Logging Planning and Layout Costs for Thinning:

Experience from the Willamette Young Stand Project

by

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Abstract

Logging planning and layout costs were examined for commercial thinning of 40- to 50-yr-old stands of Douglas-fir on the Willamette National Forest in the Cascade Mountains of Oregon. The study consisted of four replications of three silvicultural treatments. Thinning involved three types of logging systems: mechanized cut-to-length (a combination of single-grip harvester and forwarder), tractor, and skyline. Data for the study came from two sources: activities completed by the Forest Service in preparing sales for bid, and the layout completed by the logging contractor after a contract was awarded. Planning and layout costs showed no consistent relationship to type of silvicultural treatment. Logging contractor layout costs showed a relationship to type of logging system: the mechanized system had the lowest layout cost, followed by the tractor systems, with the skyline systems having the highest costs.

Executive Summary

Logging planning and layout costs were examined for commercial thinning of 40- to 50-yr-old stands of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) on the Willamette National Forest in the Cascade Mountains of Oregon. The study consisted of four replications of three silvicultural treatments, in addition to a control unit at each site: 1) light thinning, leaving 100 to 110 residual trees per acre (tpa); 2) light thinning with small patch cuts (0.5-ac openings in 20% of the stand), followed by planting the patch cuts with a mixture of Douglas-fir, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western redcedar (*Thuja plicata* Donn ex D. Don); and 3) heavy thinning, leaving 50 to 55 residual tpa, followed by underplanting with a mixture of Douglas-fir, western hemlock, and western redcedar. Thinning involved three types of logging systems: mechanized cut-to-length (a combination of single-grip harvester and forwarder), tractor, and skyline.

Data for the study came from two sources: activities completed by the Forest Service in preparing sales for bid, and the layout completed by the logging contractor after a contract was awarded. The Forest Service recorded time spent on the following planning and layout components: reconnaissance planning (office and field); logging design; computer analysis; marking and traversing unit boundaries; flagging haul roads and landings; ground profile surveys (for skyline systems only); flagging harvester/forwarder trails, skid trails, and skyline corridors; marking leave trees and flagging patch perimeters; timber cruising; and preparing the sale contract, appraisal, and prospectus. The logging contractors recorded time spent laying out designated equipment trails and skyline corridors.

Because this was a large-scale study covering 800 ac spread across four thinning sales and three ranger districts, the work took place over several years. Most of the Forest Service planning and layout took place from November 1992 to November 1993. Logging contractor layout occurred as the units were logged, from November 1994 to April 1997.

Forest Service planning and layout costs (1994 dollar basis) varied widely among the four thinning sales studied, from \$50.68/ac (\$3.68/Mbf) to \$124.31/ac (\$14.48/Mbf). Logging contractor costs (1996 dollar basis) varied from an average of \$9.22/ac (\$0.65/Mbf) for the mechanized system to \$94.40/ac (\$12.39/Mbf) at one of the skyline thinning sales. Planning and layout costs showed no consistent relationship to type of silvicultural treatment.

For the Forest Service, the planning and layout activities that contributed the most to total costs were marking leave trees and flagging patch perimeters, preparing contracts, marking unit boundaries, travel, and timber cruising. The most expensive component, marking leave trees and flagging patch perimeters, was almost 40% of the cost. Components directly related to type of logging system accounted for only 7% of the total cost.

Logging contractor layout time and costs varied with type of logging system. The mechanized system had the lowest layout cost, followed by the tractor systems, with the skyline systems having the highest costs.

Site characteristics can affect planning and layout costs; although they were not quantified for this study, they affect how quickly on-the-ground work can proceed. Important site characteristics may include topography, amount of

understory vegetation, tree density, harvest volume per acre, number and size of riparian areas, and amount of boundary to be marked relative to unit size. In addition, worker or crew experience affects planning and layout time and costs.

Introduction

Young stands are an important component of the forested landscape of the Pacific Northwest. These stands, occurring west of the Cascade Mountains in Oregon and Washington, are generally younger than 50 yr old and are dominated by planted Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). In Oregon, trees less than 16 in. diameter at breast height are expected to account for about 21% of the total westside harvest for all landowners between 1991 and 2000, increasing to about 33% over the next nine decades (Sessions et al. 1991).

In the past, the goal in managing these forests was to maximize timber production. More recently, management objectives have shifted to include increasing the structural and biological diversity of these stands and accelerating the development of late-successional habitat. Because these management objectives are relatively new, little information based on field studies is available to guide managers toward accomplishing these objectives.

In order to fill part of this information gap, a large-scale integrated study called the "Young Stand Thinning and Diversity Project" was undertaken on the Willamette National Forest. Participants in the study include scientists from the Cascade Center for Ecosystem Management, Willamette National Forest, Oregon State University, University of Oregon, and the USDA Forest Service Pacific Northwest Research Station. The overall objective of the study is to provide an ecological and managerial basis for future management of forests west of the Cascades.

The study will determine whether different thinning, underplanting, and snag creation treatments can accelerate the development of late-successional habitat and increase plant and wildlife habitat diversity in 40- to 50-yr-old Douglas-fir plantations. The study also looks for ways to minimize soil and water impacts from harvesting and maximize economic efficiency.

Major aspects of the study include effects of silvicultural treatments on wildlife, vegetation, harvesting, nutrient cycling, and mushroom productivity, as well as public reaction to the different thinning treatments. In addition, the effects of three different logging systems are being studied.

The harvesting portion of the study has four parts: planning and layout costs; harvesting production and cost; residual stand damage; and soil disturbance and compaction. This paper presents results from the planning and layout portion of the harvesting study.

Within the Forest Service, the forest resource planning process includes such elements as preparation of an overall land-use plan, field identification of areas suitable for accomplishing management objectives, and environmental analysis of proposed projects by an interdisciplinary team of resource specialists. Our study covered the implementation of thinning sales after they were approved; it should not be confused with the resource planning process. Specifically, our study included the field and office work done by the Forest Service to prepare selected thinning sales to be advertised for contract bid. In addition, we studied logging layout requirements completed by the logging contractor after a contract was awarded.

Past studies have shown that logging planning and layout costs are higher for partial cuts than for clearcuts. In one study, layout for two-story and group-selection treatments (0.5-ac openings) took 2 to 5 times longer (in hr/ac) than clearcut layout, largely because of the detailed skid trail and skyline corridor planning required (Kellogg et al. 1991). In another study comparing skyline harvesting of five group-selection treatments (small patch cuts 0.5 to 3 ac) and clearcutting, planning and layout took 4 to 7 times longer (in hr/ac) for the group-selection treatments than for clearcutting (Kellogg et al. 1996). Both studies emphasized the importance of proper planning and layout for efficient harvesting operations.

Another study investigated using a single-grip harvester and small cable yarder to thin and salvage log a stand on flat terrain (Brown and Kellogg 1996). Skyline corridors were flagged prior to logging, and potential intermediate support trees and tailtrees were marked to ensure that they were not removed by the single-grip harvester operator. Proper layout for the yarding operation allowed good coordination between felling and cable yarding contractors. For example, the harvester operator was better able to position logs for yarding because the locations of skyline corridors were marked on the ground. Careful layout was considered to be essential for achieving productive operations in the thinning and salvage logging prescription.

The current study of logging planning and layout requirements for the Young Stand Thinning and Diversity Project examines planning and layout time and costs over a range of silvicultural treatments, logging systems, and site conditions. The objectives of the study were to determine the following:

1. the Forest Service's time and costs for planning and layout of the thinning sales; and
2. the logging contractors' time and cost for layout of harvester/forwarder trails, skid trails, and skyline corridors.

Methods

Study Sites and Treatments

The study sites are located on the Willamette National Forest on the west side of the Cascade Mountains in Lane County, Oregon. All of the sites are 40- to 50-yr-old planted Douglas-fir stands. The overall study design consists of four replications of four silvicultural treatments:

1. Control (no thinning), with approximately 250 trees per acre (tpa). (Since no harvesting was done in the control units, however, they were not part of this study.)
2. Light thinning, leaving 100 to 110 residual tpa.

3. Light thinning with small patch cuts (0.5-ac openings in 20% of the stand). After logging, the patch cuts were planted with a mixture of Douglas-fir, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western redcedar (*Thuja plicata* Donn ex D. Don).
4. Heavy thinning, leaving 50 to 55 residual tpa, followed by underplanting with a mixture of Douglas-fir, western hemlock, and western redcedar.

The sites include units from five thinning sales on three ranger districts (Oakridge, McKenzie, and Blue River). Mill Thin on the McKenzie Ranger District was administered as two sales, Mill Thin 1 and Mill Thin 2, but for simplicity it will be referred to as one sale here. At Walk Thin, two separate units received the patch treatment. Table 1 summarizes basic information about the thinning sales for the units included.

Table 1. Summary information for thinning sales.

Sale name (Ranger District)	Treatment	Unit #	Logging system	Area (ac)	Harvest volume[a] (Mbf)	Harvest volume[a] (Mbf/ac)
Flat Thin (Oakridge)	Light	84	Mechanized	79	1000	12.7
	Patch	82	Mechanized	96	1300	13.5
	Heavy	81	Mechanized	50	800	16.0
	All	84, 82,81	Mechanized	225	3100	13.8
Mill Thin (McKenzie)	Light	1	Tractor	80	810	10.1
			Skyline	12	121	10.1
	Patch	4	Tractor	49	623	12.7
	Heavy	2	Tractor	17	193	11.4
			Skyline	69	772	11.2
	All	1, 4, 2	Tractor and Skyline	227	2519	11.1
Walk Thin (Oakridge)	Light	85	Skyline	55	394	7.2
	Patch 1	89	Skyline	40	262	6.6
	Patch 2	86	Skyline	35	399	11.4
	Heavy	88	Skyline	47	445	9.5
	All	85, 89, 86, 88	Skyline	177	1500	8.5
Tap Thin (Blue River)	Light	3	Tractor	33	320	9.7
			Skyline	60	580	9.7
	Patch	4	Tractor	4	30	7.5
			Skyline	32	270	8.4
	Heavy	1	Tractor	29	192	6.6
			Skyline	19	128	6.7
	All	3, 4, 1	Tractor and Skyline	177	1520	8.6

[a]Cruise estimate of harvest volume. Does not include volume removed from landings, corridors, and equipment trails.

Logging Systems

Three types of logging systems were used for the thinning: mechanized cut-to-length (a combination of single-grip harvester and forwarder), tractor, and skyline. For the tractor and skyline systems, trees were manually felled with chainsaws. On Mill Thin and Tap Thin, both tractor and skyline systems were used within the same units. The logging system for each unit is listed in Table 1, and examples of the equipment used are shown in Figures 1–4. The equipment and crew size for each thinning sale are described below.

Flat Thin

Mechanized system:

- Harvester: 2618 Timberjack (track-mounted)
  - South Fork Squirt Boom
  - Waterous 762b hydraulic harvesting head
- Forwarder: 1210 Timberjack (8-wheel bogie drive)

Approximately 60% of the area was harvested with 2 pairs of harvesters and forwarders and a 4-person crew (2 harvester operators and 2 forwarder operators). The remainder of the area used one harvester/forwarder pair and a 2-person crew (harvester operator and forwarder operator).

The harvesters and forwarders used designated equipment trails.

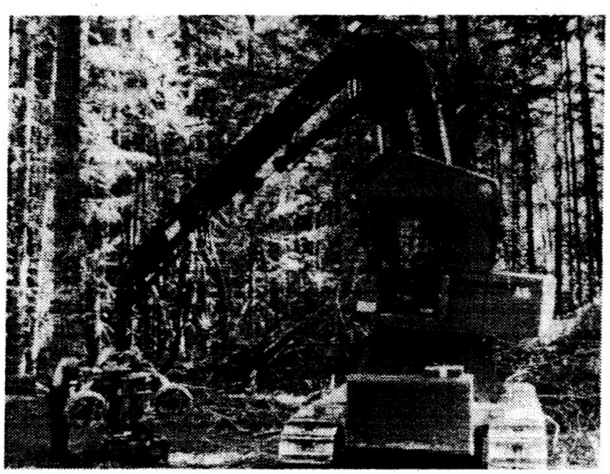

Figure 1. 2618 Timberjack harvester at Flat Thin.

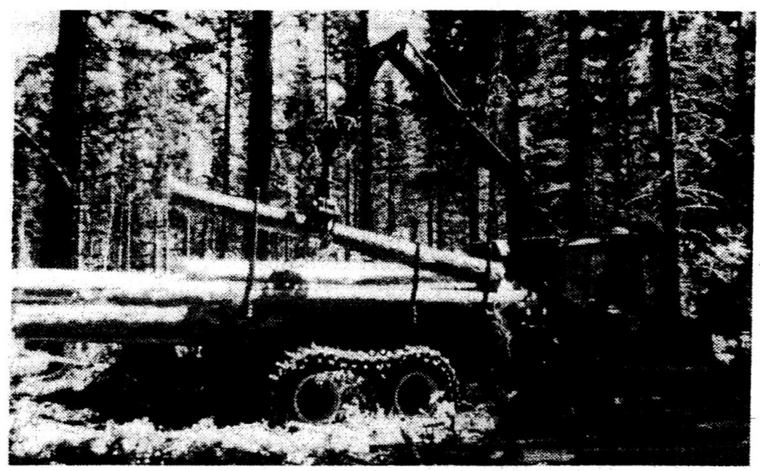

Figure 2. 1210 Timberjack forwarder at Flat Thin.

Mill Thin

Tractor system:

Equipment used for the tractor system varied slightly for each unit, depending on the contractor and size of unit. All tractors used designated skid trails.

Unit 1 (Light Treatment):

- Two Case 550 crawler tractors
- D-5 Caterpillar crawler tractor

Figure 3. Case 850G tractor at Mill Thin.

- Case 125B track-mounted loader
- 5-person crew (3 tractor operators, loader operator, and chaser)

Unit 4 (Patch Treatment):

- Two Case 850G crawler tractors
- 3-person crew (2 tractor operators and chaser)
- Self-loader log trucks

Unit 2 (Heavy Treatment):

- Case 550 crawler tractor
- Case 125B track-mounted loader
- 3-person crew (tractor operator, loader operator, and chaser)

Skyline system:

- Madill 071 mobile 4-drum yarder
- Danebo mechanical slackpulling carriage
- Case 125B track-mounted loader
- 5-person crew (hooktender, yarder engineer, loader operator, rigging slinger, and chaser)
- Standing skyline, primarily uphill yarding with a haulback line used for outhaul. Layout was a mixture of fan and parallel skyline corridors.

Walk Thin

Skyline system:

- Koller K501 trailer-mounted 3-drum yarder
- Eaglet mechanical slackpulling carriage
- Thunderbird 634 track-mounted loader
- 5-person crew (hooktender, yarder engineer, loader operator, rigging slinger, and chaser)
- Standing skyline, primarily uphill yarding with gravity outhaul; multispan capability with intermediate supports used on 16% of skyline corridors. Layout was approximately 60% fan-shaped skyline corridors and 40% parallel skyline corridors.

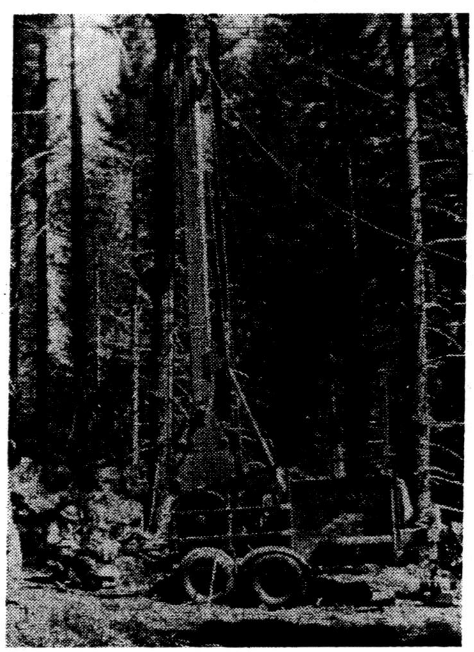

Figure 4. Koller K501 yarder at Tap Thin.

Tap Thin

Tractor system:

Designated skid trails were used for the tractor logging.

Unit 3 (Light Treatment):

- John Deere 550 crawler tractor
- Koehring 6630 track-mounted loader
- 3-person crew (tractor operator, loader operator, and chaser)

Units 4 and 1 (Patch and Heavy Treatments):

- Two John Deere 550 crawler tractors
- Koehring 6630 track-mounted loader
- 4-person crew (2 tractor operators, loader operator, and chaser)

Skyline system:

- Koller K501 trailer-mounted 3-drum yarder
- Eaglet mechanical slackpulling carriage
- Koehring 266L track-mounted loader
- 7-person crew (hooktender, yarder engineer, loader operator, rigging slinger, 2 choker setters, and chaser)
- Standing skyline, primarily uphill yarding with gravity outhaul; multispan with intermediate supports used on 60% of skyline corridors. Layout was approximately 65% fan-shaped skyline corridors and 35% parallel skyline corridors.

Data Collection Procedures

Data collected for the logging planning and layout study came from two sources: activities completed by the Forest Service in preparing sales for bid, and the layout completed by the logging contractor after a contract was awarded. Since this was a large-scale study covering 800 ac spread across four thinning sales and three ranger districts, the work took place over several years. Most of the Forest Service planning and layout took place from November 1992 to November 1993. Logging contractor layout occurred as the units were logged, from November 1994 to April 1997.

The planning and layout process for the Forest Service was divided into the components listed in Table 2, and each activity was assigned a code number. Forest Service personnel working on the thinning sales used a form to record date, unit number, activity code, work time, travel time, number of people, and comments. Work and travel time were recorded to the nearest 0.25 hr for each unit. When two logging systems were used in the same unit (as on Mill Thin and Tap Thin), planning and layout activities were recorded for the unit as a whole and not segregated by logging system. Forest Service planning and layout activities and data collection ended for each sale when the contract was prepared and the sale was advertised for bid.

Table 2. Logging planning and layout components recorded by the Forest Service and average hourly labor costs in 1994 dollars (includes fringe benefits).

Code	Planning and layout component	Average cost ($/hr)
10	Reconnaissance planning, maps, photos	18.50
20	Logging design, feasibility, costs, etc.	20.05
30	Computer analysis (e.g., LoggerPC)	20.05
40	Marking unit boundaries (includes flagging boundaries, posting signs, traversing, and painting trees)	18.42
50	Flagging haul roads and landings	19.33
60	Ground profile surveys	18.70
70	Flagging harvester/forwarder trails, skidding trails, skyline corridors	21.62
80	Marking leave trees and flagging patch perimeters	14.88
85	Timber cruising	16.18
90	Preparing contract (includes contract, appraisal, and prospectus)	18.71
100	Miscellaneous	17.33
110	Travel time (round trip from office)	*

*Based on labor cost for the planning and layout component related to the travel.

The Forest Service ranger districts provided information on hourly labor costs in 1994 dollars (including fringe benefits) for personnel who worked on each planning and layout component. The labor cost for a particular planning or layout component varied among the three ranger districts, depending on the wage level of the person who did the work. In order to evenly compare costs among the sales, an average labor cost based on all three ranger districts was used for all Forest Service cost calculations (Table 2).

Logging contractors recorded time spent laying out skyline corridors and designated equipment trails on forms provided to them. When two logging systems were used within a unit, separate layout times were recorded for each logging system. Layout time was recorded to the nearest 0.5 hr. Layout costs (in $/ac and $/Mbf) were calculated from an approximate wage (based on 1996 dollars) for an appropriate crew member to do the layout work for each type of logging system, multiplied by 1.4 to include fringe benefits. Travel was not considered to be an extra expense because the layout was usually done while workers were on site for other harvesting work. However, at Walk Thin a subcontractor completed the skyline layout, and the hourly cost included all expenses such as travel and fringe benefits. The same hourly cost was used for the skyline layout work at Tap Thin.

Forest Service Planning and Layout Procedures

In general, the three ranger districts used similar procedures for planning and laying out the thinning sales; there was a certain amount of freedom concerning the order and amount of work for each component. The general procedure was reconnaissance planning (office and field); logging design; marking and traversing unit boundaries; flagging haul roads and landings; ground profile surveys (for skyline systems only); computer analysis; marking leave trees and flagging patch perimeters; timber cruising; and preparing the sale contract, appraisal, and prospectus.

If haul roads already existed in the sale area, flagging haul roads was not necessary. In addition, landings were often chosen by the contractor, with Forest Service approval. Flagging skyline corridors and equipment trails was generally completed by the logging contractor (with Forest Service approval), but it was sometimes done by the Forest Service when a sensitive area such as a riparian site was involved.

The patch treatment involved 0.5-ac patch cuts covering 20% of the unit, with light thinning (100–110 residual tpa) between patches. To lay out the treatment, the perimeters of the 0.5-ac patches were flagged so that all trees inside were cut during harvesting, and the leave trees for the light thinning between patches were marked. Together, the patches and the light thinning between them were regarded as one silvicultural treatment within a single unit, rather than separate 0.5-ac "clearcut" units within a sale.

Because the patch treatment procedure had not been previously established, there was some variation in how the ranger districts laid out the 0.5-ac patches. At Flat Thin, a few squares and rectangles were used on the first unit (unit 82), and then circles were used. Circles were laid out in a systematic grid on a map of the unit and located in the field by using traverse points and a compass. A tape was used to measure the radius of the circle in four directions. Patch location was adjusted in the field as needed in order to avoid riparian areas or groups of hardwood trees. At Mill Thin, the patches were somewhat variable and located along skid trails. Circles were used at Walk Thin and Tap Thin, following the same procedure as at Flat Thin.

Designation of riparian areas in the planning and layout procedures differed among sales. At Mill Thin, leave trees were marked to designate the riparian areas; at Tap Thin, the boundaries of riparian areas were marked, thus dividing each unit into two to seven subunits.

The main difference in procedures for the different logging systems was that ground profile surveys and associated computer analysis were needed for determining logging feasibility for the skyline system but not for the other two logging systems.

Logging Contractor Layout Procedures

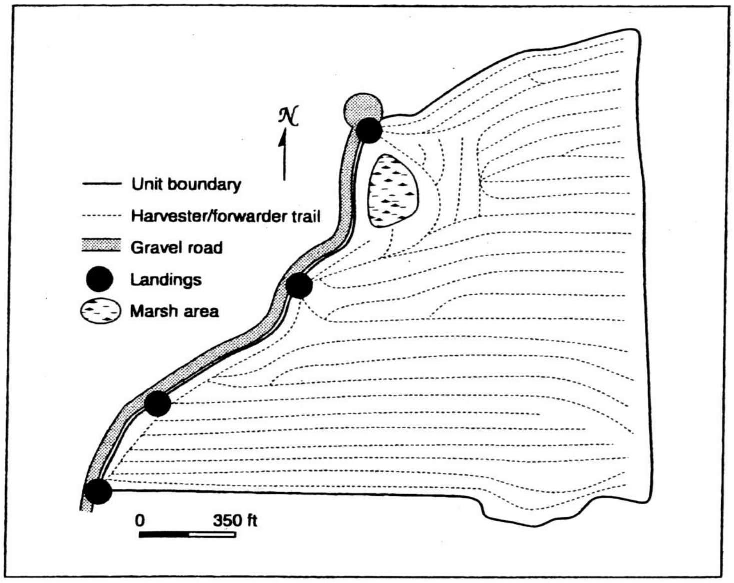

Figure 5. Example of harvester/forwarder trail layout (Flat Thin, unit 81, heavy treatment). Forwarder travel was flat to slightly downhill to the landings.

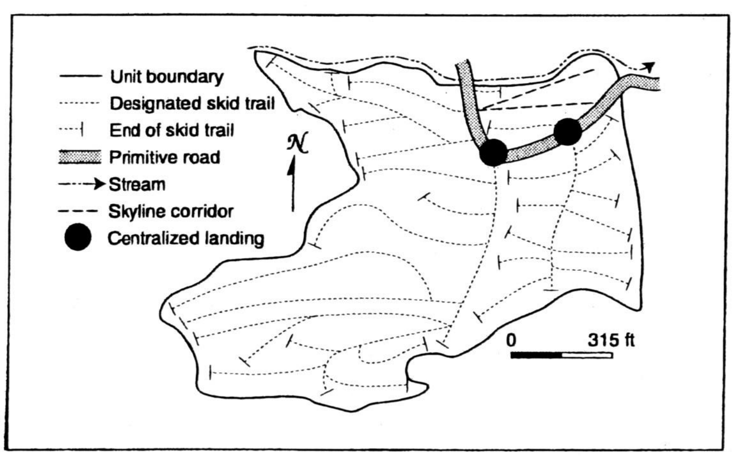

Figure 6. Example of skid trail layout (Tap Thin, unit 3f, light treatment). Skidding was generally downhill to the main skid trails and flat along the main skid trails to the landings.

It was the logging contractors' responsibility to lay out harvester/forwarder trails, skid trails, and skyline corridors, with approval from the Forest Service.

For the mechanized harvesting at Flat Thin, the Forest Service allowed logging to proceed on the first 30 ac (unit 82) without designated trails but then decided designated trails should be used on the remainder of the sale. The logging contractor laid out the trails with Forest Service approval prior to harvester operations. The trails were spaced approximately 60 ft apart, generally in a parallel pattern. The forwarder traveled over the same trails. An example of layout with designated harvester/forwarder trails is shown in Figure 5.

Designated skid trails for tractor logging were laid out by the tractor operators at Mill Thin and by the owner of the logging company at Tap Thin. Layout took place prior to any felling and was approved by the Forest Service. The trails were spaced approximately 120 ft apart in a mixture of parallel and branching patterns. Old skid trails were identified and used as much as possible. An example of skid trail layout is shown in Figure 6.

At Mill Thin, the Forest Service allowed the skyline corridors to be put in during yarding by the logging contractor without advance planning. At Walk Thin, a subcontractor was hired by the logging contractor to plan and mark the skyline corridors. At Tap Thin, the owner of the logging company planned and marked the skyline corridors. For both of these sales, skyline corridors were flagged prior to felling, with Forest Service approval. An example of skyline corridor layout, with both fan-shaped and parallel skyline corridors from landings, is shown in Figure 7.

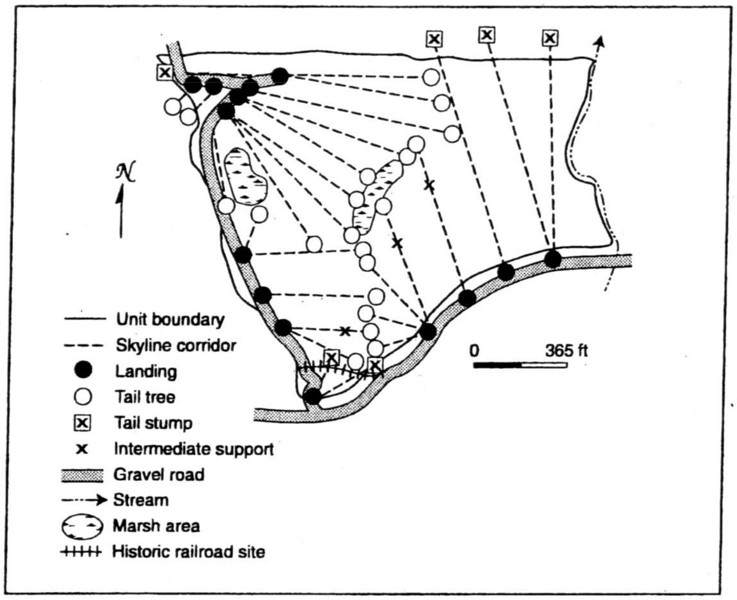

Figure 7. Example of skyline corridor layout (Walk Thin, unit 89, patch treatment). Yarding was uphill to the landings.

Results

Forest Service Planning and Layout Costs

Table 3. Summary of Forest Service planning and layout costs by sale (all treatments averaged together).

Sale (Logging system)	Hr/ac	$/ac	$/Mbf
Flat Thin (Mechanized)	3.18	50.68	3.68
Mill Thin (Tractor/Skyline)	3.75	63.30	5.70
Walk Thin (Skyline)	4.25	69.27	8.17
Tap Thin (Tractor/Skyline)	7.28	124.31	14.48
Average	4.62	76.89	8.01

When planning and layout time and costs were averaged for all treatments, costs ranged from $50.68/ac ($3.68/Mbf) at Flat Thin to $124.31/ac ($14.48/Mbf) at Tap Thin (Table 3).

For all sales averaged, the light treatment was the least expensive, followed by the patch and heavy treatments (Table 4). Although the heavy treatment was the most expensive, the patch treatment was nearly as costly.

When time and costs were broken down by treatment for each sale, Flat Thin and Tap Thin (Table 5, Figure 8) showed the same relative order as the overall average for all the sales (Table 4), with the light treatment the least expensive, followed by the patch treatment, and then the heavy treatment. (See Table 1 for Mbf/ac for each unit.) Mill Thin and Walk Thin, on the other hand, did not follow the overall trend. At Mill Thin, the light treatment was least expensive, followed by the heavy treatment; the patch treatment had the highest cost. At Walk Thin, the heavy treatment was the least expensive, with the light treatment next and the patch treatment the most expensive.

Table 4. Summary of Forest Service planning and layout costs by treatment (all sales averaged together).

Treatment	Hr/ac	$/ac	$/Mbf
Light	3.82	63.45	6.88
Patch	5.20	86.93	9.09
Heavy	5.30	88.54	10.18

Table 5. Forest Service planning and layout time and cost for each treatment, by sale.

Sale (Logging system)	Treatment	Hr/ac	$/ac	$/Mbf
Flat Thin (Mechanized)	Light	2.55	41.31	3.26
	Patch	3.20	50.56	3.73
	Heavy	4.14	65.73	4.11
	Average	3.18	50.68	3.68
Mill Thin (Tractor/Skyline)	Light	2.56	42.86	4.24
	Patch	5.75	100.67	7.92
	Heavy	3.87	63.88	5.69
	Average	3.75	63.30	5.70
Walk Thin (Skyline)	Light	4.26	69.36	9.68
	Patch 1	4.39	70.32	10.74
	Patch 2	4.76	77.39	6.79
	Heavy	3.75	62.21	6.57
	Average	4.25	69.27	8.17
Tap Thin (Tractor/Skyline)	Light	5.90	100.28	10.36
	Patch	7.91	135.73	16.29
	Heavy	9.46	162.32	24.35
	Average	7.28	124.31	14.48

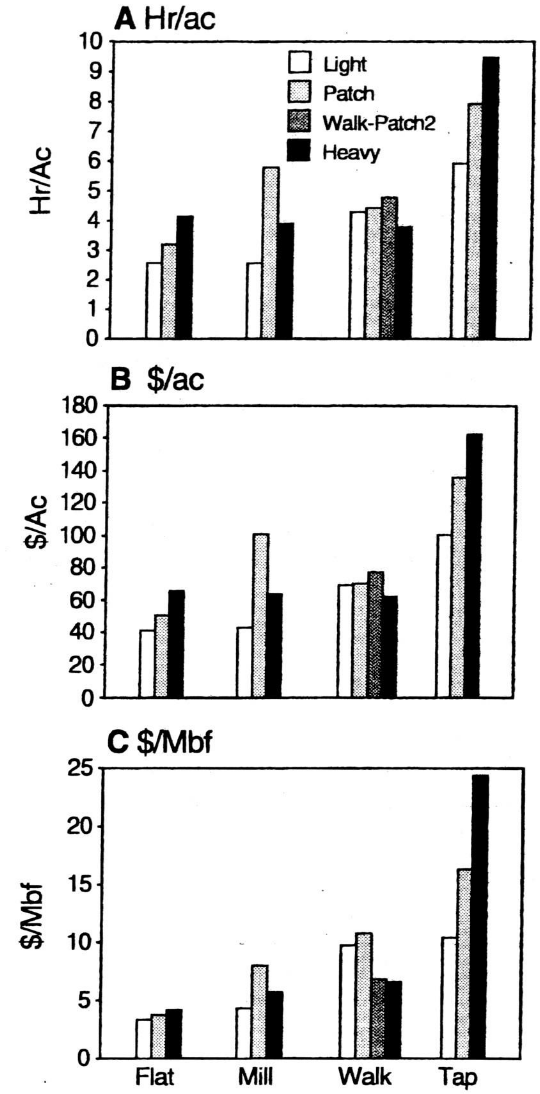

Figure 8. Time and cost of Forest Service planning and layout by treatment for each sale in A) hr/ac, B) $/ac, and C) $/Mbf.

Cost of Individual Forest Service Planning and Layout Components

When all sales were averaged, the five components that accounted for the highest percentage of costs were marking leave trees and flagging patch perimeters, preparing contracts, marking unit boundaries, travel, and timber cruising (Figure 9). These components made up 90.3% of the entire planning and layout cost. The most expensive component, marking leave trees and flagging patch perimeters, made up nearly 40% of the cost. Logging design, the sixth highest component, was only 3% of the cost. The components represented by "other" in the figure are ground profile surveys (1.7%), reconnaissance plan-

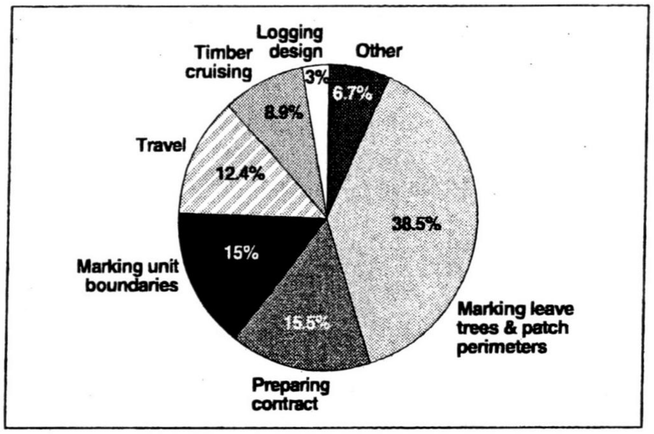

Figure 9. Percent cost of Forest Service planning and layout components, based on $/ac averaged for all thinning sales. (Refer to Table 2 for a more complete description of each component.)

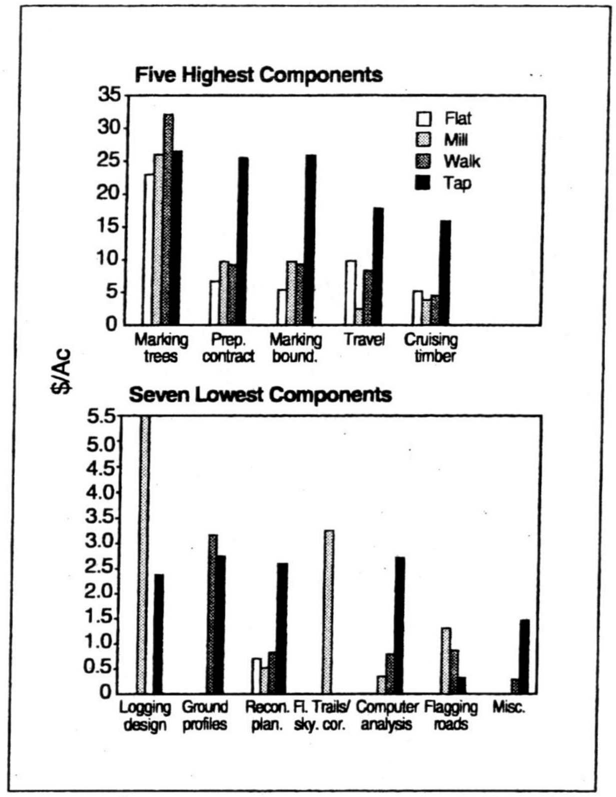

Figure 10. Cost ($/ac) of individual Forest Service planning and layout components for each sale, averaged for all treatments. Note: for some sales, no time was recorded for some components.

ning (1.4%), flagging trails/skyline corridors (1.3%), computer analysis (1.0%), flagging roads/landings (0.9%), and miscellaneous (0.4%).

In Figure 10, the costs of individual components are shown for each sale (averaged for all treatments). Results for the five most expensive components show how these components contributed the most to the high planning and layout costs at Tap Thin. Although the cost for marking trees at Tap Thin was similar to costs for other sales (and lower than for Walk Thin), the costs for preparing contracts, marking unit boundaries, travel, and timber cruising were all much higher at Tap Thin than at the other sales.

Detailed results for each planning and layout component by treatment for each sale (in $/ac) are displayed in Figure 11. Costs of preparing contracts were allocated equally to each unit of a sale (Figure 11B).

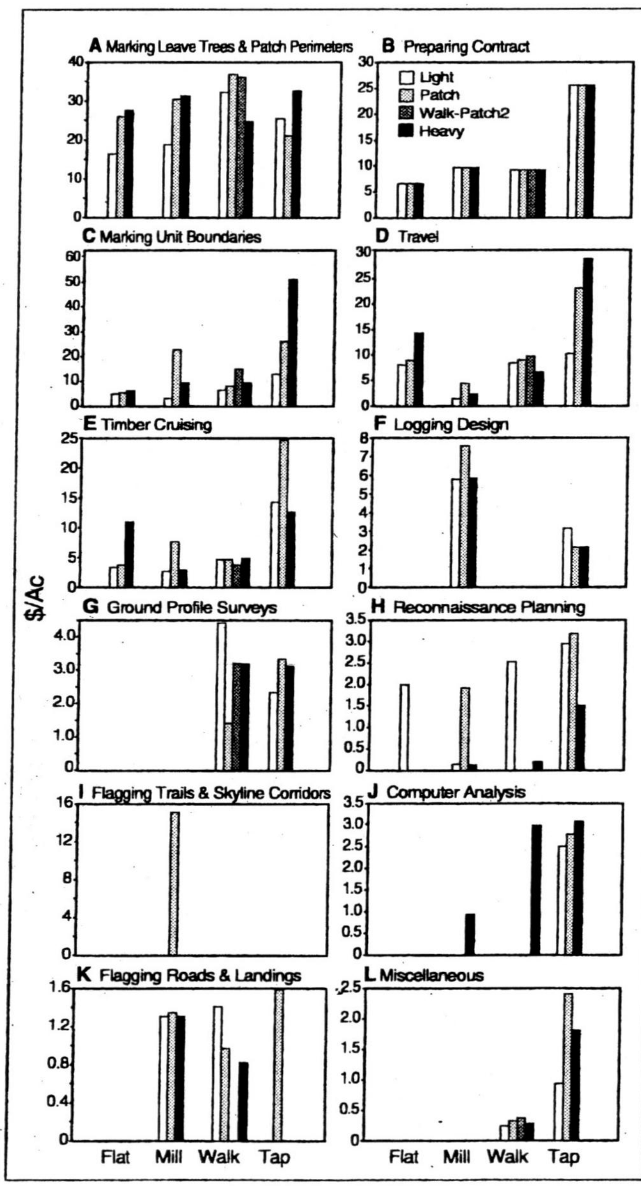

Figure 11. Cost ($/ac) of each Forest Service planning and layout component by treatment for each sale. Note: for some sales or treatments, no time was recorded for some components.

Logging Contractor Layout Time and Costs

Average layout time for logging contractors ranged from 0.5 hr/ac on Flat Thin (mechanized) to 3.1 hr/ac on Tap Thin (skyline) (Table 6, Figure 12). The average cost of layout ranged from $9.22/ac ($0.65/Mbf) on Flat Thin (mechanized) to $94.40/ac ($12.39/Mbf) on Tap Thin (skyline).

Table 6. Summary of logging contractor layout time and cost.

Sale (Logging system)	Treatment	Time (hr)	$/hr	Area (ac)[a]	Mbf/ac	Hr/ac	$/ac	$/Mbf
Flat Thin (Mechanized)	Light	26.0	20.09[b]	79	12.7	0.3	6.61	0.52
	Patch	29.5	20.09[b]	63	13.5	0.5	9.41	0.70
	Heavy	29.0	20.09[b]	50	16.0	0.6	11.65	0.73
	Average					0.5	9.22	0.65
Mill Thin (Tractor)	Light	44.5	17.85[c]	80	10.1	0.6	9.93	0.98
	Patch	15.0	17.85[c]	25	12.7	0.6	10.71	0.84
	Heavy	4.0	17.85[c]	6	11.4	0.7	11.90	1.04
	Average					0.6	10.85	0.96
Tap Thin (Tractor)	Light	23.5	17.85[c]	33	9.7	0.7	12.71	1.31
	Patch	11.0	17.85[c]	4	7.5	2.8	49.09	6.55
	Heavy	38.5	17.85[c]	29	6.6	1.3	23.70	3.59
	Average					1.6	28.50	3.82
Walk Thin (Skyline)	Light	76.0	30.00[d]	55	7.2	1.4	41.45	5.76
	Patch 1	36.0	30.00[d]	40	6.6	0.9	27.00	4.09
	Patch 2	50.0	30.00[d]	35	11.4	1.4	42.86	3.76
	Heavy	38.0	30.00[d]	47	9.5	0.8	24.26	2.55
	Average					1.1	33.89	4.04
Tap Thin (Skyline)	Light	52.5	30.00[e]	30	9.7	1.8	52.50	5.41
	Patch	94.5	30.00[e]	32	8.4	3.0	88.59	10.55
	Heavy	90.0	30.00[e]	19	6.7	4.7	142.11	21.21
	Average					3.1	94.40	12.39

[a]Size of area studied for logging contractor layout time; in several cases this was smaller than the total unit size.
[b]Harvester/forwarder operator; includes 40% fringe benefits.
[c]Tractor operator; includes 40% fringe benefits.
[d]Subcontractor cost; includes vehicle, equipment, fringe benefits, and travel time.
[e]Layout done by company owner; used same hourly cost as subcontractor for Walk Thin.

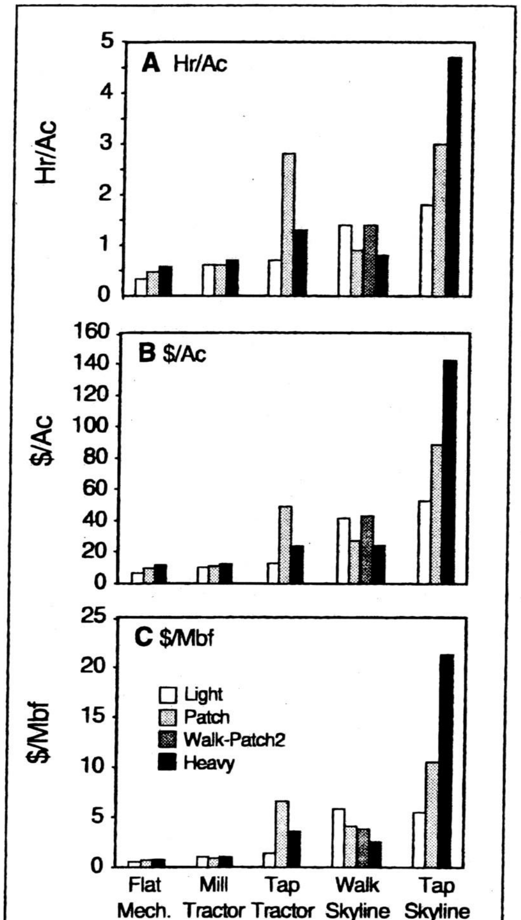

Figure 12. Logging contractor layout time and cost by treatment for each sale/logging system in A) hr/ac, B) $/ac, and C) $/Mbf.

Discussion

Effects of Silvicultural Treatment on Planning and Layout Costs

There was no consistent trend in the effect of silvicultural treatment on Forest Service planning and layout costs (Figure 8). Although Flat Thin and Tap Thin showed the same relative order, with the light treatment the least expensive and the heavy treatment the most, Mill Thin and Walk Thin did not follow this pattern.

Logically, marking trees should be the planning and layout component most directly affected by silvicultural treatment. Because only the leave trees were marked, the light treatment had the most trees marked, and the heavy treatment had the fewest. The patch treatment required marking trees for light thinning between patches and the extra step of designating the perimeter of the patches on 20% of the unit. However, individual trees inside patches were not marked.

One might therefore expect the patch treatment to be the most expensive for marking trees, with the heavy treatment the least expensive. However, on three out of four sales, marking trees in the heavy thinning was the most expensive in $/ac (Figure 11A). Walk Thin was the only sale that showed the "expected" outcome; at Tap Thin, the patch treatment was the least expensive. Clearly, other factors are more important than type of silvicultural treatment in influencing planning and layout costs under the conditions studied for the four sales.

Silvicultural treatment also showed no consistent effect on logging contractor layout time and costs (Figure 12).

Effects of Logging System on Planning and Layout Costs

Four of the twelve Forest Service planning and layout components are directly affected by the type of logging system: logging design, computer analysis, ground profile surveys, and flagging trails or skyline corridors. Two of these components—LoggerPC computer analysis of skyline corridors and ground profile surveys—are associated only with the skyline logging system. Because the sum of the four components was only 7% of the total Forest Service planning and layout costs, logging system had only a small effect on these costs for the sales we studied.

Figure 12 shows a general trend for the effect of logging systems on logging contractor layout time and costs. The mechanized system at Flat Thin had the lowest cost, followed by the tractor systems at Mill Thin and Tap Thin. The patch unit at Tap Thin had a higher cost per acre than the other tractor units because it was a small unit (4 ac) and had a centralized landing that required extra planning and layout work. The skyline systems at Walk Thin and Tap Thin had the highest costs. The skyline system at Mill Thin had no layout time because the skyline corridors were put in during logging without advance planning or analysis.

Other Factors Affecting Planning and Layout Costs

Site characteristics affect how quickly on-the-ground work can proceed. Forest Service (Figure 8) and logging contractor (Figure 12) layout times and costs for the same sites follow similar patterns. Even though the work was done by different people (Forest Service personnel and logging contractors), relative costs and the relative order of treatments were similar within a sale. These similarities seem to indicate that site characteristics had a consistent effect on planning and layout costs for the two groups.

Important site characteristics include topography (especially slope steepness), amount of understory vegetation, tree density, and number and size of riparian areas. Another factor is whether existing roads provide access to the sale area. If not, laying out the roads takes extra time; other tasks such as marking trees, timber cruising, and marking unit boundaries all take longer when workers need to walk before roads are constructed.

Harvest volume per acre also affects planning and layout costs, especially costs per unit volume. Two units may have the same overall costs per acre for planning and layout, but if one has more Mbf/ac, its cost in $/Mbf will be smaller. Flat Thin (13.8 Mbf/ac) and Mill Thin (11.1 Mbf/ac) had higher Mbf/ac volumes than Walk Thin (8.5 Mbf/ac) and Tap Thin (8.6 Mbf/ac) (Table 1), and they show smaller relative costs per Mbf (Figure 8C) compared with $/ac (Figure 8B) than the other two sites.

The amount of boundary to be marked for a unit relative to its total size is another factor affecting planning and layout costs. Traversing the units and marking boundaries takes less time when units in a sale share common boundaries. Marking the boundaries of subunits (for example, to protect riparian areas as on Tap Thin) also takes additional time. In order to examine the effects of boundary length, we divided the perimeter of each unit (from a traverse of the unit) by the area of the unit, yielding a perimeter/area ratio (Table 7). Flat Thin, which had the lowest costs per acre for marking unit boundaries (Figure 11C), also had the lowest perimeter/area ratio (Table 7), and Tap Thin, which had the highest costs, had the highest overall perimeter/area ratio.

Table 7. Perimeter/area ratios, based on traverse data.

Sale (Logging system)	Treatment	Perimeter (ft)	Area (ac)	Perimeter/ area (ft/ac)	Average for sale (ft/ac)
Flat Thin	Light	7,938.3	78.7	100.9	
(Mechanized)	Patch	8,169.4	96.1	85.0	101.1
	Heavy	6,712.8	50.9	131.8	
Mill Thin	Light	19,966.7	97.9	203.9	
(Tractor/	Patch	7,295.3	49.6	147.2	184.3
Skyline)	Heavy	16,793.5	91.6	183.3	
Walk Thin	Light	6,893.2	56.9	121.2	
(Skyline)	Patch 1	5,920.7	41.5	142.5	137.1
	Patch 2	5,219.0	34.7	150.6	
	Heavy	6,672.4	47.1	141.7	
Tap Thin	Light	29,922.5	92.6	323.2	
(Tractor/	Patch	8,293.2	35.9	230.9	294.9
Skyline)	Heavy	13,862.4	48.1	288.3	

This trend did not always apply to individual units within a sale. For example, on Tap Thin, the light treatment had the highest perimeter/area ratio but the lowest cost for boundary layout. So although the amount of boundary that needs to be marked affects boundary layout costs, this component is also affected by other factors, such as slope steepness and amount of understory vegetation.

Travel time, the fourth largest component comprising Forest Service planning and layout costs, is affected by distance from the office and quality of road access. Poor roads increase travel time, and lack of roads may mean workers must walk partway to sites. The number of times a unit must be visited also affects total travel time. Figure 11D shows travel costs ($/ac) based on travel time multiplied by a worker's labor costs. The graph correlates well with round trip travel times from the ranger district office preparing the sale, which were approximately 1.5 hr at Flat Thin, 20 min at Mill Thin, and 1 hr at Walk Thin. The units at Tap Thin were spread out over a larger area. Round trip travel was 1 hr to the light treatment unit and about 1.5 hr to the patch and heavy treatment units. In addition, a crew from Sweet Home helped prepare the heavy treatment unit, with a round trip travel time of 3.5 hr.

Worker or crew experience also affects planning and layout time and costs. For example, at Tap Thin the owner of the logging company planned and marked the skyline corridors, but he was just learning to do this work; the first unit (heavy treatment) took considerably longer than the other units. The average contractor layout time at Tap Thin was 3.1 hr/ac compared with 1.1 hr/ac at Walk Thin, where skyline corridor layout was completed by a subcontractor with more experience. A person's working style also affects time and job quality.

Conclusions

This study provides a sample of logging planning and layout costs over a range of silvicultural treatments, logging systems, and site conditions. Forest Service planning and layout costs varied widely among the four thinning sales, from $50.68/ac ($3.68/Mbf) at Flat Thin to $124.31/ac ($14.48/Mbf) at Tap Thin. Logging contractor costs varied from an average of $9.22/ac ($0.65/Mbf) for the mechanized system at Flat Thin to $94.40/ac ($12.39/Mbf) for the skyline system at Tap Thin. Planning and layout costs showed no consistent relationship to type of silvicultural treatment for either the Forest Service or the logging contractors.

The Forest Service planning and layout activities that contributed most to total costs were marking leave trees and flagging patch perimeters, preparing contracts, marking unit boundaries, travel, and timber cruising. The most expensive component, marking leave trees and flagging patch perimeters, was almost 40% of the Forest Service's cost. Components directly related to type of logging system accounted for only 7% of the total cost.

Logging contractor layout time and costs were related to type of logging system. The mechanized system had the lowest layout cost, followed by the tractor systems, and the skyline systems had the highest costs.

Site characteristics were not quantified for our study but are an important factor for planning and layout costs because they affect how quickly on-the-ground work can proceed. Important site characteristics may include topography, amount of understory vegetation, tree density, harvest volume per acre, number and size of riparian areas, and amount of boundary to be marked relative to unit size. In addition, worker or crew experience affects planning and layout time and costs.

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