest of the treatment, predominantly in a herringbone felling pattern.

Fallers left the top of the tree attached to the last log and limbed (top side) and bucked the butt log to preferred mill lengths. At Walk Thin, the minimum mill requirements for a sawlog were a 16-ft length with a 5-in. diameter at the small end. Pulpwood requirements went to a 1-in. top. At Tap Thin, the minimum requirements for a sawlog were a 12-ft length with a 4-in. diameter at the small end; pulpwood was not used.

Mill Thin

Felling was done by the contract logging crew, whose cutting experience in commercial thinnings ranged from 3 yr to over 10 yr. The fallers typically started at the far boundary of the unit and cut uphill towards the landings. Herringbone felling patterns were not achieved because skyline corridors were not planned or flagged before felling. Fallers processed the entire tree at the felling site. The minimum requirements for a sawlog were a 12-ft length with a 4-in. diameter at the small end; pulpwood was not used.

Yarding and Loading

Walk Thin

A five-person yarding crew (yarder engineer, chaser, loader operator, rigging slinger, and hooktender) carried out each treatment, using the following equipment:

- Koller K501 trailer-mount three-drum yarder
    - 33-ft tower
    - skyline drum, 1,640 ft of 0.75-in. diameter wire rope
    - mainline drum, 1,965 ft of 0.5-in. diameter wire rope
    - haulback drum, 4,000 ft of 0.375-in. diameter wire rope
- Thunderbird 634 crawler-mount loader
- Cat D-7G
- Danzco PT 20 pull-through delimber
- Eaglet mechanical slackpulling carriage.

The skyline corridor patterns were either fan-shaped (59%) or parallel (41%). Tail trees were used on 84% of the corridors and intermediate supports on 16% of the corridors. Maximum yarding distances ranged from 200–1300 ft.

The carriage was propelled to the rigging crew by gravity. The yarder engineer controlled the movement and the location of the carriage along the skyline in response to radio signals from the rigging slinger. In addition, the rigging slinger could reposition the carriage downhill by direct radio control of the carriage. Generally, the people in the rigging crew worked together presetting or alternating turns (one person closer to the landing and the other closer to the tail tree). Hotsetting[1] turns occurred within approximately 250 ft of the landing. Only 12% of the skyline roads were pre-rigged.

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[1]Chokers are placed on logs while carriage is above the rigging crew in the brush.

Tap Thin

A seven-person yarding crew (yarder engineer, chaser, loader operator, rigging slinger, hooktender, and two choker setters) carried out each treatment, using the following equipment:

- Koller K501 trailer-mount three-drum yarder, with the same specifications used on Walk Thin
- Koehring 266L crawler-mount loader
- Eaglet mechanical slackpulling carriage
- John Deere grapple skidder

The skyline corridors were either fan-shaped (66%) or parallel (34%). Tail trees were used on 88% of the corridors and intermediate supports on 60% of the corridors. Maximum yarding distances ranged from 150 to 1300 ft. In a few areas inaccessible to log trucks, a grapple skidder was used to skid logs on swing roads from the yarder to a central landing location. Swing-road distances ranged from 100 to 600 ft.

The carriage operating procedure was the same as that described for Walk Thin. The three-person rigging crew generally preset turns unless they were working too close to the landing. The hooktender pre-rigged 95% of the skyline roads.

Mill Thin

A five-person yarding crew (yarder engineer, chaser, loader operator, rigging slinger, and hooktender) carried out the single treatment, using the following equipment:

- Madill 071 mobile four-drum yarder
    - 50-ft tower
    - skyline drum, 2,000 ft of 0.875-in. diameter wire rope
    - mainline drum, 2,200 ft of 0.5-in. diameter wire rope
    - haulback drum, 4,400 ft of 0.5-in. diameter wire rope
- Case 125B crawler-mount loader
- Danebo mechanical slackpulling carriage.

The skyline corridors were either fan-shaped (67%) or parallel (33%). Tail trees were used on 55% of the corridors; no intermediate supports were used. Maximum yarding distances ranged from 150 to 950 ft.

The carriage was moved to the rigging crew with the haulback line. The yarder engineer controlled the movement and location of the carriage along the skyline in response to radio signals from the rigging slinger. The two-person rigging crew yarded the corridor first and then finished each skyline road by methods similar to those used at Walk Thin. The hooktender pre-rigged less than 5% of the skyline roads.

Study Methods

A detailed time study and a shift-level study were designed to capture cycle times, small delays, large delays, and production rates. Data from the two studies were combined to calculate total percent delay time.

Detailed Time Studies

In the detailed time studies, data were collected on elements of productive time in each activity cycle and other independent variables, as defined in Glossaries 1 (felling cycle, p. 15) and 2 (yarding cycle, p. 20). Small delays(<10 min; see boxes, pp. 15 and 20) were also recorded and categorized, and production rates were calculated. One or two researchers collected the data, depending on the activity.

Time data were collected in centiminutes with a Husky Hunter II handheld computer and the SIWORK3 software package (Danish Institute of Forest Technology 1988). Data were downloaded to a personal computer for analysis. Equations for predicting felling and yarding cycle times without delays were developed with forward stepwise multiple regression. The equations were based on significant ($P \leq 0.05$) independent variables. A random 10% of data from the detailed time study was withheld from the regression equation to use in validating the regression models. Predicted cycle times were compared with actual times by paired *t*-test ($\alpha = 0.05$). All the regression models are valid for the range of conditions in the data set; they should be used with caution elsewhere.

The LTO and the HT treatments were compared with the LT treatment, which was considered the traditional thinning treatment and is referred to as the base treatment throughout the report. For the LTO treatment, the data for the LT areas between the openings were analyzed separately from those for the openings in order to capture the actual effects of the openings. A weighted average based on volume removed from each area [LT between openings (LTBO) and openings (Op)] was applied when determining production rates and costs.

Felling

Trees were identified by painted numbers before felling began. Data recorded for each tree included species, diameter at breast height (DBH), ground slope, and whether the tree was in the skyline corridor. Study areas were chosen ahead of time, which allowed terrain and other stand characteristics to be uniformly matched among the treatments. Approximately 200 samples were collected on each treatment; the range was 92–290 samples per treatment.

Yarding

The cycle time began as the carriage left the landing and ended at its next departure. Approximately 260 samples (yarding cycles) were collected on each treatment; the range was 187–351 samples per treatment. Data were collected by two researchers over 8–12 days per treatment. Distances from the landings were marked at roughly 50-ft intervals along the skyline corridor. Lateral distances and carriage heights were estimated; accuracy was checked periodically with a clinometer and a Spencer tape. Ground slopes were measured with clinometers where the turn was hooked. The piece types (log, top, or fiber) were determined visually.

Shift-Level Studies

Shift-level studies were conducted to gather data on scheduled hours, daily production, and large delays (>10 min; see boxes, p. 15 and 20). Road- and landing-change information was recorded to the nearest 10 min. One person each from the felling and the yarding crews was responsible for filling out the forms daily. The loader operator recorded the scale ticket information and the number of loads for each day.

Volume information on piece types was obtained through a random sample of sawlog and fiber loads. Average CCF per piece was calculated for each treatment and site. Analysis of variance was used to determine if the number of pieces per turn (logs, tops, and fiber) differed significantly among treatments at a site. The average site values for the number of logs, tops, or fiber pieces per turn were used in the regression model when estimating cycle times, unless a particular treatment differed significantly from the site average.

Cost Analysis

The following components were used to calculate production rates and costs for felling and yarding:

- *effective hour (min/hr)*—productive time, determined from the percent of time lost in delays (felling or yarding) for a site. A site with 20% of its time in delays would have an effective hour of 60(1 – 0.20) = 48 min/hr.
- *delay-free cycle time*—determined by inserting the average values for the independent variables into the felling or yarding regression equation for a site. Units for felling are min/tree; units for yarding are min/turn.
- *volume per cycle*—volume per piece type (log, top, fiber) determined from the shift-level study, total pieces per cycle determined from the detailed time study. Units for felling are CCF/tree; units for yarding are CCF/turn.
- *owning, operating, and labor cost*—determined from a cost appraisal of the specific equipment and personnel used at each site (Appendix, Tables A1–A4). Units are $/hr.
- *net:gross timber scale*—a ratio of net volume (no defects in wood) to gross volume, determined from the shift-level study.

These components were used to calculate production rates and costs as follows, using data for either felling or yarding:

Production rate = (effective hour/delay-free cycle time) (volume per cycle)

Cost = (owning, operating, and labor cost)/[(production rate) (net:gross timber scale)]

Skyline road-change costs were determined by multiplying scheduled time for road/landing changes by the owning, operating, and labor cost of each operation (Appendix), and then dividing by the volume harvested at each site. Fixed yarding costs, such as moving equipment to and from a site, setting up, and tearing down, were also calculated to determine total yarding costs.

The stump-to-truck logging costs do not include profit and risk allowances. Planning and layout costs [reported by Kellogg et al. (1998)] and sale administration expenses also were not included in the cost analysis.

Results

Felling

Delay Codes and Descriptions for Felling

- **1 – Walk in**
- **2 – Walk out**
- **5 – Planning**
- **10 – Mechanical (saw breakdown, chain replacement, fuel, oil, etc.)**
- **50 – Personal (food, water, personal breaks)**
- **69 – Brushing (clearing brush to get to tree)**
- **70 – Tree hang-up**
- **100 – Move fuel or saw**
- **110 – Discussion with other faller**
- **120 – Discussion with sale administrator**
- **130 – Discussion with researcher**
- **150 – Bar hangups**
- **200 – Miscellaneous**

Glossary 1: Cycle Time Elements and Variables Measured for Felling

Elements

Travel and preparation: Travel between trees. Starts when bucking or limbing is complete, ends when felling for the next tree starts

Fell: Starts when chainsaw touches the tree, ends when tree hits the ground

Limb and measure: Starts when tree hits the ground, ends when bucking cut starts

Buck: Starts (usually after limb and measure) when chainsaw begins cutting a horizontal cross-section of the main stem, ends when travel or limb and measure begins

Delays: The time involved with individual delays (see sidebar)

Variables measured

DBH: Diameter at breast height (in.)

Limbs: Tally of each limb cut with chainsaw (no.)

Logs: Stems that are bucked at both ends (no.)

Tops: Stems that have 1 buck cut or attached top (e.g., 1 log + 1 fiber). No limbing or bucking (no.)

Fiber: Stems that are less than 12 ft long or less than 4 in. in diameter at the small end (no.)

Cuts: The number of cross cuts (cut outs, topping, bucking) (no.)

Slope: Average ground slope (%) at felling

Corridor: 0 = tree cut was not in corridor, 1 = tree cut was in corridor

Wedge: The felling method, where 0 = no assistance, 1 = wedges

Light thin (LT): 0 = not in light-thin area, 1 = in light-thin area

Light-between (LTBO): 0 = not in light-thin area between openings, 1 = in light-thin area between openings

Openings (Op): 0 = not in openings, 1 = in openings

Heavy (HT): 0 = not in heavy thinning, 1 = in heavy thinning

Walk Thin

The average total cycle time for felling was 1.86 min over all treatments; Table 3 shows a breakdown of the felling cycle. "Travel and preparation" and "limb and measure" (Glossary 1) each accounted for 25% of the average total cycle time. Felling delays (see sidebar) consumed 21% of the average cycle time; the major delays were "mechanical", "personal", and "walk-in/out" (Figure 3A).

Table 3. Average felling cycle for each site from the detailed time study.

Element	Walk Thin Average time (min)	Walk Thin % of cycle	Tap Thin Average time (min)	Tap Thin % of cycle	Mill Thin Average time (min)	Mill Thin % of cycle
Travel and preparation	0.47	25	0.41	16	0.36	6
Fell	0.42	23	0.45	17	0.92	17
Limb and measure	0.47	25	0.96	37	2.18	39
Buck	0.11	6	0.12	5	0.47	8
Delay-free cycle	**1.47**	**79**	**1.94**	**75**	**3.93**	**70**
Delays	0.40	21	0.66	25	1.65	30
Total felling cycle	**1.86**	**100**	**2.60**	**100**	**5.58**	**100**

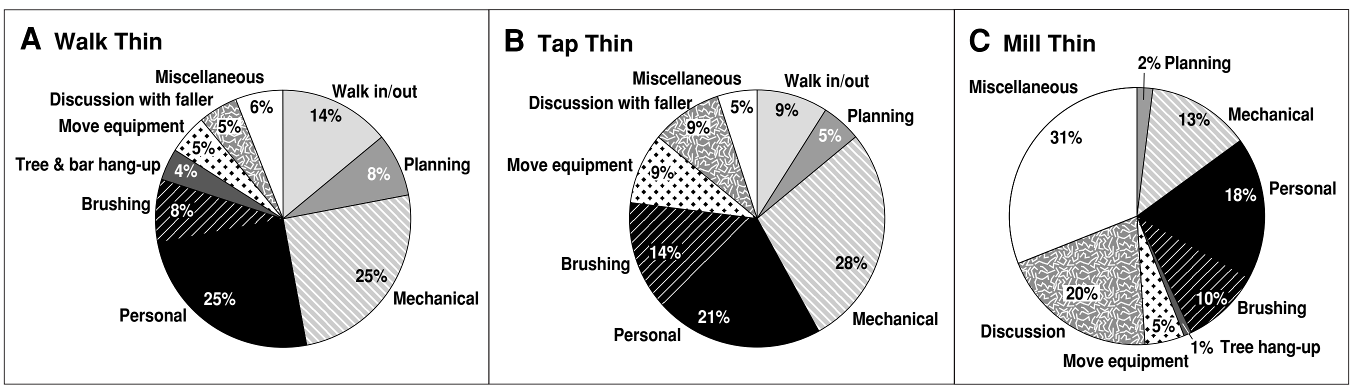

Figure 3. Breakdown of total felling delays at each site.

The following regression model to predict delay-free felling cycle time per tree was developed from the detailed time study:

$$\text{Fell cycle (min)} = -0.116 + 0.120\ \mathit{DBH}\ (\text{in.}) + 0.032\ \mathit{Limbs}\ (\text{no.}) + 0.474\ \mathit{Logs}\ (\text{no.}) + 0.567\ \mathit{Wedge}\ (0-1) - 0.255\ \mathit{Op}\ (0-1) + 0.069\ \mathit{Heavy}\ (0-1)$$

$$(\text{adjusted } R^2 = 69.5\%;\ \text{standard error} = 0.395;\ \text{sample size} = 745 \text{ trees}) \qquad [1]$$

where the independent variables are as defined in Glossary 1.

The cycle time for a given set of conditions at Walk Thin can be estimated from Eq. [1]. For example, the time to fall and process a tree with 9-in. DBH, 2 limbs removed, 1 commercial log bucked from the tree, no wedging done to adjust the falling direction, and in the HT treatment would be

$$\text{Fell cycle (min)} = -0.116 + 0.120(9) + 0.032(2) + 0.474(1) + 0.567(0) - 0.255(0) + 0.069(1)$$
$$= 1.57 \text{ min} \qquad [1a]$$

Statistics for the independent variables that were significant (P ≤ 0.05) in determining delay-free felling time are summarized in Table 4. The HT treatment and the Op in the LT0 treatment differed significantly in felling time from the LT (base) treatment; the LTBO in the LTO treatment did not.

Table 4. Summary statistics for the independent variables significant in the felling regression equation for Walk Thin [Eq. 1] in the light thin (LT), light thin with openings (LTO), heavy thin (HT), and all treatments.

	Treatment			
Variable[a]	LT (*n* = 185)	LTO (*n* = 270)	HT (*n* = 290)	All (*n* = 745)
DBH (in.)				
Average	9.14	8.99	10.02	9.44
Standard deviation	2.61	2.87	2.62	2.73
Range	5–19	5–20	6–19	5–20
Limbs (no.)				
Average	2.22	1.80	1.47	1.78
Standard deviation	4.05	3.27	5.14	4.27
Range	0–41	0–21	0–47	0–47
Logs (no.)				
Average	0.76	0.66	0.89	0.77
Standard deviation	0.45	0.49	0.33	0.44
Range	0–2	0–2	0–2	0–2
Wedge[b]				
Average	0.12	0.03	0.01	0.04
Standard deviation	0.32	0.16	0.10	0.19
Range	0–1	0–1	0–1	0–1
Openings[b]				
Average	0	0.47	0	0.17
Standard deviation	0	0.50	0	0.38
Range	0	0–1	0	0–1
Heavy[b]				
Average	0	0	1	0.39
Standard deviation	0	0	0	0.49
Range	0	0	1	0–1

[a]Independent variables are defined in Glossary 1.

[b]Used as an indicator variable with a value of either 0 or 1.

Tap Thin

The average total cycle time for felling was 2.60 min over all treatments. Table 3 shows a breakdown of the felling cycle. "Limb and measure" required 37% of the average total felling cycle. Felling delays were 25% of the average cycle time; the major delays were "mechanical", "personal", and "brushing" (Figure 3B).

The following regression model to predict delay-free felling cycle time was developed from the detailed time study:

$$\text{Fell cycle (min)} = -0.465 + 0.102\,\textit{DBH}\text{ (in.)} + 0.016\,\textit{Limbs}\text{ (no.)} + 0.562\,\textit{Logs}\text{ (no.)} + 0.009\,\textit{Slope}\text{ (\%)} + 0.734\,\textit{Wedge}\text{ (0–1)} + 0.137\,\textit{Corridor}\text{ (0–1)} + 0.449\,\textit{LBTO}\text{ (0–1)} + 0.437\,\textit{Op}\text{ (0–1)} + 0.426\,\textit{HT}\text{ (0–1)}$$

$$\text{(adjusted } R^2 = 80.7\%;\ \text{standard error} = 0.442;\ \text{sample size} = 581\text{ trees)} \quad [2]$$

where all variables are as defined in Glossary 1.

Most of the independent variables measured were significant ($P \leq 0.05$) in determining delay-free felling time. Statistics for these are summarized in Table 5. Each treatment differed significantly in felling time from the LT treatment.

Table 5. Summary statistics for the independent variables significant in the felling regression equation for Tap Thin [Eq. 2] in the light thin (LT), light thin with openings (LTO), heavy thin (HT), and all treatments

	Treatment			
Variable[a]	LT (*n* = 209)	LTO (*n* = 147)	HT (*n* = 225)	All (*n* = 581)
DBH (in.)				
Average	9.05	9.32	11.39	10.03
Standard deviation	2.65	2.49	2.71	2.84
Range	5–18	5–15	5–19	5–19
Limbs (no.)				
Average	31.50	1.17	40.72	27.48
Standard deviation	30.43	3.07	23.46	28.21
Range	0–144	0–20	0–133	0–144
Logs (no.)				
Average	0.83	0.71	0.92	0.84
Standard deviation	0.49	0.45	0.44	0.47
Range	0–2	0–1	0–2	0–2
Slope (%)				
Average	23	10	19	18
Standard deviation	6	7	6	8
Range	10–45	0–35	10–30	0–45
Wedge[b]				
Average	0.02	0	0.05	0.03
Standard deviation	0.15	0	0.22	0.16
Range	0–1	0	0–1	0–1
Corridor[b]				
Average	0.21	0.16	0.08	0.14
Standard deviation	0.40	0.37	0.28	0.35
Range	0–1	0–1	0–1	0–1

Table 5 continued

Variable[a]	Treatment LT (*n* = 209)	LTO (*n* = 147)	HT (*n* = 225)	All (*n* = 581)
LTBO[b]				
Average	0	0.54	0	0.14
Standard deviation	0	0.50	0	0.34
Range	0	0–1	0	0–1
Op[b]				
Average	0	0.46	0	0.11
Standard deviation	0	0.49	0	0.32
Range	0	0–1	0	0–1
Heavy[b]				
Average	0	0	1	0.39
Standard deviation	0	0	0	0.49
Range	0	0	1	0–1

[a]Independent variables are defined in Glossary 1.
[b]Used as an indicator variable with a value of either 0 or 1.

Mill Thin

The average total cycle time for felling was 5.58 min, with "limb and measure" occupying 39% of that time (Table 3). Felling delays were 30% of the average cycle time; the major types were "miscellaneous", "discussion", and "personal" (Figure 3C).

The following regression model was developed from the detailed time study to predict delay-free felling cycle time:

$$\text{Fell cycle (min)} = -0.893 + 0.281\ \textit{DBH}\ \text{(in.)} + 0.026\ \textit{Limbs}\ \text{(no.)} + 0.996\ \textit{Wedge}\ (0-1)$$

$$\text{(adjusted } R^2 = 80.7\%;\ \text{standard error} = 0.442;\ \text{sample size} = 581 \text{ trees)} \qquad [3]$$

where all variables are as defined in Glossary 1.

Fewer of the independent variables measured were significant ($P \leq 0.05$) in determining delay-free felling time for HT at this site than at Walk Thin or Tap Thin. Statistics for these variables are summarized in Table 6. No other treatments were done at this site.

Table 6. Summary statistics for the independent variables significant in the felling regression equation for Mill Thin [Eq. 3] in the heavy thin (HT) treatment.

Variable[a]	Treatment HT (*n* = 92)
DBH (in.)	
Average	10.45
Standard deviation	3.68
Range	5–21
Limbs (no.)	
Average	63.66
Standard deviation	40.84
Range	0–169
Wedge[b]	
Average	0.25
Standard deviation	0.43
Range	0–1

[a]Independent variables are defined in Glossary 1.
[b]Used as an indicator variable with a value of either 0 or 1.

Yarding and Loading

Delay Codes and Descriptions for Yarding

Operational

- 5 - Landing delays
- 10 - Reposition carriage/reset chokers
- 15 - Planning
- 20 - Felling and bucking
- 25 - Rigging cuts
- 30 - Pulled anchor stump or tail-tree/ stump tailhold
- 35 - Yarder adjustments/ wait for yarder
- 40 – Line and rigging adjustments, checks
- 45 - Wait for loader
- 50 - Wait for chaser
- 55 - Put on/take off extra chokers
- 60 - Transfer of rigging, equipment, powersaws, lunches along skyline
- 65 - Clear corridor obstacles with carriage
- 70 - Fuel
- 75 - Pick up logs
- 80 - Miscellaneous

Repair

- 100 - Yarder
- 110 - Loader
- 120 – Line or carriage
- 130 - Block
- 140 - Miscellaneous

Personal

- 200 - Food, water
- 210 - Discussion
- 220 – Miscellaneous

Nonproductive Activities

- 300 - Researcher in way
- 400 - Miscellaneous

Walk Thin

The average total cycle time for yarding over all treatments was 5.80 min. The percentages of the yarding cycle elements (Glossary 2) for an average cycle are shown in Table 7. "Hook" was the most time-consuming element. Delays (see side-bar) consumed 16% of the average yarding cycle. Delays were not treatment-specific (Hossain 1998). The major small delay (<10 min) from the detailed time study was "reposition carriage/reset chokers" (Figure 4A). Road changes averaged 0.89 hr and landing changes, 2.08 hr (Table 8).

Glossary 2: Cycle Time Elements and Variables Measured for Yarding

Elements

Outhaul: Starts when the carriage leaves the landing, ends when carriage stops on the skyline

Drop: Starts when the carriage stops on the skyline, ends when hooktender has chokers under control (untangled)

Lateral out: Starts when hooktender has chokers under control, ends when the chokers reach the turn

Hook: Starts when lateral out ends, ends when the signal to go ahead is given

Lateral in: Starts when hooking ends, ends when the turn reaches the skyline

Inhaul: Starts when lateral in has finished, ends when the turn arrives at the landing

Unhook: Starts when the turn arrives at the landing, ends when the carriage starts back to the field

Delays: The time involved for each individual delay (see sidebar)

Variables Measured

Yarding distance: Distance from the yarder to the location where the carriage stops on skyline (ft)

Lateral distance: Distance perpendicular from the skyline to the choked turn (ft)

Carriage height: Distance from carriage to ground (ft), recorded every 50 ft or major terrain break

Logs: Stems that have been cut at both ends (no.)

Tops: Stems that have 1 buck cut or top is attached (e.g., 1 log + 1 fiber) (no.)

Fibers: Stems that are less than 12 ft long or less than 4 in. diameter at the small end (no.)

Slope: Slope (%) where the logs are hooked

Chokers: The number of chokers hooked to logs (no.)

Preset: 0 = hotset, 1 = preset

Span: 0 = single span, 1 = multi-span

Stand damage: 0 = no tree(s) scarred during turn; 1 = tree(s) scarred during turn. Scar is counted if the bark removed to the cambium is larger than 3 in^2

Light thin (LT): 0 = not in light-thin area, 1 = in light-thin area

Light-between (LTBO): 0 = not in light-thin area between openings, 1 = in light-thin area between openings

Openings (Op): 0 = turn hooked outside openings, 1 = turn hooked inside openings

Heavy (H): 0 = not in heavy thinning, 1 = in heavy thinning

Table 7. Average yarding cycle for each site from the detailed time study; large delays were calculated from the shift-level study.

Element	Walk Thin		Tap Thin		Mill Thin	
	Average time (min)	% of cycle	Average time (min)	% of cycle	Average time (min)	% of cycle
Outhaul	0.46	8	0.71	14	0.57	9
Drop	0.19	3	0.12	2	0.17	3
Lateral out	0.49	8	0.23	4	0.65	11
Hook	1.28	22	0.49	10	1.07	17
Lateral in	0.85	15	0.64	12	0.51	8
Inhaul	1.01	17	1.15	22	0.71	11
Unhook	0.62	11	0.70	14	0.60	10
Delay-free cycle	**4.90**	**84**	**4.04**	**78**	**4.28**	**69**
Small delays	0.75	13	0.78	15	0.98	16
Large delays	0.15	3	0.39	7	0.93	15
Total yarding cycle	**5.80**	**100**	**5.21**	**100**	**6.19**	**100**

Table 8. Summary of road and landing changes and their costs.

	Walk Thin	Tap Thin	Mill Thin
Number of corridors	97	62	45
Average time (hr)			
Road changes	0.89	1.75	1.62
Landing changes	2.08	2.22	3.94
Corridors (%) with			
Tail (lift) trees	84	88	55
Intermediate support trees	16	60	0
Skyline roads pre-rigged (%)	12	95	5
Cost ($/CCF)	6.12	10.63	15.09

The following regression model to predict delay-free yarding cycle time was developed from the detailed time study:

$$\text{Yard cycle (min)} = 2.627 + 0.003\ \textit{Yarding distance}\ \text{(ft)} + 0.012\ \textit{Lateral distance}\ \text{(ft)} + 0.003\ \textit{Carriage height}\ \text{(ft)} + 0.239\ \textit{Logs}\ \text{(no.)} + 0.196\ \textit{Tops}\ \text{(no.)} + 0.118\ \textit{Fibers}\ \text{(no.)} - 0.468\ \textit{Preset}\ (0\text{–}1) + 0.136\ \textit{Span}\ (0\text{–}1) - 0.470\ \textit{LTBO}\ (0\text{–}1) - 0.729\ \textit{Op}\ (0\text{–}1) - 0.871\ \textit{Heavy}\ (0\text{–}1) \quad [4]$$

(adjusted $R^2 = 52.7\%$; standard error = 0.741; sample size = 937 yarding cycles)

where all variables are as described in Glossary 2.

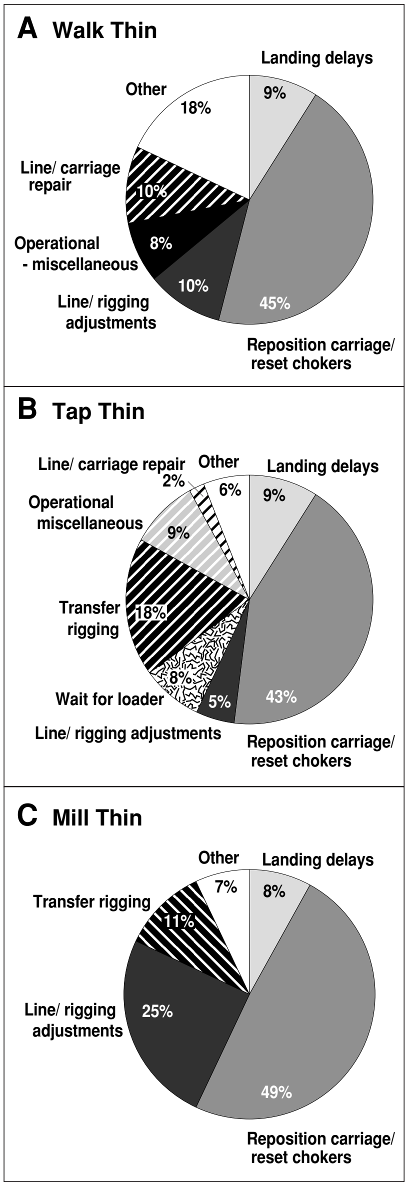

Figure 4. Breakdown of small yarding delays (<10 min), obtained from the detailed time study at each site.

For example, a corridor with average conditions of a yarding distance of 570 ft, a lateral distance of 20 ft, a carriage height of 50 ft, 1.68 logs, 1.84 tops, 1.21 fiber pieces, turns preset, no intermediate support, 80% of cycles in LTBO, 20% of cycles in openings (0p), and no HT treatment would have the following cycle time:

$$\begin{aligned}\text{Yard cycle} = {} & 2.627 + 0.003(570) + 0.012(20) + 0.003(50) + 0.239(1.68) \\ & + 0.196(1.84) + 0.118(1.21) - 0.468(1) + 0.136(0) - 0.470(0.8) \\ & - 0.729(0.2) - 0.0871(0) \\ = {} & 4.64 \text{ min}\end{aligned} \qquad [4a]$$

Statistics for the independent variables significant in determining delay-free yarding time in Eq. [4] ($P \leq 0.05$) are summarized in Table 9. Three treatment variables (*HT*, *LTBO*, and *Op*) differed significantly from those for the base LT treatment. The differences among the treatments in number of piece types yarded per turn were relatively small (Table 10).

Table 9. Summary statistics for the independent variables significant in the yarding regression equation for Walk Thin [Eq. 4] in the light thin (LT), light thin with openings (LTO), heavy thin (HT), and all treatments.

	Treatment			
Variable[a]	LT (*n* = 285)	LTO (*n* = 351)	HT (*n* = 301)	All (*n* = 937)
Yarding distance (ft)				
Average	634	357	759	570
Standard deviation	201	175	258	273
Range	40–940	55–840	60–1200	40–1200
Lateral distance (ft)				
Average	21	21	19	21
Standard deviation	15	15	13	15
Range	0–75	0–90	0–60	0–90
Carriage height (ft)				
Average	48	54	51	51
Standard deviation	20	20	19	20
Range	15–80	5–162	15–90	5–162
Logs (no.)				
Average	1.83	1.58	1.66	1.68
Standard deviation	1.16	1.15	1.05	1.12
Range	0–6	0–6	0–4	0–6
Tops (no.)				
Average	1.62	2.10	1.73	1.84
Standard deviation	1.23	1.36	1.09	1.24
Range	0–5	0–8	0–4	0–8
Fibers (no.)				
Average	1.27	1.38	0.96	1.21
Standard deviation	1.23	1.40	1.02	1.24
Range	0–7	0–7	0–5	0

Table 9 continued.

Variable[a]	Treatment LT (*n* = 285)	 LTO (*n* = 351)	 HT (*n* = 301)	 All (*n* = 937)
Preset[b]				
Average	0	0	0.56	0.18
Standard deviation	0	0	0.50	0.38
Range	0	0	0–1	0–1
Span[b]				
Average	0.25	0.12	0.23	0.20
Standard deviation	0.43	0.33	0.42	0.40
Range	0–1	0–1	0–1	0–1
LTBO[b]				
Average	0	0.73	0	0.27
Standard deviation	0	0.45	0	0.44
Range	0	0–1	0	0–1
Openings[b]				
Average	0	0.27	0	0.10
Standard deviation	0	0.45	0	0.30
Range	0	0–1	0	0–1
Heavy[b]				
Average	0	0	1	0.32
Standard deviation	0	0	0	0.46
Range	0	0	1	0–1

[a]Independent variables are defined in Glossary 2.

[b]Used as an indicator variable with a value of either 0 or 1.

Table 10. Average number of pieces per turn, by type, and average total volume per turn for the light thin (LT), light thin between openings (LTBO), openings (Op), heavy thin (HT), and all treatments at each site.

Site/ piece type/ total	Treatment LT	 LTBO	 OP	 HT	 All
Walk Thin					
Logs	1.75	1.52	1.75	1.75	1.68
Tops	1.68	1.98	2.43	1.68	1.84
Fibers	1.30	1.30	1.30	0.96	1.21
Total pieces	**4.73**	**4.80**	**5.48**	**4.39**	**4.73**
Total volume[a] (CCF)	**0.457**	**0.433**	**0.503**	**0.450**	**0.452**
Tap Thin					
Logs	2.59	2.59	1.75	2.59	2.53
Tops	1.56	1.20	1.20	1.20	1.30
Fibers	0.94	0.40	0.40	0.40	0.55
Total pieces	**5.09**	**4.19**	**3.35**	**4.19**	**4.38**
Total volume[b] (CCF)	**0.544**	**0.510**	**0.372**	**0.510**	**0.510**
Mill Thin					
Logs	–	–	–	3.13	–
Tops	–	–	–	0.14	–
Fibers	–	–	–	0.35	–
Total pieces	–	–	–	**3.62**	–
Total volume[c] (CCF)	–	–	–	**0.670**	–

[a]Based on 0.186 CCF/log, 0.062 CCF/top, and 0.021 CCF/fiber piece.
[b]Based on 0.165 CCF/log, 0.062 CCF/top, and 0.021 CCF/fiber piece.
[c]Based on 0.209 CCF/log, 0.062 CCF/top, and 0.021 CCF/fiber piece.

Tap Thin

The average total yarding cycle was 5.21 min over all treatments. The percentages of the yarding cycle elements are shown in Table 7. "Inhaul" was the most time-consuming element. Delays consumed 22% of the average cycle time. Major small delays were "reposition carriage/reset chokers" and "transfer rigging" (Figure 4B). Road changes averaged 1.75 hr and landing changes, 2.22 hr (Table 8).

The following regression model was developed from the detailed time study to predict delay-free yarding cycle time:

$$\begin{aligned}\text{Yard cycle (min)} = {} & 1.231 + 0.003\ \textit{Yarding distance}\ (\text{ft}) + 0.010\ \textit{Lateral distance}\ (\text{ft}) \\ & + 0.017\ \textit{Carriage height}\ (\text{ft}) + 0.141\ \textit{Logs}\ (\text{no.}) + 0.111\ \textit{Tops}\ (\text{no.}) \\ & + 0.078\ \textit{Fibers}\ (\text{no.}) + 0.012\ \textit{Slope}\ (\%) - 0.668\ \textit{Preset}\ (0-1) - 0.186 \\ & \textit{LTBO}\ (0-1) - 0.415\ \textit{Op}\ (0-1) \qquad [5]\end{aligned}$$

$$(\text{adjusted } R^2 = 58.9\%;\ \text{standard error} = 0.473;\ \text{sample size} = 671 \text{ yarding cycles})$$

where all variables are as defined in Glossary 2.

Statistics for the significant ($P \leq 0.05$) independent variables are summarized in Table 11. Two treatment variables (*LTBO* and *Op*) differed significantly from the LT treatment. The HT and LT treatments were not significantly different from each other. The LT treatment averaged more pieces per turn than the other treatments (Table 10).

Mill Thin

The average total cycle time for yarding was 6.19 min. "Hook" was the most time-consuming element (Table 7). Yarding delays consumed 31% of the average cycle time. Major small delays were "reposition carriage/reset chokers" and "line/rigging adjustments" (Figure 4C). Road changes averaged 1.62 hr and landing changes, 3.94 hr (Table 8).

The following regression model to predict delay-free yarding cycle time was developed from the detailed time study:

$$\begin{aligned}\text{Yard cycle (min)} = {} & 2.394 + 0.001\ \textit{Yarding distance}\ (\text{ft}) + 0.021\ \textit{Lateral distance}\ (\text{ft}) \\ & + 0.031\ \textit{Carriage height}\ (\text{ft}) + 0.356\ \textit{Logs}\ (\text{no.}) + 0.547\ \textit{Tops}\ (\text{no.}) \\ & + 0.473\ \textit{Fibers}\ (\text{no.}) - 0.047\ \textit{Slope}\ (\%) - 0.730\ \textit{Preset}\ (0-1) \qquad [6]\end{aligned}$$

$$(\text{adjusted } R^2 = 37.2\%;\ \text{standard error} = 0.813;\ \text{sample size} = 229 \text{ yarding cycles})$$

where all terms are as described in Glossary 2.

Statistics for the independent variables that were significant ($P \leq 0.05$) in determining delay-free yarding time are summarized in Table 12.

The average number of each piece type per turn was 3.13 logs, 0.14 tops, and 0.35 fiber (Table 10).

Yarding Sensitivity

The greater productivity capability (e.g., faster line speed or larger diameter wire rope) of bigger yarders over smaller yarders may not offset higher

Table 11. Summary statistics for the independent variables significant in the yarding regression equation for Tap Thin [Eq. 5] in the light thin (LT), light thin with openings (LTO), heavy thin (HT), and all treatments.

	Treatment			
Variable[a]	LT (n = 187)	LTO (n = 276)	HT (n = 208)	All (n = 671)
Yarding distance (ft)				
Average	517	603	702	610
Standard deviation	236	199	225	229
Range	5–840	150–990	190–1120	5–1120
Lateral distance (ft)				
Average	23	21	17	20
Standard deviation	16	16	13	15
Range	0–70	5–85	0–80	0–85
Carriage height (ft)				
Average	38	45	42	42
Standard deviation	8	13	9	11
Range	25–50	5–70	30–65	5–70
Logs (no.)				
Average	2.69	2.60	2.48	2.59
Standard deviation	1.11	1.11	1.01	1.08
Range	0–6	0–5	0–5	0–6
Tops (no.)				
Average	1.56	1.24	1.15	1.30
Standard deviation	1.09	1.04	0.95	1.04
Range	0–4	0–4	0–4	0–4
Fibers (no.)				
Average	0.95	0.40	0.40	0.55
Standard deviation	1.14	0.67	0.67	0.86
Range	0–8	0–3	0–3	0–8
Slope (%)				
Average	15	16	18	16
Standard deviation	3	7	7	6
Range	10–25	10–35	10–40	10–40
Preset[b]				
Average	0.82	0.89	0.95	0.89
Standard deviation	0.38	0.30	0.22	0.31
Range	0–1	0–1	0–1	0–1
LBTO[b]				
Average	0	0.74	0	0.30
Standard deviation	0	0.44	0	0.46
Range	0	0–1	0	0–1
Openings[b]				
Average	0	0.26	0	0.11
Standard deviation	0	0.44	0	0.31
Range	0	0–1	0	0–1

[a]Independent variables are defined in Glossary 2.
[b]Used as an indicator variable with a value of either 0 or 1.

Table 12. Summary statistics for the independent variables significant in the yarding regression equation for Mill Thin [Eq. 6] in the heavy thin (HT) treatment.

Variable[a]	Treatment HT (n = 229)
Yarding distance (ft)	
Average	375
Standard deviation	230
Range	50–910
Lateral distance (ft)	
Average	25
Standard deviation	19
Range	0–95
Carriage height (ft)	
Average	32
Standard deviation	7
Range	5–45
Logs (no.)	
Average	3.13
Standard deviation	1.22
Range	1–8
Tops (no.)	
Average	0.14
Standard deviation	0.39
Range	0–2
Fibers (no.)	
Average	0.35
Standard deviation	0.58
Range	0–3
Slope (%)	
Average	18
Standard deviation	4
Range	0–20
Preset[b]	
Average	0.52
Standard deviation	0.50
Range	0–1

[a]Independent variables are defined in Glossary 2.
[b]Used as an indicator variable with a value of either 0 or 1.

owning and operating costs. Thinning requires finesse and technique more than power and speed. To compare yarding costs among the three sites more evenly, we eliminated differences in number of pieces, yarding distance, and presetting by inserting average values over the three sites for the independent variables in each regression equation. Volumes also were standardized among the sites. The main assumption was that the number of pieces hooked was the same for all sites, regardless of yarder size. Neither the Koller K501s nor the Madill 071 were operating near their maximum turn size; other factors, such as log availability, may have controlled the number of pieces per turn. Costs were calculated based on yarding delays for each operation and individual regression models from each site.

The resulting average yarding costs were $37.01/CCF at Walk Thin, $44.93/CCF at Tap Thin, and $53.17/CCF at Mill Thin. Thus, the larger yarder with haulback line at Mill Thin had a higher yarding cost than the smaller yarders at Walk Thin and Tap Thin. Increased delays associated with the type of carriage used and the additional time required to operate the haulback system with the large yarder contributed to the higher costs.

Harvesting Costs

Treatment Comparisons

Felling production rates and costs showed no consistent relationship to type of silvicultural treatment at the Walk Thin and Tap Thin sites (Table 13). At Walk Thin, the LTO treatment was the least costly, while the HT was the most costly. The cost differences relative to the LT, however, were small. At Tap Thin, the LT treatment was the least costly; costs in the HT and the LTO treatments were nearly the same, and about 25% higher than the LT treatment.

Yarding production rates and costs also showed no consistent relationship to type of silvicultural treatment (Table 14). At Walk Thin, the HT treatment was the least costly, while the LT treatment was the most costly. At Tap Thin, the LT and LTO costs were nearly identical, and slightly less than the HT treatment.

At both Walk Thin and Tap Thin, the small openings in the LTO treatment increased felling and yarding production, but treatment effect was diminished overall because of the small percentage of area influenced.

Total harvesting costs showed no consistent relationship to type of silvicultural treatment (Table 15). At Walk Thin, the HT treatment cost 12.5% less, and the LTO treatment, 7.8% less, than the LT treatment. At Tap Thin, the LT treatment was the least costly, with the LTO treatment costing 2.5% more and the HT treatment, 7.2% more.

Site Comparisons

Average felling costs ranged from $4.65/CCF at Walk Thin to $9.91/CCF at Mill Thin (Table 13). Mill Thin's delay-free cycle time was about twice as long as that at Walk Thin or Tap Thin, and felling delays were substantially longer than those on the other two sites (Table 3), resulting in a lower production rate and higher felling cost.

Table 13. Felling production rates and costs in the light thin (LT), light thin with openings (LTO), heavy thin (HT), and all treatments at each site.

Site	Treatment	Delay-free cycle time[a] (min) (CI)[b]	Production rate[c] (CCF/hr)	Cost ($/CCF)[d]	Cost change relative to LT (%)
Walk Thin	All	1.45 (0.028)	8.09	4.65	–
	LT	1.46 (0.028)	8.03	4.66	–
	LTO[e]	1.37 (0.028)	8.55	4.42	(5.2)
	HT	1.53 (0.028)	7.69	4.86	4.3
Tap Thin	All	1.96 (0.036)	5.30	7.14	–
	LT	1.67 (0.036)	6.14	6.09	–
	LTO[f]	2.12 (0.036)	4.85	7.70	26.4
	HT	2.10 (0.036)	4.90	7.64	25.4
Mill Thin	HT	3.93 (0.107)	3.77	9.91	–
All Sites	All	2.45	5.72	7.23	–

[a]From regression equation.
[b]95% confidence interval.
[c]Net scale volume: includes all delay time.
[d]Owning, operating, and labor cost was $37.02/hr at all sites.
[e]Values for the LTO treatment were calculated by using a weighted average of 65% "light-between" and 35% "openings", based on volume removed from each area.
[f]Values for the LTO treatment were calculated by using a weighted average of 67% "light-between" and 33% "openings", based on volume removed from each area.

Table 14. Yarding and loading production rates and costs in the light thin (LT), light thin with openings (LTO), heavy thin (HT), and all treatments at each site. Costs of road and landing changes (Table 8) are not included.

Site	Treatment	Delay-free cycle time[a] (min)(CI)[b]	Production rate[c] (CCF/hr)	Cost[d] ($/CCF)	Cost change over LT (%)
Walk Thin	All	4.90 (0.024)	4.75	46.82	–
	LT	5.37 (0.024)	4.33	51.02	–
	LTO[e]	4.86 (0.024)	4.79	46.39	(9.1)
	HT	4.46 (0.024)	5.13	43.04	(15.7)
Tap Thin	All	4.05 (0.18)	6.03	45.60	–
	LT	4.14 (0.18)	6.16	44.63	–
	LTO[f]	3.87 (0.18)	6.17	44.58	(0.1)
	HT	4.14 (0.18)	5.77	47.58	6.7
Mill Thin	HT	4.28 (0.025)	6.43	38.48	–
All Sites	All	4.41	5.74	43.63	

[a]From regression equation.
[b]95% confidence interval.
[c]Net scale volume: includes all delay time.
[d]Owning, operating, and labor cost was $218.62/hr at Walk Thin, $271.97/hr at Tap Thin, and $244.88/hr at Mill Thin.
[e]Values for the LTO treatment were calculated by using a weighted average of 65% "light-between" and 35% "openings", based on volume removed from each area.
[f]Values for the LTO treatment were calculated by using a weighted average of 67% "light-between" and 33% "openings", based on volume removed from each area.

Table 15. Total harvesting costs in the light thin (LT), light thin with openings (LTO), heavy thin (HT), and all treatments at each site.

		Cost ($/CCF)					
Site	Treatment	Felling	Yarding & loading	Road/landing change	Move-in/ move-out	Total	Cost change over LT (%)
Walk Thin	All	4.65	46.82	6.12	0.50	58.08	–
	LT	4.66	51.02	6.12	0.50	62.30	–
	LTO	4.42	46.39	6.12	0.50	57.43	(7.8)
	HT	4.86	43.04	6.12	0.50	54.52	(12.5)
Tap Thin	All	7.14	45.60	10.63	0.78	64.15	–
	LT	6.09	44.63	10.63	0.78	62.13	–
	LTO	7.70	44.58	10.63	0.78	63.69	2.5
	HT	7.64	47.58	10.63	0.78	66.63	7.2
Mill Thin	HT	9.91	38.48	15.09	0.78	64.26	–
All Sites	All	7.23	43.63	10.61	0.69	62.16	–

Average yarding and loading costs ranged from $38.48 at Mill Thin to $46.82 at Walk Thin, with costs at Tap Thin nearly as much as Walk Thin (Table 14). Tap Thin had the shortest delay-free cycle time, followed closely by Mill Thin (Table 14). Yarding delays were substantially longer at Mill Thin than at the other two sites (Table 7). However, total volume per turn was highest at Mill Thin (Table 10), and average yarding distance was shorter, resulting in a higher production rate and lower yarding and loading costs than at the other two sites.

The decrease in yarding production rates as yarding distances increased varied among the sites (Figure 5). The minimum decrease was 12% at Mill Thin, over a distance of 800 ft; the maximum decrease was 55% at Tap Thin, over a distance of 1,000 ft.

Costs of road and landing changes incurred with the Madill 071 yarder used at Mill Thin averaged 1.5–2.4 times higher than those with the Koller K501 yarder used at Tap Thin and Walk Thin (Table 8). Only 5% of the skyline roads were pre-rigged at Mill Thin, whereas 95% were pre-rigged at Tap Thin.

Differences in total harvesting costs among the sites were relatively small, ranging from an average of $58.08/CCF at Walk Thin to $64.26/CCF at Mill Thin (Table 15). Road and landing changes (17% of costs) had a larger impact on the total harvesting cost than did felling (12%). Yarding and loading averaged 70% of the total cost.

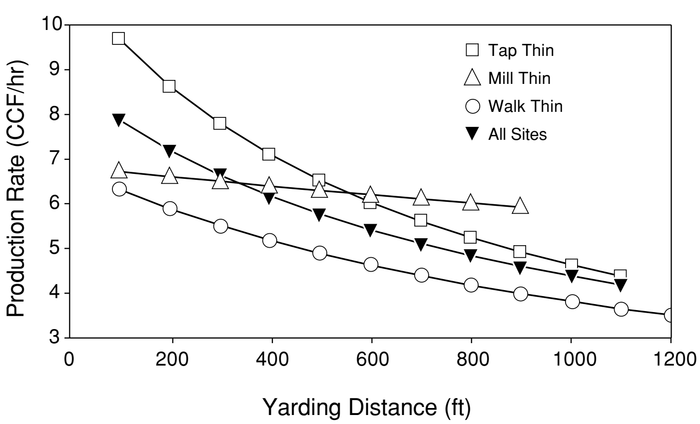

Figure 5. Yarding production rate by yarding distance for each site.

Discussion

Except for the HT yarding cycle at Tap Thin, the delay-free felling and yarding cycle times for the HT and LTO treatments differed significantly from those for the LT treatment at Walk Thin and Tap Thin. However, these differences did not follow any consistent relationship to type of silvicultural treatment: no treatment consistently had the shortest or longest cycle time (Tables 13, 14). In a similar study (Kellogg et al. 1996b), delay-free felling time increased as the number of residual trees increased; as thinning intensity increased, both felling and yarding production rates increased, and costs decreased. The initial stocking levels were similar within a site, so the silvicultural treatment corresponded to the volume harvested. In our study, the initial stocking levels varied among treatments within a site; thus, the silvicultural treatment did not necessarily correspond to the volume harvested (Table 2), resulting in no consistent influence of silvicultural treatment on production rates and costs.

The option to process the trees as either log-length or top-attached affected felling costs among the sites. Even though the average DBH was largest at Mill Thin, felling cost there was 68% higher than the combined average of Walk Thin and Tap Thin. Log-length processing, the highest standard, was used at Mill Thin, whereas top-attached processing was used at the other sites. In another study (Putnam et al. 1984), log-length processing in the field increased felling costs by an average of 42% over leaving the top attached to the last log.

"Limb and measure", which accounted for the most delay-free cycle time at all three sites, provides the greatest opportunity to reduce felling costs. The number of limbs cut was a very good indicator of time spent limbing and measuring. The mechanical delimber used on the landing at Walk Thin allowed the fallers to spend virtually no time limbing, which resulted in an average 35% decrease in felling costs relative to those at Tap Thin.

The operational decision of whether to preset turns affected delay-free yarding cycle times as much as or more than treatment differences within sites. The rigging crew preset chokers for only 18% of the turns at Walk Thin, compared with 89% at Tap Thin. An additional rigging member at Tap Thin contributed to the higher percentage of preset turns. The two-person rigging crew at Mill Thin preset chokers in 52% of the turns, even though they had less time between turns (cycles) to preset. This disparity was caused by a contrast in rigging philosophies, crew motivation, and knowledge.

The Mill Thin operation had the highest machine cost (Appendix, Tables A2–A4) and the most yarding delays, factors that increase yarding cost. However, it averaged the lowest yarding cost because of factors attributable to site conditions: highest average volume per turn (Table 10) and an average yarding distance 200 feet less than those on the other sites. When yarding costs were calculated using a sensitivity analysis that standardized yarding distance, volume per turn, and presetting among the sites, costs were lowest at Walk Thin and highest at Mill Thin.

Even though actual yarding costs were highest at Walk Thin, average total harvesting cost was lower there than at Tap Thin and Mill Thin. The combination of lower felling and road and landing change costs more than offset the higher yarding costs over Tap Thin and Mill Thin.

Conclusions

The three types of silvicultural treatments studied had no consistent influence on skyline production rates and costs, because the initial stocking levels varied among treatments and the volume harvested did not necessarily correspond to the silvicultural treatment. As part of a larger, multi-disciplinary project, these factors were not within our control.

Cost differences within sites, where operational methods were uniform, were small. Cost differences among sites for each activity, such as felling or yarding, were larger because of differences in operational methods. The combination of a lower processing standard and use of a delimber reduced felling costs at Walk Thin by more than 50% relative to Mill Thin. The seven-person yarding crew at Tap Thin offset higher labor costs, compared with the five-person crew used at the other sites, by pre-rigging skyline roads and presetting more turns. Any mechanical or physical advantages the larger Madill 071 yarder used at Mill Thin held over the Koller K501 yarders were diminished by use of the Danebo MSP carriage with a haulback line, which resulted in more delays and longer road/landing change times, and by less planning of skyline corridors.

Differences in total harvesting costs among the sites were relatively small, ranging from an average of $58.08/CCF at Walk Thin to $64.26/CCF at Mill Thin. Road and landing changes (17% of costs) had a larger impact on the total harvesting cost than did felling (12%). Yarding and loading averaged 70% of the total cost. A favorable advantage in one activity, such as felling, often was offset by an unfavorable cost in another activity, such as road and landing changes, resulting in similar total costs among the sites.

This study provided a good sample of skyline harvesting costs over a range of site conditions, crew size, equipment, and logging methods. The cost differences were small enough, given the range of volumes harvested, that a land manager should choose the most appropriate silvicultural treatment to meet the landowner's objectives.

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Appendix: Hourly Owning, Operating, and Labor Costs

Table A1. Felling costs, applicable to all sites.

Item	Ownership	Operating	Labor[a]	Total
Stihl 044, 28-in. bar	$0.27	$1.31	$31.36	$32.94
Backup saw, used	0.18	0.00	0.00	0.18
Pickup, 1995 Chevrolet, 3/4 ton 4WD	1.76	1.68	0.00	3.44
Miscellaneous supplies	0.46	0.00	0.00	0.46
Total felling cost/hour for 1 cutter	**–**	**–**	**–**	**37.02**

[a]Cutter worked 6.0 hr/day, 40% fringe benefits included.

Table A2. Yarding and loading costs at Walk Thin.

Item[a]	Ownership	Operating	Labor	Total
Koller K501 trailer-mount yarder	$13.20	$11.10	$103.10[b]	$127.40
Eaglet mechanical slackpulling carriage	4.21	2.38	0.00	6.59
Thunderbird 634 Tract-mount loader	21.26	12.02	26.74[c]	60.02
Danzco PT-20 pull-thru delimber	3.19	1.78	0.00	4.97
Landing Cat (D7G), used	6.36	2.10	0.00	8.46
Talkie Tooter communicators	0.60	0.34	0.00	0.94
Fire truck, 1500 gal, used	0.41	0.08	0.00	0.49
Van, 1995 Ford (8 passenger)	2.31	1.65	0.00	3.96
Pickup, 1995 Chevrolet, 1-ton diesel, 4WD	2.42	1.36	0.00	3.78
Landing supplies	–	–	–	2.01
Total yarding and loading cost/hr	**–**	**–**	**–**	**$218.62**

[a]Landing cat and vehicles prorated over a 10-hr day.
[b]For a 4-person logging crew and 40% fringe benefits; based on 10 hr/day and 200 days/yr.
[c]Loader operator and 40% fringe benefits; based on 10 hr/day and 200 days/yr.

Table A3. Yarding and loading costs at Tap Thin.

Item[a]	Ownership	Operating	Labor	Total
Koller K501 trailer-mount yarder	$13.20	$11.10	$150.32[b]	$174.62
Eaglet mechanical slackpulling carriage	4.21	2.38	0.00	6.59
Koehring 6630 Tract-mount loader	24.32	12.74	26.74[c]	63.80
John Deere 540 B grapple skidder[d]	11.87	3.13	0.00	15.00
Talkie Tooter communicators	0.60	0.34	0.00	0.94
Fire truck, 1500 gal, used	0.41	0.08	0.00	0.49
Pickup, 1995 Chevrolet, 3/4 ton, crew cab, 4WD	2.76	2.09	0.00	4.85
Pickup, 1995 Ford, 1-ton diesel, 4WD	2.31	1.36	0.00	3.67
Landing supplies	–	–	–	2.01
Total yarding and loading cost/hr	**–**	**–**	**–**	**$271.97**

[a]Vehicles and skidder prorated over a 10-hr day.
[b]For a 6-person logging crew and 40% fringe benefits; based on 10 hr/day and 200 days/yr.
[c]Loader operator and 40% fringe benefits; based on 10 hr/day and 200 days/yr.
[d]Average use of 1 hr/day.

Table A4. Yarding and loading costs at Mill Thin.

Item[a]	Ownership	Operating	Labor	Total
Madill 071 yarder	$39.95	$24.67	$103.10[b]	$167.72
Danebo MSP carriage	2.23	0.00	0.00	2.23
Case 125B Tract-mount loader	22.79	12.38	26.74[c]	61.91
Talkie Tooter communicators	0.60	0.34	0.00	0.94
Fire truck, 1500 gal, used	0.41	0.08	0.00	0.49
Pickup, 1995 Chevrolet, 3/4 ton, extended cab, 4WD	2.89	1.84	0.00	4.73
Pickup, 1995 Chevrolet, 3/4 ton, crew cab, 4WD	2.76	2.09	0.00	4.85
Landing supplies	–	–	–	2.01
Total yarding and loading cost/hr	**–**	**–**	**–**	**244.88**

[a]Vehicles prorated over a 10-hr day.
[b]For a 4-person logging crew and 40% fringe benefits; based on 10 hr/day and 200 days/yr.
[b]Loader operator and 40% fringe benefits; based on 10 hr/day and 200 days/yr.

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