LOGGING PLANNING, FELLING, AND YARDING COSTS IN FIVE ALTERNATIVE SKYLINE GROUP SELECTION HARVESTS

By

Richard M. Edwards

A PAPER
submitted to
Department of Forest Engineering
Oregon State University
Corvallis, Oregon 97331

in partial fulfillment of
the requirements for the
degree of

Master of Forestry

Completed 18 December 1992

Commencement June 1993

AN ABSTRACT OF THE PAPER OF

Richard M. Edwards for the degree of Master of Forestry in Forest Engineering presented 18 December 1992.

Title: Logging Planning, Felling, and Yarding Costs in Five Alternative Skyline Group Selection Harvests.

Abstract approved: Loren D. Kellogg

Loren D. Kellogg

Alternative silvicultural systems, such as group selections, have recently come into vogue in the U.S. Pacific Northwest in response to political and public pressure against traditional, even-aged silviculture. There is also interest in silvicultural systems for multiple resources. Little is known about planning logistics, operational requirements, and harvest costs for timber and site conditions of alternative silvicultural systems. Much of the terrain demands expensive cable logging systems requiring up-to-date production and cost information for harvest planning and administration.

This paper describes logging planning and harvest requirements, production, and cost results of an interdisciplinary experiment comparing alternative silvicultural systems for multiple resource management. The study was conducted in Oregon Coast Range, second growth timber using five types of group selection harvest setting designs. Skyline group selections were compared to a

clearcut. Group sizes ranged from 0.5 to 3 acres (0.20 to 1.21 hectares). Group shapes included rectangular to polygonal and wedge-shape, with parallel and fan shaped setting skyline road plans. Harvest units were assessed for their efficiencies and/or inadequacies for unit planning and layout, felling, and yarding production and cost.

In group selection units, total harvest costs increased from 7.3 to 31.5 percent over clearcutting. Patch size had the largest influence over total costs (i.e. larger size; lower cost). Total cost was also related to skyline setting road plan and shape. Harvest cost components were greater for group selection units than the clearcut.

Felling costs increased a minimal amount (0.4 to 2.6 percent) over clearcutting in most of the group selections because of the need for more directional tree wedging. However, standard yarding costs were estimated to be slightly lower than the clearcut (0.2 to 4.2 percent) in all group selections due to increased frequency of turn presetting. The wedge-shape group selection unit exhibited a 52 percent lower road change cost over the clearcut. Other group selection units were more costly (1.6 to 107.8 percent) than the clearcut road/landing change cost. The amount of timber volume removed was a key factor affecting the final yarding cost. Final yarding costs for all group selection units increased 3.4 to 26.0 percent over clearcutting.

Logging planning is the key to operationally efficient and cost effective group selection harvesting. Although such planning required 2.6 to 5.9 times more planning time and cost commitment as the clearcut, lack of such planning would cause other harvest costs to escalate as a result of increased operational difficulties.

APPROVED:

Dr. Loren D. Kellogg - Major Professor
Forest Engineering

Dr. William A. Atkinson - Department Head
Forest Engineering

Paper presented 18 December 1992

ACKNOWLEDGEMENTS

The planning and harvest data used in this study were collected during the third replication of an interdisciplinary alternative silvicultural systems research project conducted and funded by the Oregon State University (OSU) College of Forestry. Valuable assistance regarding silviculture and wildlife considerations was rendered throughout the project by interdisciplinary study members Carol Chambers, Dr. William C. McComb, and Dr. John Tappeiner. Staff members of the OSU Research Forest also provided help during all phases of the study. Personnel included: Marc Barnes, Pam Beebe, Debbie Cummings, Jeff Garver, Mike Rector, and Rick Schaefer.

Assistance during project design and unit layout was provided by OSU Department of Forest Engineering Research Assistants Pete Bettinger, who also worked extensively during the data collection phase of the study, and Steve Pilkerton. Brett Atkinson, a Forest Engineering Graduate Research Assistant (GRA) also helped during unit layout. Alan Steffert (also a GRA) and OSU Research Forest employees Greg Cox and Brian Stacey assisted during data collection.

Yarding and road construction was conducted by More Logs, Inc., Foster, OR. In addition to the landing and rigging crew, Gary Betts, Dick Renoud, and Carmen Smallwood provided valuable assistance and cooperation during the project. Felling was subcontracted by Wischnofske Timber Falling, Inc., Philomath, OR. In addition to the felling crew, Marvin Bennett and Bill Wischnofske also provided useful assistance, cooperation, and input into the study.

Dr. Loren D. Kellogg contributed much appreciated assistance, guidance, and review throughout the entire study as a major professor. Other graduate committee members, Dr. John J. Garland and Dr. Eldon D. Olsen, also provided guidance and review in analysis procedure, structure, and final write-up of the study.

Finally, the cooperation of my wife, Gloria, was/is greatly appreciated in preparation of the excellent maps contained in this research paper and for incredible patience throughout my graduate studies. In addition, I am indebted to my family and fellow Forest Engineering graduate students for moral support.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

Page

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF TABLES

Page

LOGGING PLANNING, FELLING, AND YARDING COSTS IN FIVE ALTERNATIVE SKYLINE GROUP SELECTION HARVESTS

I. INTRODUCTION

Political and public concerns within the past few years have focused on perceived inadequacies of traditional plantation even-aged silvicultural forest management, specifically clearcutting. Public timber management agencies have responded with "New Forestry" (or "New Perspectives") techniques to address these matters, with private industry somewhat reluctantly following (Franklin, 1989). Spies, et al. (1991) refers to this new direction as "ecosystem management" and defines it as such:

> "... in which forests are viewed as more than timber crops, and forest preserves are viewed as only one part of the solution to the problem of maintaining biological diversity and aesthetic values in managed forest landscapes which provide many values."

Associated with these "new" or "alternative" silvicultural systems are the operational aspects of how to physically implement the harvesting in a safe, productive, and operationally feasible manner. Tappeiner et al. (1991) identify three silvicultural systems that could mimic natural disturbances: "clearcut (catastrophic fire), two-storied stand (windthrow), and group selection (root rot diseases)". Included within these systems is the arrangement/location of residual snags and green retention trees in a scattered or grouped fashion in order to provide "biological legacies" (Swanson and Berg, 1991 and Weigand and Haynes, 1991).

Small group selection harvesting represents one method to create or maintain an uneven-aged stand condition (Smith, 1986). This method also poses quite a challenge with regards to harvest unit logging planning and in primary transport (i.e. skyline yarding) of the timber resource as compared to a conventional clearcut silvicultural system. A previous Oregon State University (OSU) Department of Forest Engineering study showed a 532 percent increase in logging planning costs and a 23.6 percent increase in yarding costs for skyline group selections over clearcutting (Kellogg et al., 1991). Felling costs in this study were actually 3.4 percent less than clearcutting.

As a continuation/elaboration of the study above, a second replication of a more detailed nature was conducted as part of a larger interdisciplinary research project in Oregon Coast Range second growth timber (Tappeiner et al., 1991). The research involved specifically examining five alternative harvest setting designs for skyline group selections versus a clearcut with grouped wildlife snags and green tree retention. Patch sizes ranging from 0.5 to 3 acres (0.20 to 1.21 hectares); shapes from rectangular to wedge-like; and parallel and fan shaped setting skyline road plans were investigated. The relation of these factors to efficiencies and/or inadequacies were studied with regards to unit logging planning and layout, felling, and yarding costs. From this information, logging planning requirements and costs and felling and yarding production and costs can be compared.

II. LITERATURE REVIEW

Presently there is little published information on logging planning, costs, or felling and yarding production for any of the "New Forestry" or alternative uneven-aged silvicultural systems proposed by Franklin (1989) and Spies et al. (1991). Tesch et al. (1989) have documented the need for close coordination and interaction between harvesting and silvicultural specialists to achieve silvicultural objectives via harvesting technology and engineering. Mann et al. (1989) highlighted a projected increase in overall costs and operational difficulties as a result of a change in traditional northwest silvicultural practices from plantation even-aged to uneven-aged silvicultural systems and other alternatives to clearcutting. More recently, the National Research Council (1990) documented a need for research in "developing systems of forest management that simultaneously produce commodities and maintain and improve environmental values and that recover timber values without degrading other values." The Council calls for increased research emphasis in alternative silvicultural systems and the technology and engineering know-how to harvest within these systems.

In the first yarding production/cost study involving an alternative silvicultural system found, Dykstra (1976) reported a 67 percent increase over clearcutting in uphill yarding costs for a running skyline yarding system. The differences in costs were hypothesized to be chiefly dependent on the silvicultural method used with no generalized cutting unit shape influences noted. The system studied was specifically a Skagit GT-3, operating in large, old-growth northwest U.S. timber (i.e. primarily Douglas-fir) partial cuts. Partial cuts in this paper refers to a shelterwood silvicultural system. Direct yarding costs were compared to previous information derived in a Berger Planet-Lok L-1 running skyline study in similar old-growth clearcuts also by Dykstra (1975).

Productive yarding time using multiple regression procedures was established to be a function of slope yarding distance, volume per turn and per log, skyline chordslope, number of logs or chokers per turn, and lateral yarding distance. In addition, presetting of turns was postulated to have a large influence on and potential to reduce turn hooking time and thus reduce total cycle time. Road changing time was found to have a significant effect on production and cost in partial cuts, although large variances in time required were noted and reliance on local data was recommended. "Indirect" yarding production information (i.e. move in and out and set up and tear down costs) was not included in the study.

These production and cost results, although interesting, cannot be applied to other alternative silvicultural systems, such as group selections, utilizing newer equipment operating in second growth conditions. The resulting low coefficients of correlation (R-squared) for many of the relations derived in this study raises questions of other confounding factors not accounted for in the study. In addition, comparing two separate studies with different equipment and possible site conditions (i.e. confounding factors) may have led to erroneous conclusions.

Aubuchon (1982) lists 61 cable yarding production regression equations from 21 separate sources. Of these equations, only 3 apply to group selection silvicultural systems (all from the same study). However, although medium-size yarders were used in this study by Gardner (1980) (i.e. maximum mainline pull ≥ 25,000 lbs (111 kN) and < 71,000 lbs (316 kN)), two of the equations are for running skyline systems (uphill and downhill yarding) and one is for a live gravity outhaul system (uphill yarding) all operating in Montana, U.S. Larch-Fir stands.

The objective of Gardner's study was "to evaluate skyline harvesting feasibility (economic and environmental) under the full array of silvicultural and utilization practices that could be used." Prescribed utilization standards ranged from "conventional sawlog" to "close fiber utilization" (i.e. all trees). Group selection patch sizes ranged from 1.3 to 2.3 acres (0.53 to 0.93 hectares). Also, the author notes several confounding factors including landing conditions and differences in overall types and sizes of timber which were not standardized that limit comparisons in production (i.e. percent differences) between silvicultural systems. Some results of interest from this well documented study pertaining to group selections include:

1). The most productive logging/silvicultural system based on total solid volume occurred in the downhill running skyline close fiber utilization group selection unit studied. No comparison was made with a clearcut unit in this case, however a 29 percent increase in production over a similar downhill shelterwood unit was reported.

2). Uphill running skyline conventional saw log group selections yielded a 49 percent decrease in production over a clearcut versus a 50 percent decrease in a shelterwood unit production over clearcutting. A similar uphill shelterwood with close log utilization (i.e. trees 5 in Dbh + (12.7 cm +)), alternatively, yielded the least production based on total solid volume.

3). Uphill live skyline conventional saw log group selections exhibited a 45 percent decrease in production over a clearcut. No similar shelterwood unit was studied in this case.

4). Regression analysis yielded, in order of importance: slope yarding distance, lateral yarding distance, and number of pieces per turn as the most significant variables affecting yarding production rates.

More recently, Campbell and Sherar (1989) documented logging layout, felling, and yarding production and costs for four group selection patches in one unit with two landings, and one clearcut unit, each harvested with an identical yarder and crew in North Carolina, U.S. eastern hardwood timber. Group patch sizes ranged from 1.1 to 1.8

acres (0.45 to 0.73 hectares) and were yarded utilizing a truck-mounted two drum Christy yarder with a Mini-Mak radio controlled clamping carriage. Results are reported in "rule-of-thumb" ratios in comparison to clearcutting derived from shift-level summary data.

Group selection harvesting was found to increase layout costs 6:1, felling cost 1.5:1, yarding costs overall 2:1, rigging and moving costs 3:1, and the actual yarding task cost was approximately identical to clearcutting (i.e. 1:1). In this study actual yarding task cost refers to the cost to yard logs to the landing (i.e. standard yarding cost) and overall yarding cost refers to standard yarding cost plus fixed rigging and moving cost (i.e. final yarding cost). Overall conclusions by the authors noted that the increase in total costs of the group selections may be justified by visually sensitive areas and/or for multiple use mitigation. However, the stands in which group selection harvesting occurs should definitely have high quality, high volume per acre timber in order to offset the losses in production.

Problems noted in felling production included an increase in the number of hang-ups due to an enlarged proportion of forest edge to harvested area. This in turn also affected yarding production and road changing procedures. Another felling logistical problem peculiar to the group selection patches was reduced production due to the fact that some group patches were too far apart to facilitate communication for potential emergencies and felling safety. This limitation forced fallers to work too close to each other on their respective strips and thus reduced normal production.

Some yarding problems noted in the study included poor deflection on one group patch causing excessive hang-ups and difficult lateral line pulls. Another problem encountered was in rigging one long skyline road with lack of sufficient power on the strawline drum to pull out the skyline, thus requiring manual assistance during the road change. The most significant problem experienced also occurred on the longest of the skyline roads. This difficulty centered around the fact that in this group patch the skyline corridor was not pre-felled. Corridor trees were felled as the road was rigged by raising and lowering the skyline resulting in much lost production. Sidehill yarding was also cited as a production problem in some of the group patches.

It should be noted that unit volume per unit area ranged in the clearcut and group selection patches from 6.7 to 10.7 Mbf/acre (94 to 150 m^3/hectare). Although patch specific piece size (i.e. unit volume per log) was not given, clearcut and group selection patch specific unit volume per tree ranged from 138 to 186 bf/tree (0.782 to 1.054 m^3/tree). This data indicates that average log size may have been variable in areas studied in addition to other confounding variables such as different average yarding distance. In turn this would indicate that possible erroneous conclusions may have been made in using a shift-level approach in order to aggregate group selection data to determine logging production and cost differences over clearcutting.

In a related study by LeDoux et al. (1991), detailed time-studies were used to derive predictive regression equations in order to forecast yarding production and costs for the above mentioned Christy cable yarder. Significant variables affecting total delay-free yarding cycle time included slope yarding distance, lateral yarding distance, number of logs, cubic foot volume, and hooking crew size (assumed to be in order of importance as reported in the actual publication). Although the detailed time-study was performed in identical conditions as Campbell and Sherar's (1989) shift-level study, results are only applicable to the group selections with no detailed time-study comparisons to clearcutting. The article, however, does validate and quantify the intuitive effect of several independent variables on yarding costs (i.e. slope and lateral yarding distance, turn volume, hooking crew size, and unit/patch size). This type of data is very useful specifically for logging layout personnel and forest managers in the eastern U.S. hardwood forest types with similar logging equipment for sensitivity and economic analysis purposes.

Of interest and further relation to the above two studies: Sherar et al. (1991) used a shift-level summary to record yarding production and cost differences for two clearcut units and one shelterwood skyline harvest unit with approximately 70 percent of the standing trees removed. The study was located in North Carolina, U.S. eastern hardwood timber utilizing a Thunderbird TMY 70 cable yarder with a 50 ft (15 m) tower (carriage type not mentioned).

Conclusions of interest are an increase in stump to landing yarding cost of approximately 64 percent over clearcutting cost, although actual project increases were 109 percent due to an extremely low equipment utilization rate. It was also realized that smaller and/or custom built Southern Appalachian yarding equipment with lower ownership costs should be used, if possible, in partial cutting situations. Increase in costs were postulated to be a direct result of increased hang-ups during felling, increased corridor rigging time during road changes, and an increase in the average time spent in lateral yarding through the residual stand.

Very little information is presented in this paper with regards to volume per unit area, piece size (i.e. unit volume per log or tree), and other physical and timber-related site attributes for either the clearcut's or the shelterwood units. Average yarding distance (AYD) is presented for each corridor in the shelterwood unit, however

AYD is not reported for either of the clearcut units. As in the study documented above by Campbell and Sherar (1989), it is questionable whether or not a shift-level time-study is adequate, in this case, in order to answer the question of interest and in generating reliable production and cost information. Since much of the needed information to examine and critique the conclusion reached in this paper is lacking, it can only be assumed that there may have been numerous confounding factors.

In an unpublished study by Halme (1990 & 1991) for Plum Creek Timber Company in southwest Washington, U.S., four leave tree patterns on cable yarder settings were tested/observed for various operational aspects, including yarding production and safety. The four leave tree patterns may be categorized in relation to patterns, yarding direction, yarding production loss, and safety considerations as such:

1). Scattered, evenly distributed leave trees; downhill yarding; approximately 25 percent yarding production loss; loss of most snags due to safety considerations.

2). Leave trees in center of corridor; uphill yarding; approximately 15 percent yarding production loss; loss of most snags due to safety considerations.

3). Leave trees in grouped wedges; uphill yarding; minimal yarding production loss; no snags lost.

4). Leave trees in grouped clusters; uphill yarding; no production loss; no snags lost.

Although the results presented are very general and study methods not documented, the major conclusion from this paper is that "operationally, clumping (grouping) residual trees is superior." Residual tree and snag damage and pull over is minimized, safety conflicts are minimized, and yarding production is maximized.

Another unpublished report by Weigand (1991) lists ranges of increases in harvest costs for New Perspectives treatments on USDA Forest Service timber sales. These figures are sketchy and no indication of the specific type of silvicultural and logging systems used are presented. In addition, data collection methods are not mentioned. However, overall harvesting cost increases are estimated to be from 25 to 40 percent; production rate losses are projected to be 25 to 50 percent lower than appraisal estimates depending on the number of snag and green retention trees left per unit area; yarding costs increase from 18 to 34 percent; and felling costs using directional felling are estimated to increase 200 to 300 percent. In addition, appraisal costs are gauged to have increased approximately 44 percent with layout, marking, and cruising costs magnified by 86 percent.

Other studies that involve alternative silvicultural systems with ground-based machinery should be mentioned. Kluender and Stokes (1992) examined harvest productivity and costs in a clearcut, shelterwood, and single tree selection in Arkansas, U.S.. Erickson et al. (1992) determined the influence of group size and individual machine operators on group selection harvest productivity and costs in West Virginia, U.S. eastern hardwoods. The scope of these studies, although specifically unrelated to this study, illustrate a trend towards more research in quantifying and comparing alternative silvicultural system requirements both operationally and economically. The motivations and objectives for this study follow along similar lines of thought and will hopefully specifically address U.S. Pacific Northwest concerns with the emerging and increasing use of uneven-aged alternative silvicultural systems on terrain limited to skyline cable yarding.

III. OBJECTIVES

1). Determine logging planning and field layout requirements (hr/unit area) and costs ($/unit volume) for five alternative skyline group selection silvicultural system treatments and compare to a conventional skyline clearcut silvicultural system.

2). Develop a predictive regression equation in order to determine manual felling production (unit volume/hr) and cost ($/unit volume) for the skyline group selections above and compare to a conventional skyline clearcut.

3). Determine average road/landing change time (hrs) and costs ($/unit volume) for a Thunderbird TMY 70 yarder for the skyline group selections above and compare to a conventional skyline clearcut.

4). Develop a predictive regression equation in order to determine yarding production (unit volume/hr) and total yarding cost with road/landing changes ($/unit volume) for a Thunderbird TMY 70 yarder for the skyline group selections above and compare to a conventional skyline clearcut.

5). Utilize the component logging planning, felling, road/landing change, and yarding costs ($/unit volume) generated above to derive total planning and harvest cost for each of the above skyline group selections and compare to a conventional skyline clearcut.

6). Make recommendations for efficient and safe harvesting and unit layout.

7). Suggest areas where future research may be needed.

IV. FIELD STUDY DESIGN

A. Study Area Description

The study area was located north of Corvallis, Oregon in the Paul M. Dunn OSU Research Forest. The area occupied portions of Sections 14, 22, 23, and 27; Township 10S, Range 5W; Willamette Baseline and Meridian (see Figure 1) in the east central Oregon Coast Range.

In the study area, annual precipitation averaged 39-59 in (100-150 cm); the dominant soil type was a Price series Silty-Clay Loam; weighted average elevation above sea level was 730 ft (223 m); weighted average slope was 31 percent; and weighted average aspect was south (192° azimuth). Timber site productivity ranged from a low site II to a high site III (McArdle et al., 1961), indicating moderately productive timber growing conditions. Average study unit size was 24.9 acres (10.1 hectares).

The timber stands in the study were composed primarily of 82 percent Douglas-fir (*Pseudotsuga menziesii*), with approximately 16 percent hardwoods and 2 percent Grand Fir (*Abies grandis*). Dominant hardwoods included Oregon White Oak (*Quercus garryana*) and Bigleaf Maple (*Acer macrophyllum*). These stands were naturally regenerated from the late 1800's to the early 1900's. Some weighted average timber statistics for the softwoods are: age = 90 years;

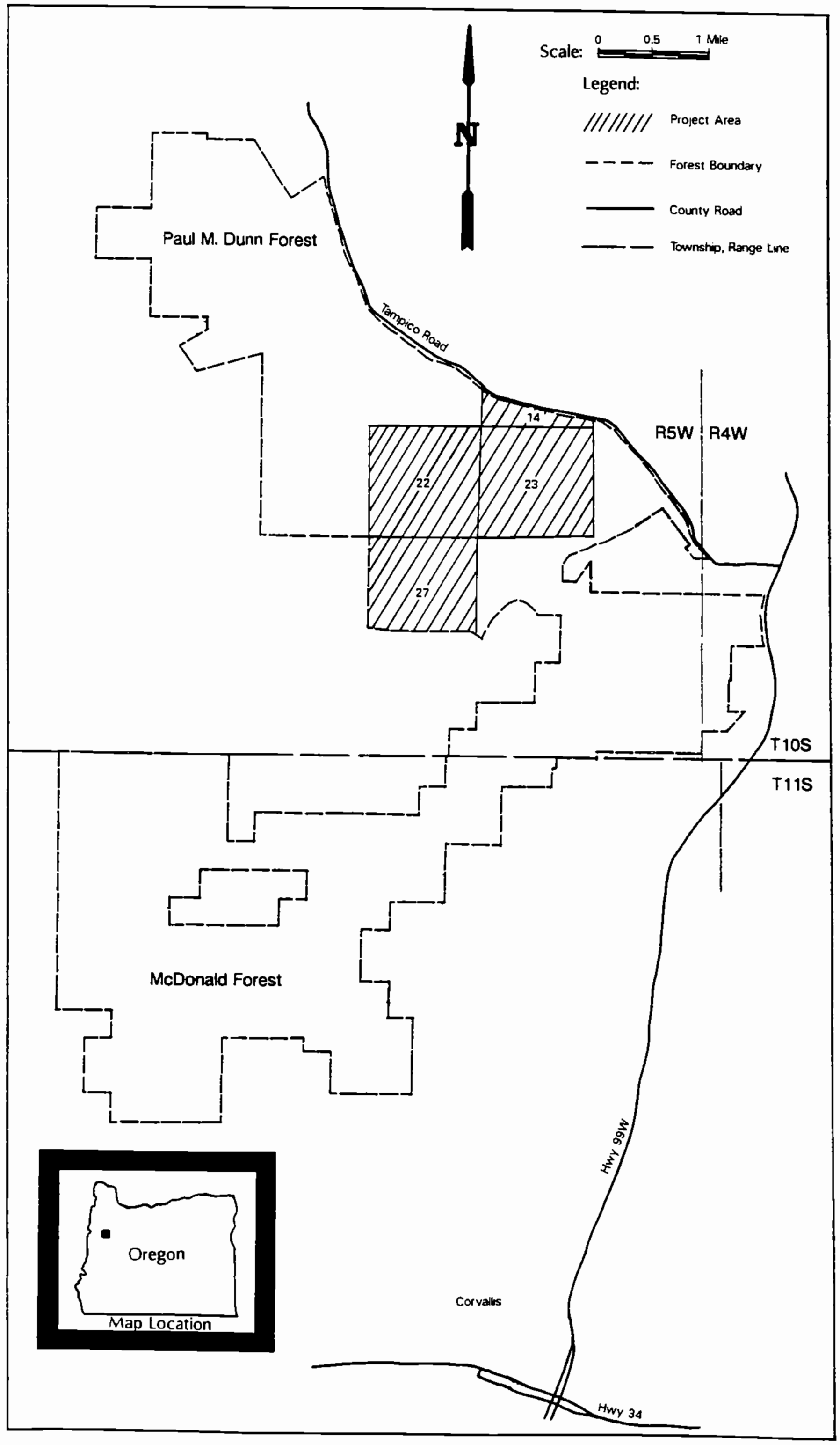


Figure 1: Study area location map

diameter at breast height = 18 in (46 cm); total tree height = 94 ft (28.7 m); trees per unit area = 82/acre (203/hectare); basal area per unit area = 240 ft^2/acre (55.1 m^2/hectare); and volume per unit area = 36.1 Scribner gross Mbf/acre (506 m^3/hectare). Additional detailed unit specific and study range values are presented in Appendix A.

B. Logging Equipment Specifications

1. Felling

Manual felling techniques with chainsaws were used throughout the study. The timber faller studied operated a Stihl 064 chainsaw (see Figure 2) with a 36 in (91 cm) bar with Stihl full complement 0.375 in (10 mm) pitch chisel chain. The 064 has a 5.2 in^3 (85 cc) displacement engine with a power rating of 6.4 hp (4.8 kW). Although wedging of trees was common and 3-5 wedges were carried by the faller at all times, tree jacking was limited to problem roadside trees. However, Silvey tree jacks were available, if needed.

2. Yarding

A Thunderbird TMY 70 side-mount mobile yarder (see Figure 3) run as a standing skyline in a slackline configuration (see Figure 4) was used by the logging

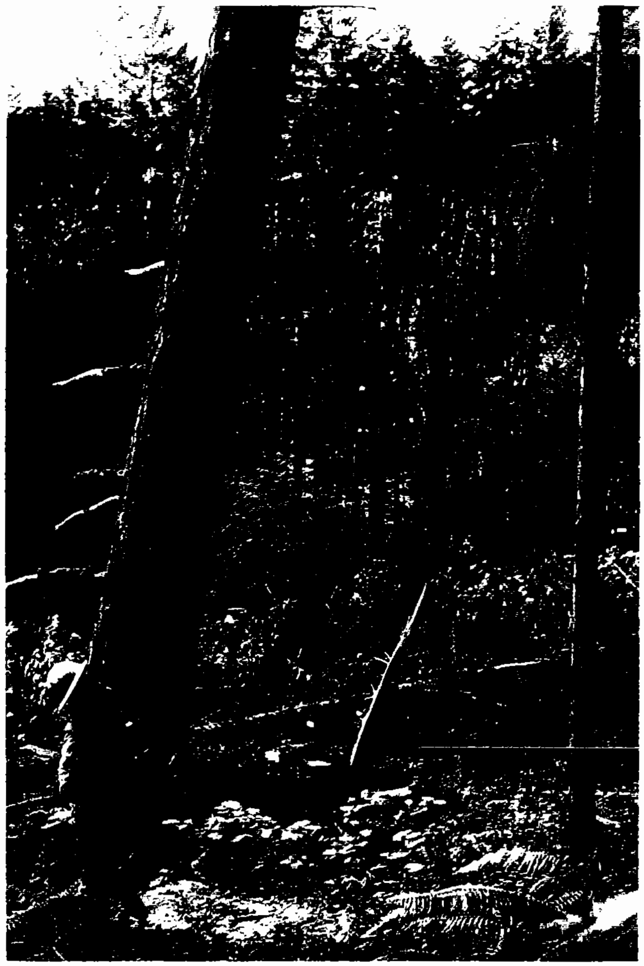


Figure 2: Timber faller with Stihl 064 chainsaw

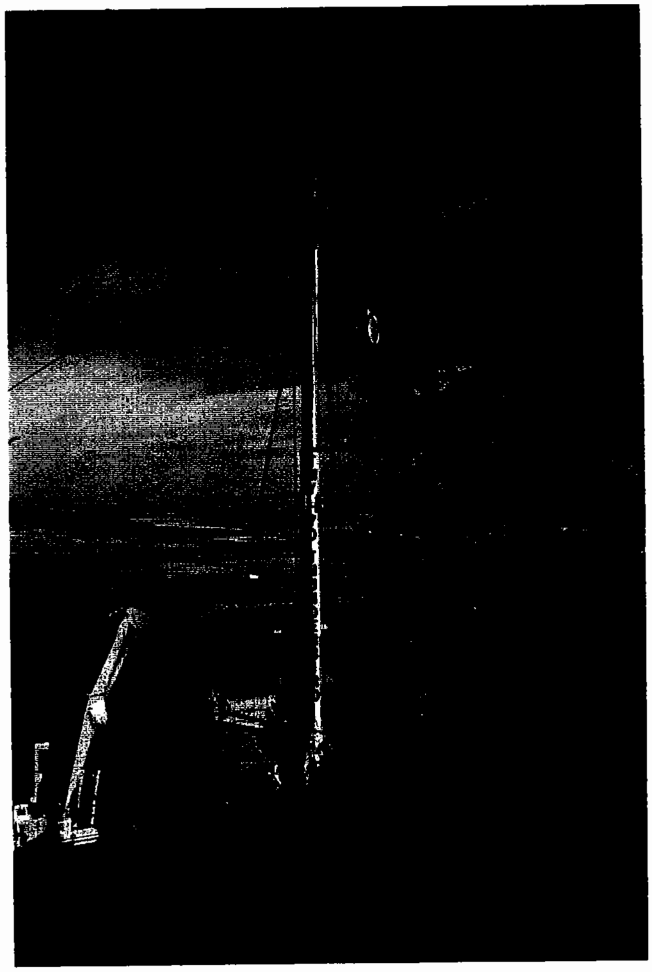


Figure 3: Landing area with Thunderbird TMY 70 side-mount mobile yarder

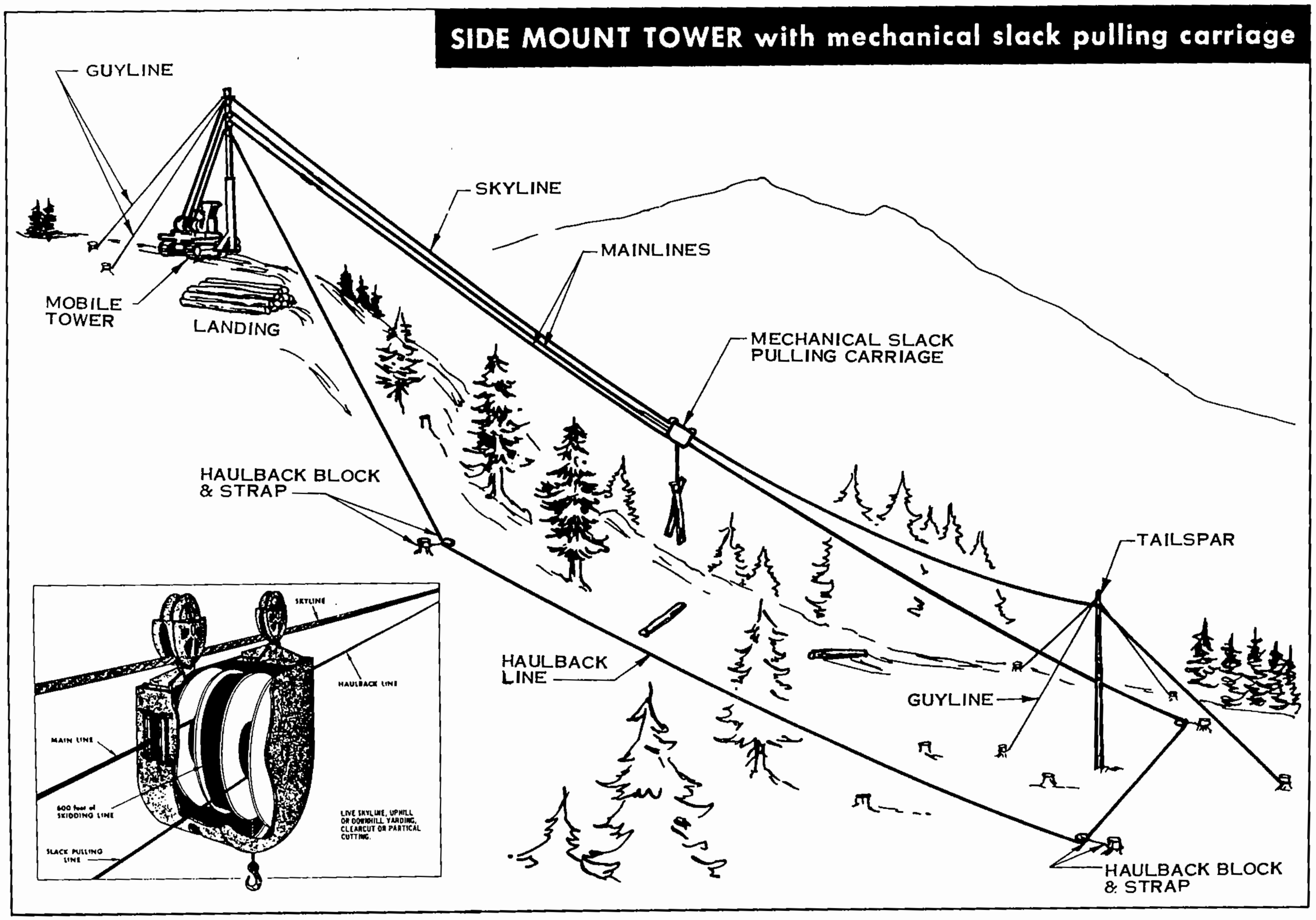


Figure 4: Standing skyline slackline configuration and carriage type (inset) used for project (from Studier and Binkley, 1974)

contractor in the study. The yarder was coupled with a Danebo S-35 DL drum lock mechanical slackpulling carriage (see Figures 4 and 5). Table 1 lists the machinery operating specifications for the yarder and the carriage.

Other associated yarding equipment is listed in Table 2. The John Deere 892D-LC crawler-mounted hydraulic log loader used possessed 205 ghp (153 kW) of rated engine power and was modified/reinforced for shovel logging (see Figure 6). The logging contractor also normally employed the use of a John Deere 550 crawler tractor with a line choker winch as a landing cat. In addition, a Caterpillar D7G with a rear-mount ripper was utilized as a mobile tailhold and for use in miscellaneous excavation and road work, when needed.

C. Unit Treatment Descriptions

Six treatments were investigated in this study. Their relative locations within the study area are illustrated in Figure 7. Each unit was assigned a number based on the order in which it was harvested. An alphanumeric code was given to each unit, for ease of reference, based on (in this order): silvicultural system, skyline setting road plan type/shape, and group selection opening type. Silvicultural system was designated CC for clearcut and GS for group selection; skyline setting road plan type was specified as F for fan and P for parallel; and group selection opening type was

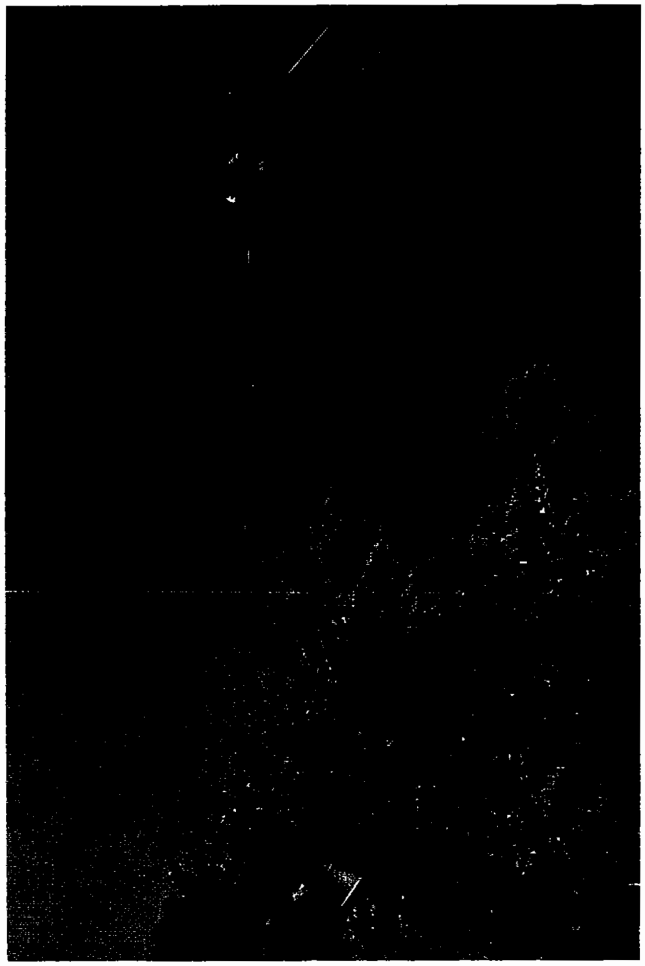


Figure 5: Danebo S-35 DL drum lock mechanical slackpulling carriage

Table 1: Thunderbird TMY 70 side-mount mobile yarder and Danebo S-35 DL drum lock mechanical slackpulling carriage operating specifications

---

Yarder:

Engine .... Cummins NTA 855 diesel

Rated engine power .... 430 ghp (321 kW)

Undercarriage .... Rubber tired; self-propelled

Tower type .... Tubular; telescoping

Tower height .... 50 or 70 ft (15.2 or 21.3 m)

Number of guylines 5

Number of drums .... 5 (includes strawline drum)

Weight .... 98,000 lbs (440 kN) with lines

Drum capacities:

Skyline .... 2000 ft (610 m) - 1.125 in (29 mm)
Mainline .... 2700 ft (823 m) - 0.75 in (19 mm)
Slackpuller .... 3100 ft (945 m) - 0.50 in (13 mm)
Haulback .... 4400 ft (1341 m) - 0.75 in (19 mm)
Strawline .... 4500 ft (1372 m) - 0.375 in (10 mm)
Guyline .... 220 ft (67 m) - 0.875 in (22 mm)

Bare-drum performance:

Stall line pulls:
Mainline .... 111,800 lb (497.3 kN)
Haulback .... 105,200 lb (468.0 kN)
No-load line speeds:
Mainline .... 4120 ft/min (1260 m/min)
Haulback .... 4300 ft/min (1310 m/min)

Carriage:

Weight .... 2200 lbs (9.8 kN) with dropline

Dropline capacity .... 250 ft (76 m) - 0.75 in (19 mm)

Table 2: Summary of yarding equipment used in study

Yarder:	Thunderbird TMY 70 mobile side-mount
Carriage:	Danebo S-35 DL drum lock mechanical slackpulling
Log loader:	John Deere 892D-LC hydraulic crawler-mount
Landing cat:	John Deere 550 crawler tractor with line choker winch
Mobile tailhold:	Caterpillar D7G with ripping tines
Fuel truck:	Ford chassis 1250 US gal (4740 liter)
Crew bus:	Ford 12-passenger cabin chassis
Landing chainsaws:	2 Husqvarna 266's 1 Husqvarna 281

Figure 6: Landing area with John Deere 892D-LC crawler-mount hydraulic log loader and Thunderbird TMY 70 side-mount mobile yarder

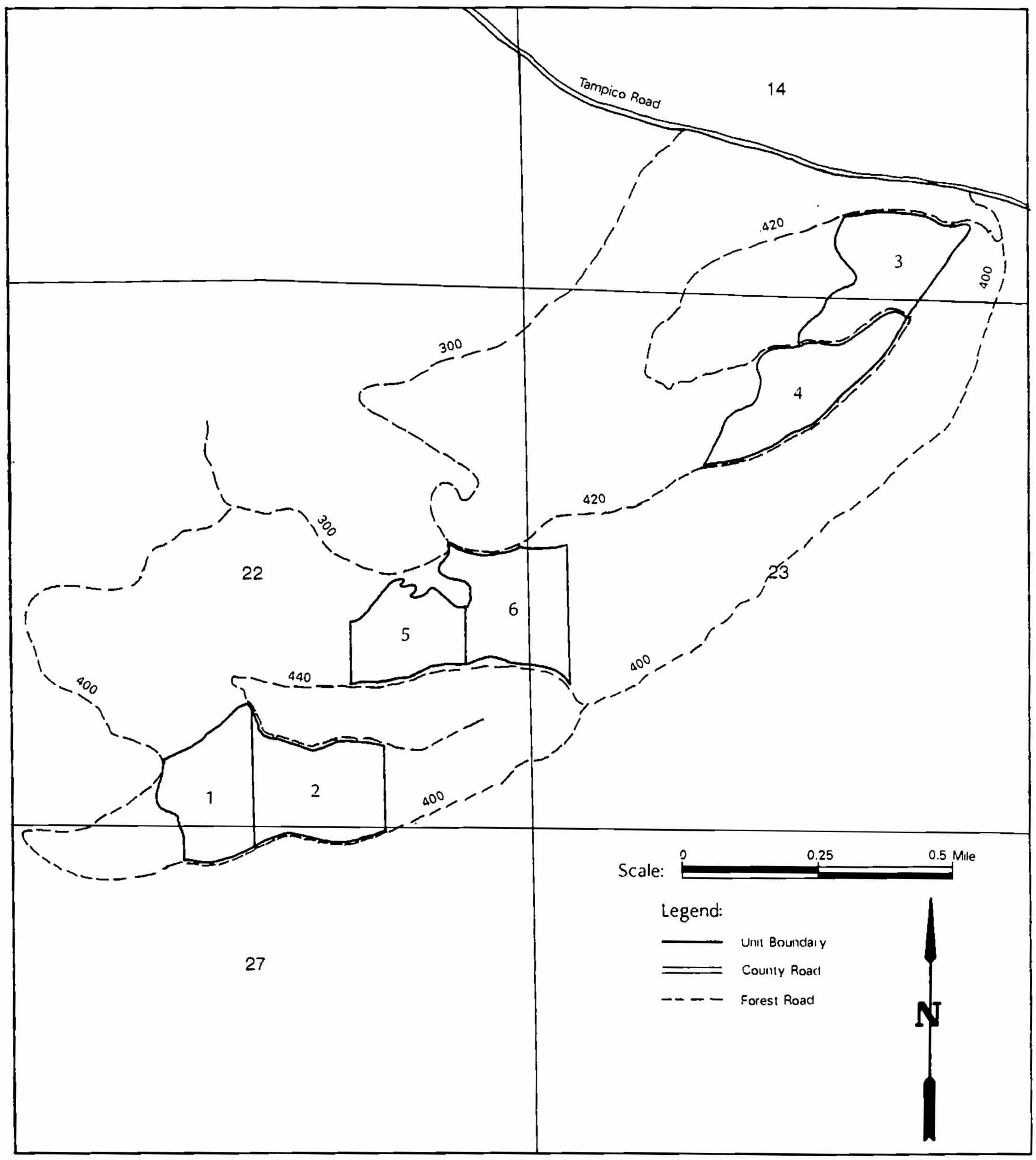


Figure 7: Treatment unit location in study area map

represented by S for rectangular strip, 0.5 or 1.5 P for 0.5 or 1.5 acre (0.20 or 0.61 hectare) rectangular patches, and W for wedge shaped.

The resulting unit designations are:

1-CCF .... Clearcut Fan

2-GSPS .... Group Selection Parallel Strip

3-GSF.5P ..... Group Selection Fan 0.5 acre Patch (0.20 hectare)

4-GSF1.5P .... Group Selection Fan 1.5 acre Patch (0.61 hectare)

5-GSFW .... Group Selection Fan Wedge

6-GSP.5P ..... Group Selection Parallel 0.5 acre Patch (0.20 hectare)

These designations will be used throughout the rest of the text and explained in greater detail below.

<u>1. 1-CCF: Unit 1 - Clearcut Fan</u>

* 2 residual trees/acre (4.9 trees/hectare) left. Of these residuals designated, 1.5 trees/acre (3.7 trees/hectare) would be topped as snags and 0.5 trees/acre (1.2 trees/hectare) would be left as green retention trees.

* Snags and green retention trees located and leave tree marked in groups (4) on the back end of unit in order to avoid present and future felling and yarding hazards. Location may also facilitate use of the trees as lift trees, when needed, for extra deflection.

* One centralized landing necessitating a fan shaped skyline road layout.

* No designated skyline roads (i.e. "logger's choice"); tail/lift trees and stump tailholds verified for rigging feasibility.

2. 2-GSPS: Unit 2 - Group Selection Parallel Strips

* 1.5 residual trees/acre (3.7 trees/hectare) left and topped as snags.
* Grouped snags located in residual stand.
* Three entries proposed; 20-30 year cutting cycle.
* Four first-entry landings with a designated parallel skyline road layout.
* Tail/lift trees designated and stump tailholds verified.
* 2 to 3 acre (0.81 to 1.21 hectare) rectangular strips; boundary marked with all trees cut within boundary.

3. 3-GSF.5P: Unit 3 - Group Selection Fan 0.5 acre Patch

* Same snag policy as Unit 2.
* Grouped snags located in residual stand.
* Same entry/cutting cycle scenario as Unit 2.
* One centralized landing with a designated fan shaped skyline road layout.
* Tail/lift trees designated and stump tailholds verified.
* Average 0.5 acre (0.20 hectare) size rectangular to polygonal patches; cut tree marked.

4. 4-GSF1.5P: Unit 4 - Group Selection Fan 1.5 acre Patch

* Same snag policy as Unit 2.
* Scattered snags located in residual stand.

* Same entry/cutting cycle as Unit 2.

* Two centralized landings with a designated fan shaped skyline road layout.

* Tail/lift trees designated and stump tailholds verified.

* Average 1.5 acre (0.61 hectare) size rectangular to polygonal patches; boundary marked with all trees cut within boundary.

5. 5-GSFW: Unit 5 - Group Selection Fan Wedge

* Same snag policy as Unit 2.

* Scattered snags located in residual stand.

* Same entry/cutting cycle as Unit 2.

* One centralized landing with tail/lift trees and stump tailholds verified for rigging feasibility.

* 2 to 3 acre (0.81 to 1.21 hectare) wedge-like patches; boundary marked with all trees cut within boundary.

6. 6-GSP.5P:Unit 6 - Group Selection Parallel 0.5 acre Patch

* Same snag policy as Unit 2.

* Scattered snags located in residual stand.

* Same entry/cutting cycle as Unit 2.

* Three first-entry landings with a designated parallel skyline road layout.

* Tail/lift trees designated and stump tailholds verified.

* Average 0.5 acre (0.20 hectare) size rectangular to polygonal patches; cut tree marked.

D. Logging Planning Time Record Methods

All logging planning activities were performed and entered observationally for each unit on data forms (see Appendix B for example) in a logical order similar to the way a unit would be laid out. Measurements were recorded to the nearest 15 minutes for all activities utilizing the labor of the principal researcher (myself), a research assistant, and the OSU Research Forest Research Coordinator during the period of 18 December 1990 to 25 September 1991. Time record logging planning components were differentiated categorically as a). area-wide pre-planning and logistics, and b). treatment specific. Codes were assigned as shown in Table 3.

Area-wide planning components are defined in this study as those activities that are not necessarily treatment related, yet required in order to efficiently access and harvest the given units. In other words, the time spent involved in this type of planning could not be specifically charged to any one given unit, but rather spread over the area as a whole. Area-wide planning was performed for other treatment units in a related on-going study (Tappeiner et al., 1991), in addition to those units within this study. The treatment specific time components were further distinguished as randomized and non-randomized.

Table 3: Logging planning time record components and codes

Area-wide pre-planning and logistics:

Component	Code
Map/photo interpretation	10
Reconnaissance	11
Office/computer	12
Other	13
Flag boundary	14
Flag haul roads	15

Randomized treatment specific:

Component	Clearcut Code	Group Selection Code
Ground profiles	20	30
Computer analysis	21	31
Flag skyline roads	22	32
Map/photo layout	23	33
Mark trees	24	34

Non-randomized treatment specific:

Component	Clearcut Code	Group Selection Code
Reconnaissance	25	35
Photo interpretation	26	36
Office	27	37
Flag landings	28	38

Randomized treatment specific time components were planning activities that required large blocks of time and that could be performed all at once. These components were randomized by drawing unit numbers from a hat for each component in order to eliminate sampling bias and any learning curve influences. The resulting sampling design is shown in Table 4. Each logging planning time component was completed for all six units before proceeding to the next activity. It should be noted that similar procedures as above were used in an earlier study by Kellogg et al. (1991), so some of the learning curve influences in unit layout may have been eliminated at least for the principal researcher/planner involved in the study. Other personnel involved had minimal experience in skyline logging unit layout.

Non-randomized treatment specific planning time components were also performed and measured throughout the layout process. These time components could not be controlled to the degree that the randomized time components were. As an example: landing locations in some cases were "roughed in" during the road layout process and subsequently refined during later stages. All time record information was entered, stored, and analyzed using computer spreadsheet software in order to evaluate logging planning requirements and costs. Equipment costs and labor rates were estimated and are summarized in Appendix C.

Table 4: Sampling design for randomized treatment specific logging planning time components

Ground profiles:

Order of completion	Unit-Rx
1	3-GSF.5P
2	5-GSFW
3	1-CCF
4	2-GSPS
5	4-GSF1.5P
6	6-GSP.5P

Computer analysis:

Order of completion	Unit-Rx
1	3-GSF.5P
2	6-GSP.5P
3	2-GSPS
4	1-CCF
5	5-GSFW
6	4-GSF1.5P

Flag skyline roads*:

Order of completion	Unit-Rx
1	4-GSF1.5P
2	2-GSPS
3	3-GSF.5P
4	5-GSFW
5	6-GSP.5P

* Not applicable for 1-CCF

Map/photo layout:

Order of completion	Unit-Rx
1	5-GSFW
2	1-CCF
3	6-GSP.5P
4	3-GSF.5P
5	4-GSF1.5P
6	2-GSPS

Mark trees:

Order of completion	Unit-Rx
1	6-GSP.5P
2	3-GSF.5P
3	4-GSF1.5P
4	2-GSPS
5	1-CCF
6	5-GSFW

An example of the procedure that was used to lay out a typical skyline group selection unit would begin with an initial drive-by and ground reconnaissance, followed with map and photo work. Boundaries were usually established at this point and any additional road construction that was required to access landing areas was flagged in and tentative landings designated. All of this initial data was then mapped on a logging plan map and at this time most area-wide planning was completed.

Critical ground profiles were then run and analyzed using LOGGER PC (OSU Department of Forest Engineering, 1991) to determine final road and landing locations, existing skyline deflection conditions, and whether or not tail/lift trees were needed. Final road and landing locations were completed and mapping was performed with a three-entry group selection layout scenario determined. Skyline roads were then flagged in and tail/lift trees designated and/or stump tailholds verified. The tree marking was the last step before harvest along with any final mapping and miscellaneous planning.

E. Felling Time-Study Methods

Two time study techniques were used to evaluate felling production and costs. A shift-level form (see Appendix D for example) was filled out daily by the lead faller for all timber fallers working in the study treatment units and also for a related ongoing study in other treatment units being conducted by Tappeiner et al. (1991). These data were used in this study as a method to cross-check subsequent more detailed data and to provide a forum for felling contractor comments regarding the specific treatments. The other method utilized to specifically evaluate felling production and costs in this study was the detailed stopwatch time-study technique.

Olsen and Kellogg (1983) documented that the stopwatch technique requires considerably more person-hours and therefore higher cost than other techniques (i.e. "at least eight times as much as do gross time-studies"). However, this technique allows for a better comparison between treatments, can be used to develop predictive regression equations, and provides for a more complete and detailed differentiation between productive and delay time (Olsen and Kellogg, 1983). It was felt that treatment differences in felling production in this study may be subtle enough such that a gross time-study technique may not adequately address these differences.

The felling production cycle was broken down into an elemental/sequential format consisting of activities/time components deemed to be part of the productive delay-free act of manually felling trees and producing logs from that tree. The following time components were used from a previous study by Kellogg et al. (1991):

1). Planning - Time used, usually at beginning of day, to look at terrain, plan timber lays, walk boundaries, etc. This is also time after arriving at a new group selection patch (or new strip in a clearcut) to look at lays, terrain, etc. Time ends when movement towards and preparation of the next tree begins.

2). Move and Prep - Travel between last tree felled and bucked to next tree. Time begins when faller steps down from log after bucking. This component also includes swamping around, squaring butt of bole ("barking") and sizing up the lean of the tree. Travel between group selection patches and new clearcut strips is included here. Time ends when saw chain touches tree for undercut.

3). Felling - Time starts when saw chain touches tree for undercut (or for backcut when using jacks) and ends when tree hits ground.

4). Bucking - Time starts when tree hits ground. Short bar hang-up delays less than one minute are not separated out. Time ends when faller steps down from tree and/or shoulders saw to move to next tree.

Relevant alphanumeric information was also identified to record during the study. This data included:

1). Tree Number - Consecutive number assigned for each merchantable softwood tree felled.

2). Non-Merchantable Tree - All hardwood trees were designated with an "X". Move and Prep and Felling times were recorded since hardwoods were not bucked.

3). Inside Bark Butt Diameter - Two measurements taken at right angles to each other which were then averaged to the nearest inch (similar to scaling procedures).

4). Number of Logs - Number of logs cut from tree.

5). Number of Buck Cuts - Number of bucking cuts performed in order to get number of logs (included bucking defect, sweep, etc.).

6). Used Wedges/Jacks? - Whether or not jacks or wedges were used. Recorded as "W" for wedge or "J" for jacks.

In order to determine the amount of time spent in a given hour actively involved in the felling or any other process (i.e. an "effective hour") for production and cost calculations, non-productive delay time must be separated from productive time (Olsen, 1992). In this study, six general categories of delays were recognized. Appendix E lists specific delays categorically in more detail. By general category, the delays recorded were:

1). Operational
2). Other (miscellaneous)
3). Repair
4). Maintenance
5). Fuel
6). Personal

Data was collected for the felling time-study using the above mentioned format of felling cycle and delay types during the period of 24 July 1991 to 18 November 1991. Collection of data was accomplished using one person timing with a handheld stopwatch (± 1 milliminute accuracy) and data forms (see Appendix F for example). Personnel (timers) involved in the collection of data included: the principle researcher, a research assistant, a graduate research assistant, and an employee of the OSU Research Forest. All Personnel were trained for at least two days in the collection of data, with specific emphasis on safety, and uniformity in beginning and ending points for cycle and delay elements, in order to minimize operator sampling bias errors.

One timber faller was timed throughout the felling detailed time-study. The worker studied was the lead faller for the contracting firm involved in the study, and had over 18 years of timber falling experience. In addition to being the most productive member of the crew, the faller was the subject of a previous study by Kellogg et al. (1991) in which case a pair of fallers was studied. Sampling areas in each treatment were chosen beforehand for similarities in slope, terrain, and timber conditions. Order of felling and yarding of units was determined based strictly on logistics and efficiency. A summary of felling production and cost components and their sources in the study is listed in Table 5.

An initial softwood felling sample was taken in order to define an optimal sample size (N) to generate an acceptable significance level for a predictive multiple

Table 5: Sources of felling production and cost components for study

Component/Cost	Source
* Effective hour (min/hr)	Delay analysis
* Softwood total delay-free cycle time (min/tree)	Predictive regression equation
* Hardwood total delay-free cycle time (min/tree)	Summary statistics and sensitivity analysis
* Volume per tree	Yarding shift-level data and summary statistics
* Logs per tree	Summary statistics
* Felling production (Unit volume/hr)	Calculated
* Owning and operating cost ($/hr)	Cost calculations and machine rates
* Gross to net timber scale	Yarding shift-level data
* Felling cost ($/unit volume)	Calculated

linear regression model. A procedure documented by Olsen and Kellogg (1983) was used. The formula is:

$$\mathbf{N = (S * t / k * \bar{x})^2}$$

where:
N = number of cycles

S = sample standard deviation

t = value from student's t-distribution

$\bar{\mathbf{x}}$ = sample mean

±k = an acceptable "error" percentage of x

It was found, from an initial trial sample size of 32 observations of total delay-free softwood felling cycle time, that 283 samples would need to be collected in order to generate a 95 percent Confidence Interval (CI); 106 samples for a 92.5 percent CI; and 49 samples for a 90 percent CI. It should be noted that these sample sizes were based on the fact that each treatment unit must statistically "stand on its' own" and did not take into account a multiple linear regression approach using treatment indicator variables. Due to personnel and time constraints, a target sample size of at least 120 softwood samples per treatment was set (i.e. 720 total samples) to adequately statistically represent each treatment unit. No minimum sample size criteria was set for the hardwood trees within the study. The number of hardwood trees that were felled in conjunction with the softwood trees were taken as the sample. A separate procedure was used to evaluate hardwood felling production.

1. Softwood Felling Production and Costs

Ten candidate explanatory variables were hypothesized as having potential influence on the total delay-free softwood felling cycle (FTOB) response variable. These included:

1). Inside bark butt diameter (DIAM)
2). Number of logs (LOGS)
3). Number of cuts (CUTS)
4). Wedging (WDGE)
5). Scribner board foot volume (BFVOL)
6-10). Group selection logging layout treatment indicator variables (T1-T5); the clearcut would be the control unit.

All of these variables except for BFVOL were easily obtainable directly from the felling time-study data form used. BFVOL was determined by designating random sample trees (i.e. every fourth tree felled) during felling time-study data collection. These samples were volume scaled after felling was completed for the day until a sample size of 25 per treatment was reached (i.e. 150 total samples for the study). DIAM, LOGS, and CUTS were also recorded at this time as candidate explanatory variables hypothesized as having potential influence on the scaled volume in each tree. A stepwise selection multiple linear regression procedure on STATGRAPHICS (Statistical Graphics Corporation, 1991) computer software was used to develop a predictive model. The resulting summary statistics and regression fit for the model is shown in Appendix G.

Equipment costs and a labor rate were estimated from information from several sources and is summarized in Appendix H. Data collected from daily time-study data forms was entered, stored, and analyzed by treatment unit using computer spreadsheet software. The entire data set was imported into SAS (Statistical Analysis Software) computer software and analyzed using procedures documented by Neter et al. (1989) and Freund and Littell (1991). Specifically, several selection and elimination multiple linear regression methods were utilized in order to determine a preferred model.

After an initial selection procedure, residual plot, and correlation analysis involving several attempted logarithmic transformations and tests for variable interaction, an outlier detection analysis/test was performed due to certain suspected influential observations. Three tests were investigated including DFFITS, Studentized Residuals, and Covariance Ratio (i.e. leverage). If any one observation failed two out of the three tests, that observation was deleted from the sample data set. A resulting 4.8 percent of the original sample size of 808 was removed, reducing the sample size to 769.

The concluding analysis showed marked improvement in a plot of residuals versus predicted values of the response variable. The final preferred model selected was identical to the initial model selected with all observations included, differing only in the magnitude of the coefficients and significance of the selected explanatory variables. No transformations were found to be necessary and the maximum significance level selected was a 0.05 p-value (minimum 2.00 t-statistic).

2. Hardwood Felling Production and Costs

Although the resulting regression equation above would predict a total delay-free cycle time for softwood trees, a different method was used to derive a delay-free felling cycle time for the hardwood trees which were yarded and transported as pulpwood during the study. A yarding and loading shift-level form (see Appendix I) was also distributed for the yarding crew to complete daily in order to obtain scale information (namely, weighted average board foot volume per tree) and for similar reasons as the felling shift-level data form was collected.

Summary statistics, such as the number of hardwood and softwood trees felled and logs yarded, from the felling and yarding detailed time-study were also used to derive number of hardwood logs per tree and an approximate break point in the number of hardwood trees that were yarded and the number that were left as unmerchantable. Felling time was selected as the portion of the hardwood felling cycle sensitive to the size and therefore the merchantability of the tree. Three average hardwood felling time scenarios were picked: median, mean, and felling time = 0.30 minutes. The data was sorted by felling time and a sensitivity analysis was performed on all three scenarios.

A felling time equal to 0.30 minutes came the closest to a calculated known hardwood log load to softwood log load ratio. The resulting total hardwood felling cycles (including the Move and Prep and Felling time components) were summed and averaged, arriving at a delay-free cycle for merchantable hardwoods. This figure was weighted with a resulting prediction from the above mentioned softwood regression equation to arrive at a felling delay-free cycle time for all merchantable trees. Sensitivity analysis also yielded an approximate number of merchantable hardwood logs per tree which was another component required for estimating production and costs. The balance of the hardwood samples were aggregated as a delay type (i.e. Fell Non-Merch) and taken out of the productive time base.

3. Delay Analysis

As noted above, delays were separated out from productive time. A separate spreadsheet analysis was performed to determine the effective hour in each treatment.

This information is essential for production and cost evaluation/comparisons. Effective hour for each unit was determined using the following relation:

$$\text{Effective hr (min/hr)} = \left[1 - \left[\frac{\text{Total all delays for all units} + \text{Treatment specific activities or delays}}{\text{Total all delays for all units} + \text{Treatment specific activities or delays} + \text{Total delay-free felling cycle times for all units}} \right] \right] * 60$$

It should be noted that in the process of determining a regression model to predict softwood delay-free felling cycle time, the planning time component caused most of the observations in which it occurred to be considered outliers (i.e. influenced the regression equation). For this reason planning was removed from the delay-free cycle and treated as the only felling treatment specific activity. After this remedial measure, the observations that originally contained planning were statistically valid and able to be used in the resulting regression equation.

F. Yarding Time-Study Methods

As in felling, two time-study techniques were used for yarding production and cost evaluation. As mentioned above, a shift-level form was filled out daily by the yarder operator for the entire yarding crew. Although the data was collected chiefly for the ongoing Tappeiner et al. (1991) study, this form also provided important log truck load and volume information needed for the yarding production analysis. In addition, comments and road/landing change information on the forms was used as a cross-check for any potential data problem areas.

The same justification for using a detailed stopwatch time-study in the felling portion of the study applies here also. Based on data collected in the previous Kellogg et al. (1991) study, subtle treatment differences in delays and production (albeit costs) were anticipated. A predictive regression equation to forecast total delay-free yarding cycle time was desired here as it was in the felling portion of the study.

The yarding production cycle was broken down into an elemental/sequential format consisting of activity/time components deemed to be part of the productive delay-free act of transporting logs from the stump to the landing via skyline cable yarding. The following time components were used based on Figure 8:

1). Outhaul - Begins when carriage starts away from the landing; ends when rigging slinger signals stop on the haulback.

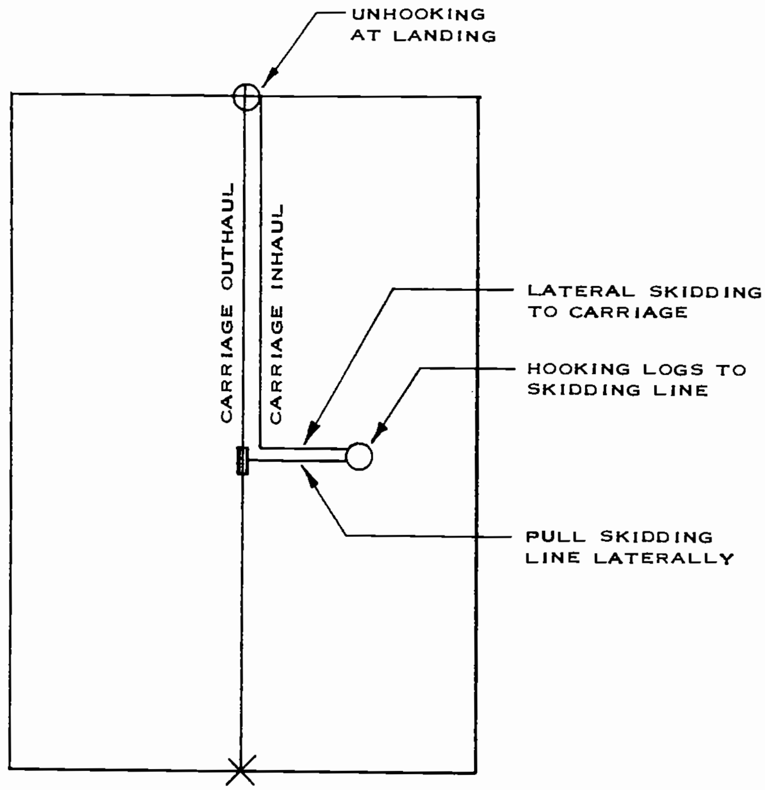


Figure 8: Graphical representation of yarding time-study cycle (from Studier and Binkley, 1974)

2). Lateral Out - Begins at stop on the haulback signal; ends when rigging slinger signals stop on the dropline. Includes untangling chokers.

3). Hook - Begins at stop on the dropline signal; ends when rigging slinger signals ahead on the mainline or dropline.

4). Lateral In - Begins at ahead on the mainline or dropline signal; ends when logs are in lead with the skyline road corridor and forward progress of carriage commences toward the landing.

5). Inhaul - Begins when logs are in lead with the skyline corridor and forward progress of carriage commences toward the landing; ends when carriage stops and logs come to rest on the landing.

6). Unhook - Begins when carriage stops and logs come to rest on the landing; ends when carriage starts away from landing.

Relevant numeric information was also identified to record during the yarding time-study. This data included:

1). Yarding Distance - Slope distance along skyline road where the carriage is spotted; estimated to the nearest 10 ft (3 m). Trees/stumps painted every 50 ft (15 m).

2). Lateral Distance - Average lateral distance measured 90 degrees to the skyline road for all the logs hooked in the turn; estimated to the nearest 5 ft (1.5 m). Trees/stumps painted every 20 ft (6.1 m).

3). Softwood Logs - Number of softwood logs in the turn.

4). Hardwood Logs - Number of hardwood logs in the turn.

5). Turn Hotset/Preset? - Whether or not the turn was hotset or preset (i.e. 0-1 indicator variable).

6). Chasers - Number of chasers present on the landing for the given turn.

7). Chokersetters - Number of chokersetters participating in hooking of the given turn.

8). Chokers - Number of chokers used on the dropline hook for the given turn.

9). Yarder Operator - Two possible yarder operators on crew studied (i.e. 0-1 indicator variable).

Non-productive delay time, as in the felling time-study, was separated out of the productive yarding time. This information was needed for an effective hour determination for the yarding delay-free cycle time. A similar formula, as used in the felling detailed time-study documented above, was used to determine the effective hour for each unit. Four general categories of delays were recognized. Appendix J lists specific delays categorically in more detail. By general category, the delays recorded were:

1). Operational
2). Repair
3). Personal
4). Other

Data was collected for the yarding time-study using the above mentioned format of yarding cycle and delay types during the period of 7 August 1991 to 9 December 1991. Data was collected using a handheld Husky Hunter 2 computer with a programmable detailed work time-study template.

A methodology developed by Bettinger (1991) was followed in order to program specific elements developed for this study. These procedures were also utilized to download data into an ASCII format for importing into personal computer spreadsheet software imbedded with a parsing macro and database functions. The Husky Hunter 2 allowed time, numeric, and fixed data elements to be entered for each skyline yarding cycle.

Two people were required to collect data for the yarding time-study. One person, the computer operator/timer, remained on the landing recording time, numeric, and fixed elements and delays that could be seen from this vantage point. The other person, the spotter, remained in contact with the timer on the landing with a walkie-talkie, reporting various elements upslope from the rigging crew.

Personnel involved in the collection of data included: the principal researcher, a research assistant, and two employees of the OSU Research Forest. As in the felling time-study, all personnel were trained for at least two days in the collection of data with attention towards uniformity between timers and spotters in cycle and delay element start and stop points. Consideration towards safety around the skyline yarding operation was also emphasized.

The logging contractor studied had an experienced and productive landing and rigging crew. Specifically the crew consisted of the following personnel:

1). Hooktender
2). Loader Operator
3). Rigging Slinger
4). Yarder Operator
5). 2 Chasers
6). 2 Chokersetters

The contractor, in general, had over 18 years of experience in partial cut skyline cable yarding. Some of the key loggers in the company and their level of individual experience are listed below:

Position	Overall Experience	Experience in Present Position
* Hooktender	22 years	12 years
* Loader Operator	16 years	14 years
* Rigging Slinger	13 years	10 years
* Yarder Operator	10 years	4 years

Sampling areas were chosen beforehand for similar slope, terrain, skyline deflection, and timber characteristics. An attempt was made to fully sample any chosen skyline road (i.e. all turns) in order to adequately represent yarding conditions and circumstances. The method of hooking (setting) the turns (i.e. hot-setting versus pre-setting) for any given area was left up to the contractor. The owner and hooktender preferred to run two rigging crews; one in the front and one in the back of skyline road being yarded. The hooktender filled in, when available, as a chokersetter on the back end of the unit. As mentioned above in the felling study methods, the order in which the units were harvested was based on logistics and efficiency. A summary of yarding production and cost components and their sources in the study is listed in Table 6.

Due to time constraints, no initial samples of delay-free yarding cycles were taken. A target sample size of 150-200 skyline yarding cycles per treatment was set (i.e. 900-1200 total samples) to adequately statistically represent each treatment unit. This was based on the fact that sample sizes in excess of 120 exhibit relatively low standard deviations, high degrees of freedom in a multiple regression model, and high normality with respect to the sampling distribution.

Thirteen candidate explanatory variables were hypothesized as having potential influence on the total delay-free yarding cycle (YTOB) response variable. These variables could all be directly obtained from the detailed time-study format outlined above. The variables included:

1). Yarding distance (YDS)
2). Lateral distance (LDS)
3). Total number of logs in turn (TLG)
4). Hotset or preset turn? (PR)
5). Number of chasers (CHA)
6). Number of chokersetters (CHO)
7). Number of chokers (CKR)
8). Yarder operator (YOP)
9-13). Group selection logging layout treatment indicator variables (T1-T5); the clearcut would be the control unit.

Yarding and loading equipment costs and labor rates were estimated from information from several sources and

Table 6: Sources of yarding production and cost components for study

Component/Cost	Source
* Effective hour (min/hr)	Delay analysis
* Total delay-free cycle time (min/turn)	Predictive regression equation
* Volume per log	Yarding shift-level data
* Logs per turn	Summary statistics
* Yarding production (Unit volume/hr)	Calculated
* Owning and operating cost ($/hr)	Cost calculations and machine rates
* Gross to net timber scale	Yarding shift-level data
* Yarding cost ($/unit volume)	Calculated

using the computer program PACE (Food and Agriculture Organization of the United Nations, 1992). These owning and operating costs are summarized in Appendix K. In addition to these hourly costs, a fixed move in and out and set up and tear down cost were calculated and is outlined in Appendix L.

The daily yarding data collected was treated much as the felling data was. Data was entered, stored, and analyzed by treatment unit using computer spreadsheet software. The entire data set was imported into SAS and a similar stepwise multiple linear regression approach was used in order to select a preferred yarding cycle predictive model. The same statistical test described for felling was used to remove 3.8 percent of the original sample size of 1234 as outliers, reducing the sample size to 1187. No transformations were necessary and a 0.05 significance level was employed as the criteria for explanatory variable selection into the resulting preferred regression model.

Delays were also treated identically as the felling data set. A separate spreadsheet analysis was performed to determine the effective hour in each treatment. Treatment specific delays were determined based on this spreadsheet analysis and on general daily observations throughout the study.

G. Road/Landing Change Time-Study Methods

Although the yarding and loading shift-level form used (Appendix I) did contain some general road and/or landing change information to be filled out by the yarder operator, this was not sufficient for the purposes of this detailed study. Road and landing changing has been documented as a relatively time consuming activity and therefore rather costly in skyline cable logging (Van Winkle, 1976). As a result of this, a slightly more detailed approach, although not as detailed as the felling and yarding time-studies discussed above, was necessary to detect any treatment differences.

Average road/landing change time is also very important in this study in order to calculate the final yarding cost. Road/landing change cost along with move in and out and set up and tear down costs must be added and divided by volume harvested. From this calculation, a figure is obtained that can be added to the standard yarding cost obtained from the yarding detailed time-study.

The road/landing change work cycle was broken down, as before, into an elemental/sequential format consisting of activities/time components. These components are part of the productive delay-free act of changing skyline roads and/or landings after all logs on the present road have been yarded. The following time components were delineated based on personal observation/experience:

1). Rig Down - Time begins when last turn for the present skyline road is landed. Includes pulling in operating lines and slackening and/or pulling in guylines. Ends when yarder outriggers are raised if before a move; ends when guylines are "jumped" to alternate stumps <u>or</u> when guylines are initially tightened if yarder is not moved.

2). Move Yarder - Starts only when outriggers have been raised and forward or backwards progress/movement is initiated.In some cases this component may not be present in a road change (especially on fan settings). Ends when yarder outriggers are fully lowered.

3). Rig Up - Begins when yarder outriggers are fully lowered if after a move; begins when guylines are "jumped" to alternate stumps <u>or</u> when guylines are initially tightened if yarder is not moved. Ends when carriage initiates movement out into harvest unit for a turn of logs.

4). Pre-Rigging - Time spent by the hooktender laying out strawline, rigging blocks, etc. for the next skyline cable road/landing change.

An effective hour for the road/landing changes was determined by similar methods as used in the yarding production/cost time-study. Non-productive delay time was recorded and separated out from productive time used actively involved in the road/landing change. Yarding delay categories and types listed in Appendix J were used in this part of the study.

Data was collected for the road/landing change time-study in the same period as for the yarding time-study. Collection of data was accomplished using one person on the landing (usually the handheld computer operator/timer) with a handheld stopwatch timing to the nearest minute accuracy. The hooktender was consulted after each road/landing change by the spotter or the timer for approximate time spent pre-rigging to the nearest 15 minute accuracy. Data was recorded on a form shown in Appendix M and entered, stored, and analyzed on computer spreadsheet software. Data collected was strictly observational and all road/landing changes were sampled.

H. Standard Treatment Unit Size Method

In order to objectively compare the treatment units described above, a uniform unit size methodology was devised to standardize the treatment units. As mentioned above and shown in Appendix A, the average treatment unit size was 24.9 acres (10.1 hectares). This figure rounded to 25 acres was used as the standard unit size. Additional weighted average statistics from the shift-level analysis (see Appendices A, N, and O) including timber volume per unit area, percent of total area yarded, gross to net timber scale ratio, and average gross log volume were used in yet another computer spreadsheet analysis to derive production and cost information for logging planning, felling, and yarding. Other information included in this analysis included the calculated costs per scheduled hour (Appendices C, H, and K), delay-based effective hours, logging planning unit specific requirements, total delay-free cycle time for each unit from the preferred regression models for felling and yarding, and other relevant summary statistics.

Each treatment unit was considered on an area basis with a logging plan map. Since three of the units contained ground-based skidder yarding terrain and one contained portions of terrain that required high lead cable yarding, a scenario was developed for each unit assuming that skyline cable yarding would be the only logging system used in a uniform 25 acre unit size. The unit was then evaluated in terms of the number of skyline cable roads necessary to harvest the projected percentage of total area yarded in the first-entry. For the clearcut this equated to 89 percent of the total area, with 11 percent of the area left in wildlife tree groups. Similarly, for the group selections, a weighted average 35 percent of the total area was used as the amount harvested in the first-entry for all treatments (see Appendix N for details).

The resulting evaluation is summarized in Table 7. This methodology, in addition to standardizing many of the

Table 7: Existing and projected number of skyline cable roads necessary to harvest standardized 25 acre (10.1 hectare) treatment unit

Unit-Rx	Area - acres (hectares)	Ground-based yarding present?	Existing number of skyline cable roads used in study	Projected number of skyline cable roads necessary for standard 25 acre unit
1-CCF	24.5 (10.1)	Yes	9*	13
2-GSPS	25.9 (10.5)	No	4	4
3-GSF.5P	25.0 (10.1)	No	7	7
4-GSF1.5P	25.3 (10.2)	Yes	8	10
5-GSFW	20.4 (8.3)	No	3	3
6-GSP.5P	28.0 (11.3)	Yes	3	3

* 9 skyline roads; 5 high lead roads

confounding unit specific effects in a study such as this, allowed for a sound comparison in the road/landing change cost component of this study. Average road/landing change time could now be used with a projected number of roads and amount of timber volume harvested to calculate a cost per unit volume. Along with the other cost components of the study (i.e. logging planning, felling, yarding, move in and out, and set up and tear down), a final total harvest cost could be derived for each group selection treatment unit and comparisons made in relation to the control clearcut unit.

V. RESULTS

Figures 9-14 illustrate topographic maps for the six treatment units in the study. These maps are a direct result of the logging planning portion of the study, although they also show felling and yarding time-study sampling areas and portions of the units that may have been yarded with ground-based equipment. In addition to these maps, Figures 15-17 show another aspect of the logging planning results: wildlife tree group locations for the clearcut unit and the resulting three-entry scenario for the group selection units. Table 8 lists the resulting average and ranges of sizes of wildlife tree groups for the clearcut unit (1-CCF) and patches for the group selection units. For visual ground view photographs of each unit, Appendix P should be consulted.

A. Logging Planning Requirements and Costs

1). Unit Layout

a). Unit 1-CCF

Unit layout requirements (shown in Figure 9) for the clearcut were minimal. Since this treatment's skyline road layout was "logger's choice", feasibility for yarding

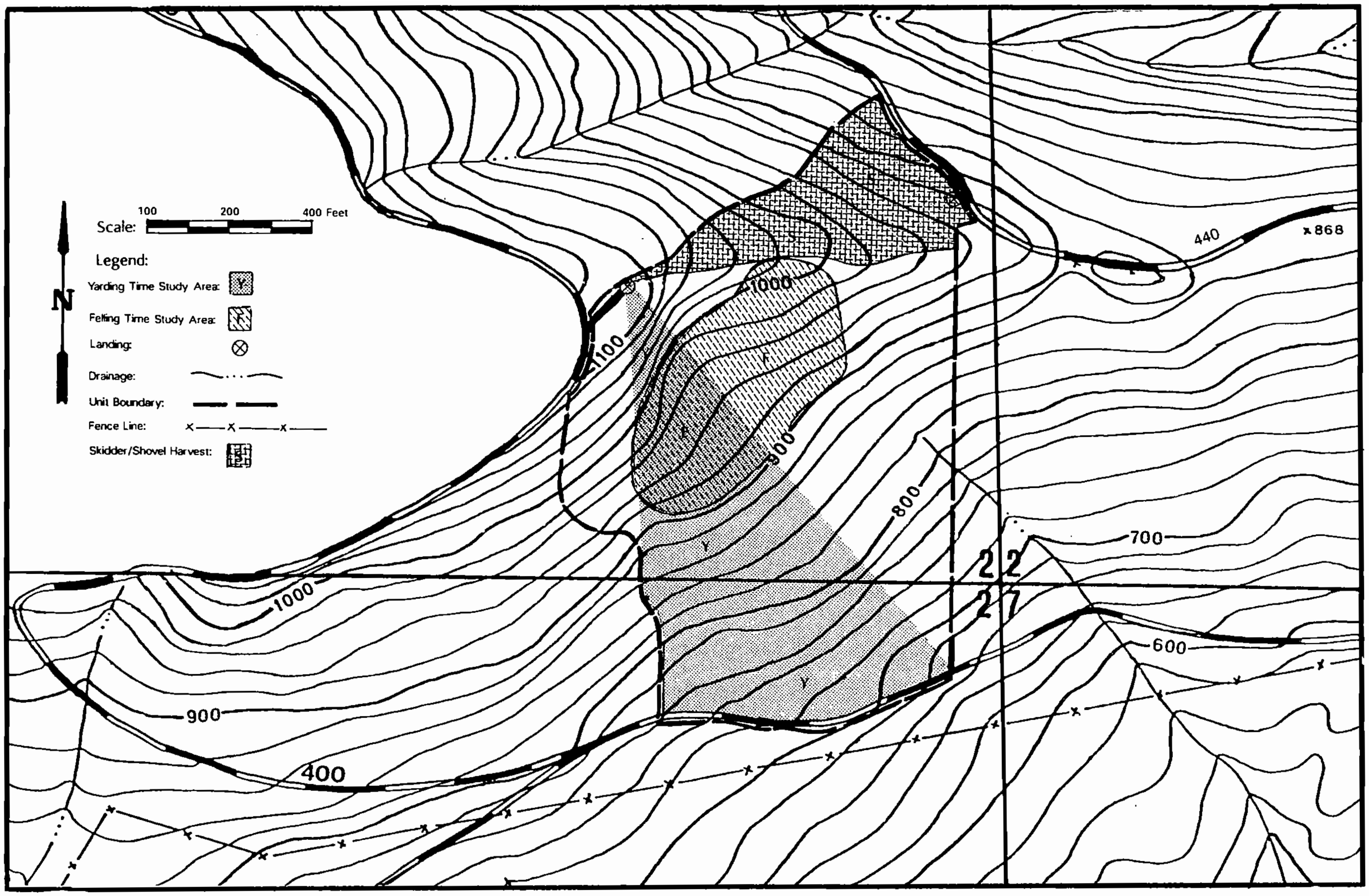


Figure 9: Unit 1 - Clearcut Fan (1-CCF) topographic map illustrating logging plan and sample areas

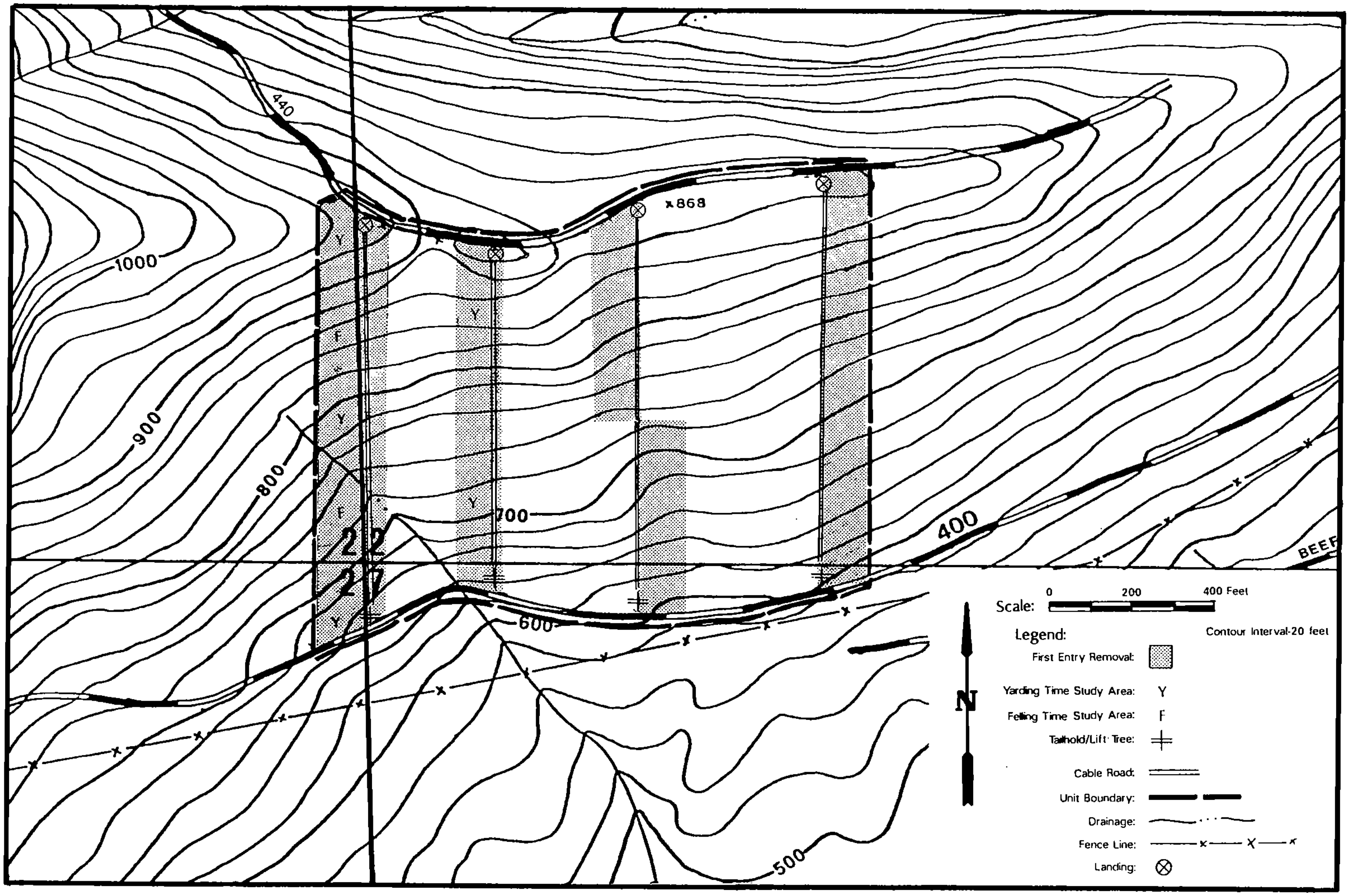


Figure 10: Unit 2 - Group Selection Parallel Strips (2-GSPS) topographic map illustrating logging plan and sample areas

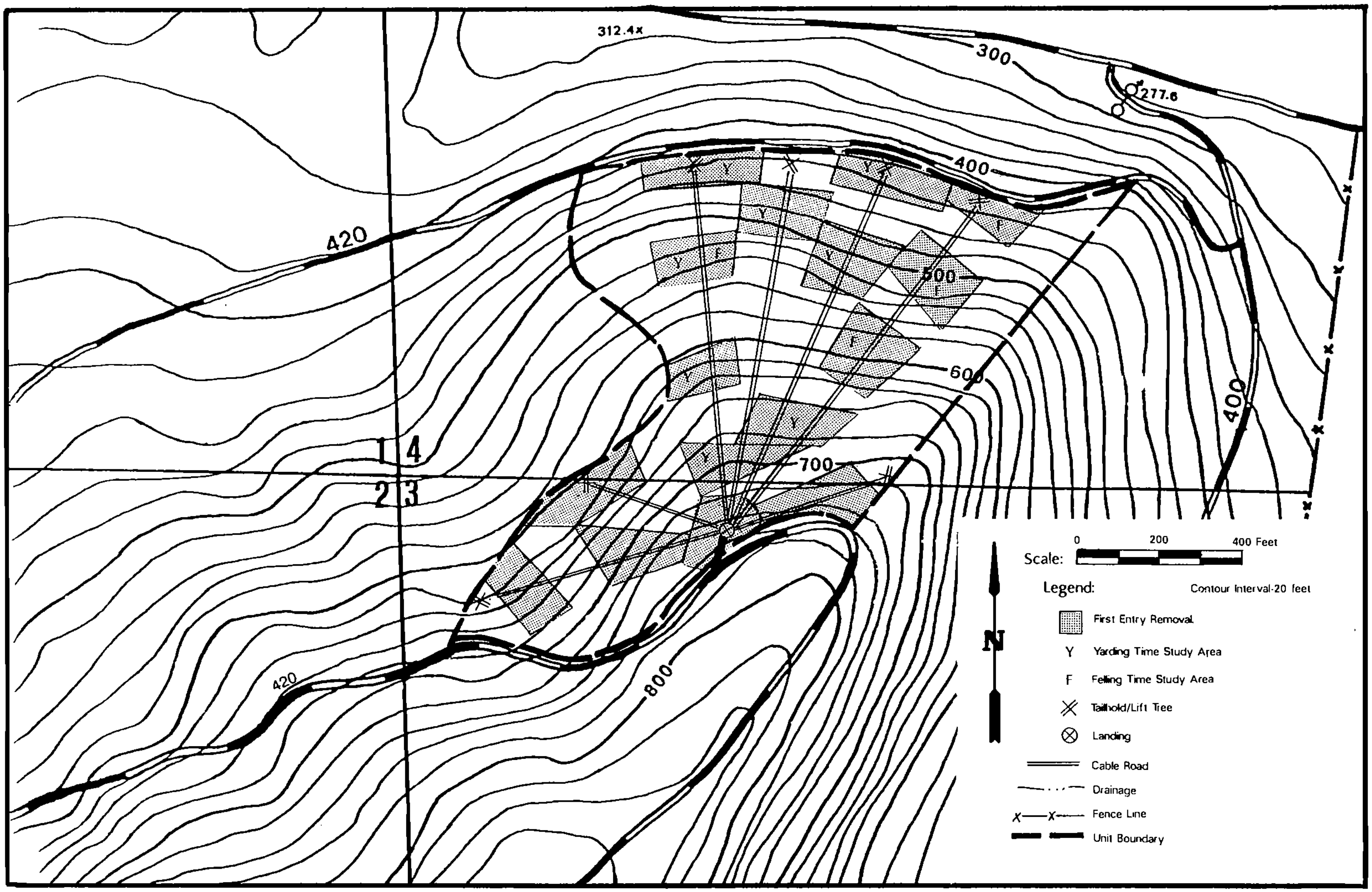


Figure 11: Unit 3 - Group Selection Fan 0.5 acre (0.20 hectare) Patch (3-GSF.5P) topographic map illustrating logging plan and sample areas

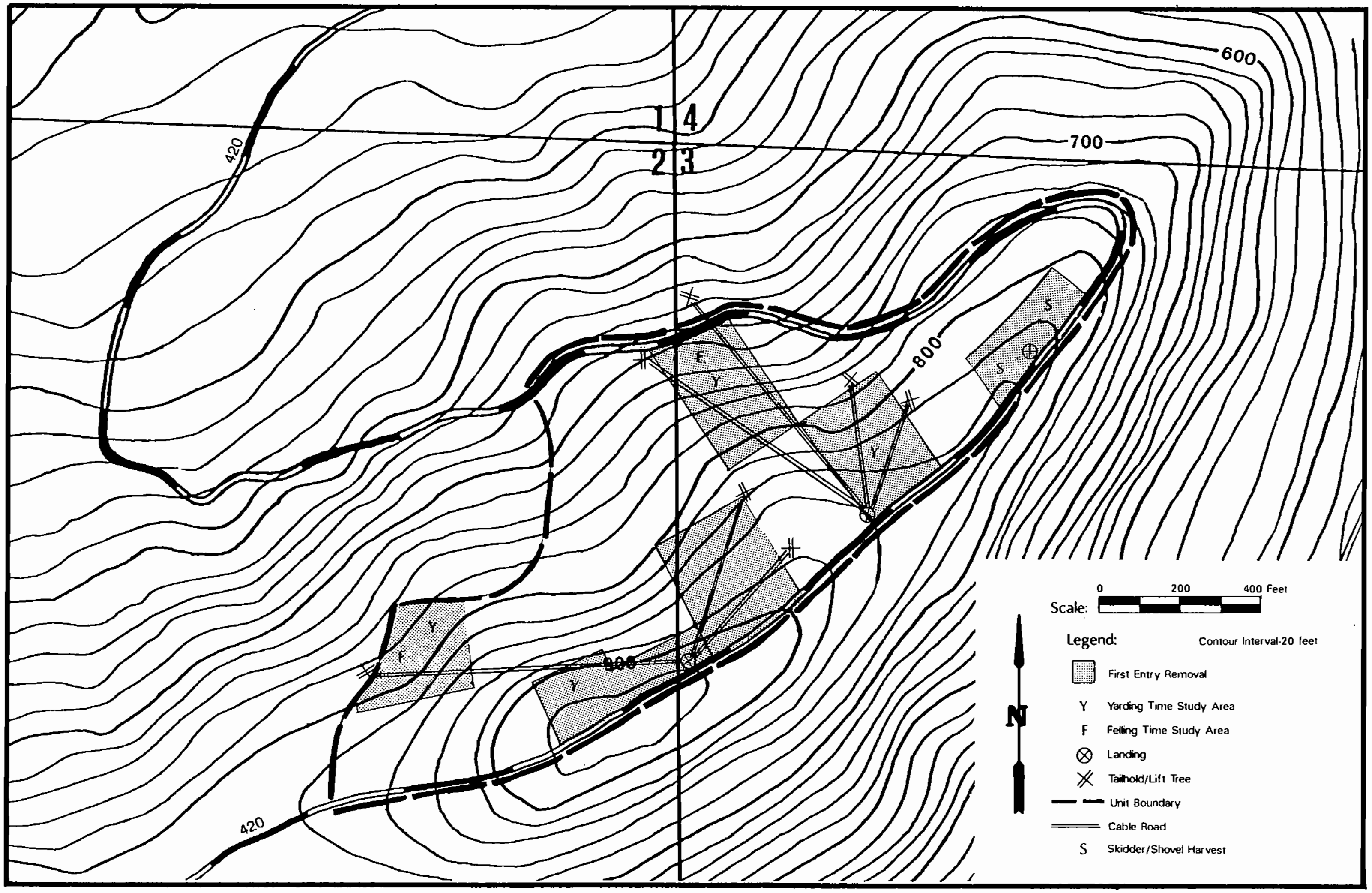


Figure 12: Unit 4 - Group Selection Fan 1.5 acre (0.61 hectare) Patch (4-GSF1.5P) topographic map illustrating logging plan and sample areas

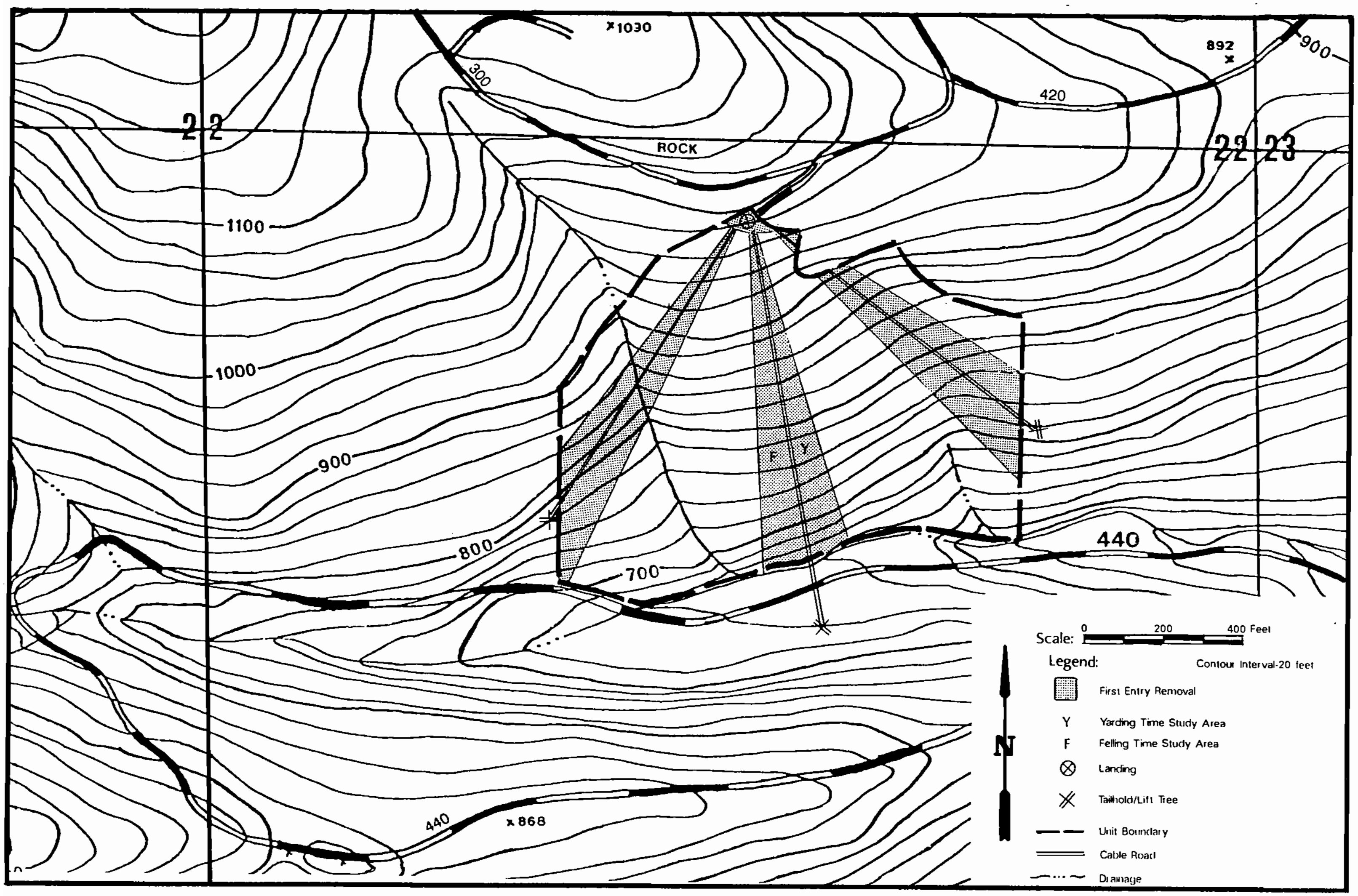


Figure 13: Unit 5 - Group Selection Fan Wedge (5-GSFW) topographic map illustrating logging plan and sample areas

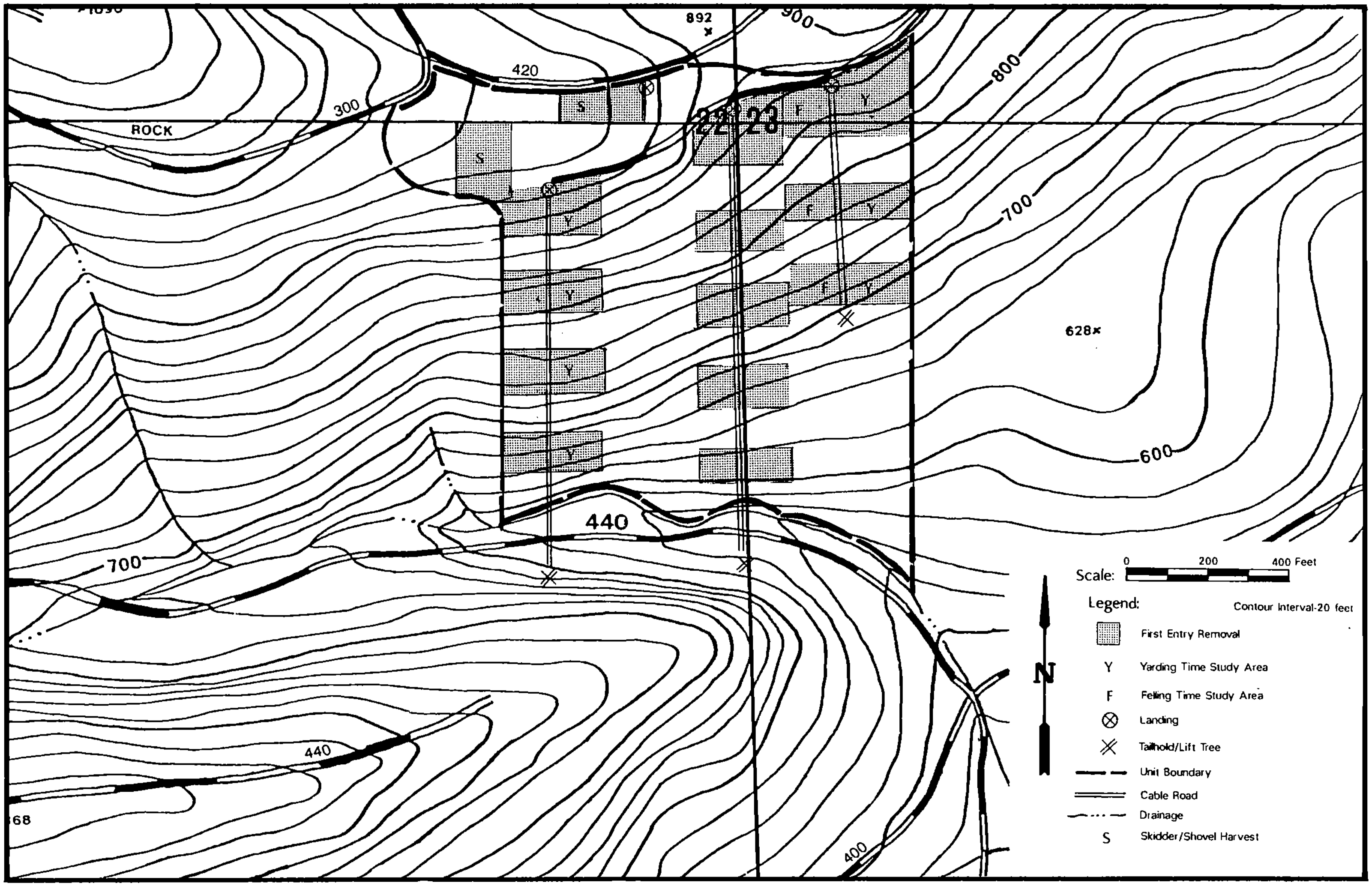


Figure 14: Unit 6 - Group Selection Parallel 0.5 acre (0.20 hectare) Patch (6-GSP.5P) topographic map illustrating logging plan and sample areas

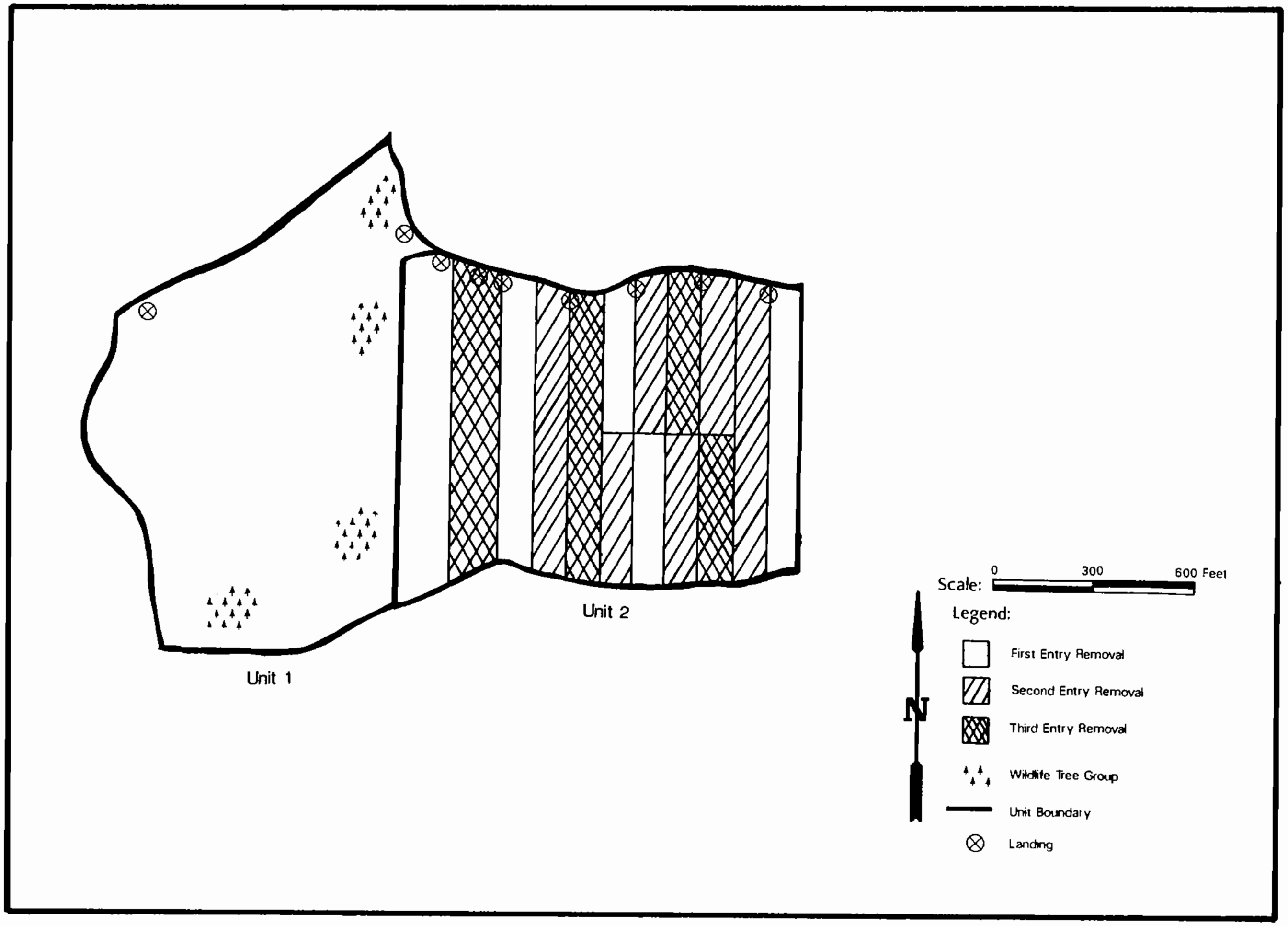


Figure 15: Planimetric map illustrating landing location with wildlife tree group placement for Unit 1 (1-CCF) and landing locations with three-entry harvest scenario for Unit 2 (2-GSPS)

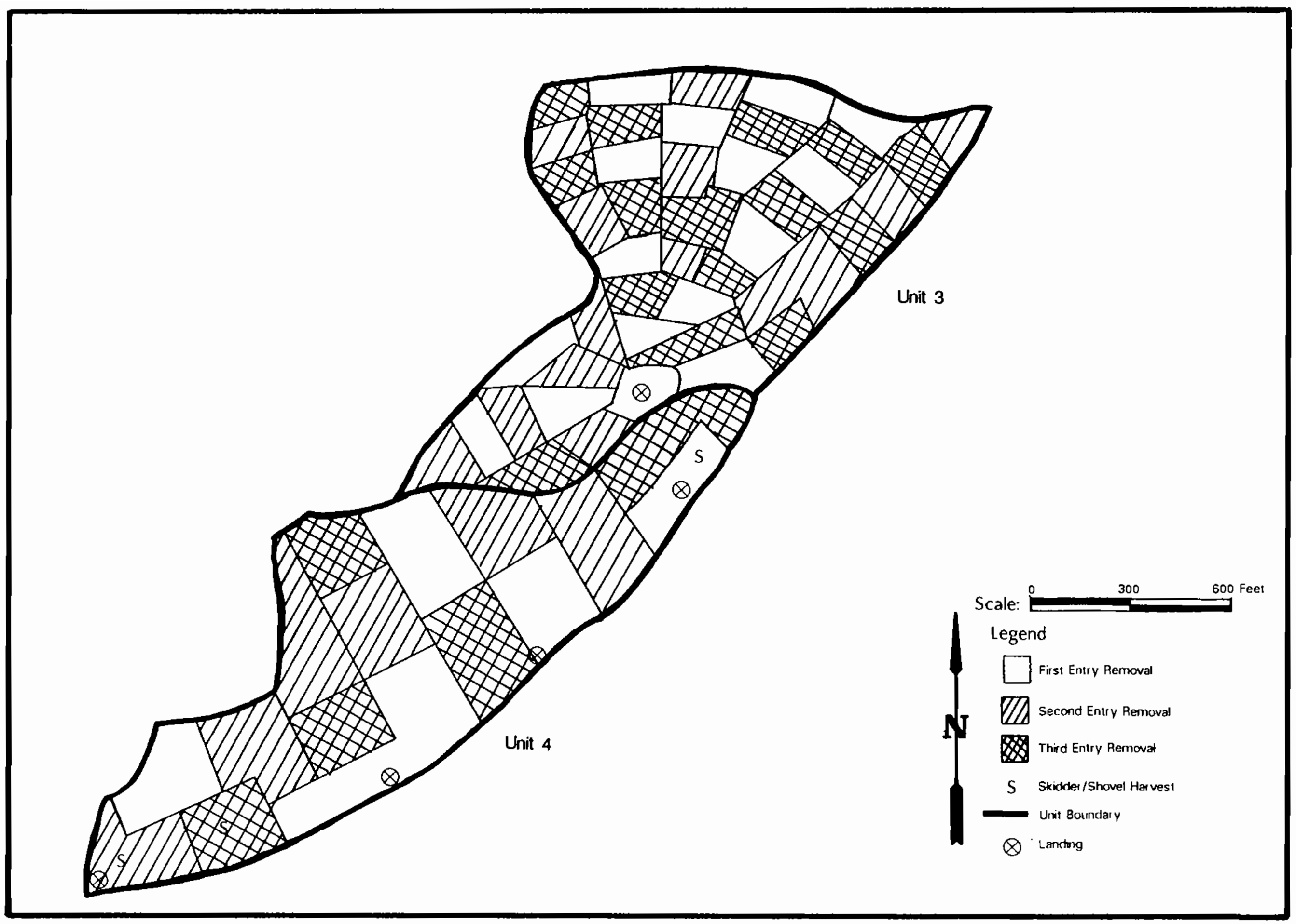


Figure 16: Planimetric map illustrating landing locations with three-entry harvest scenario for Units 3 (3-GSF.5P) and 4 (4-GSF1.5P)

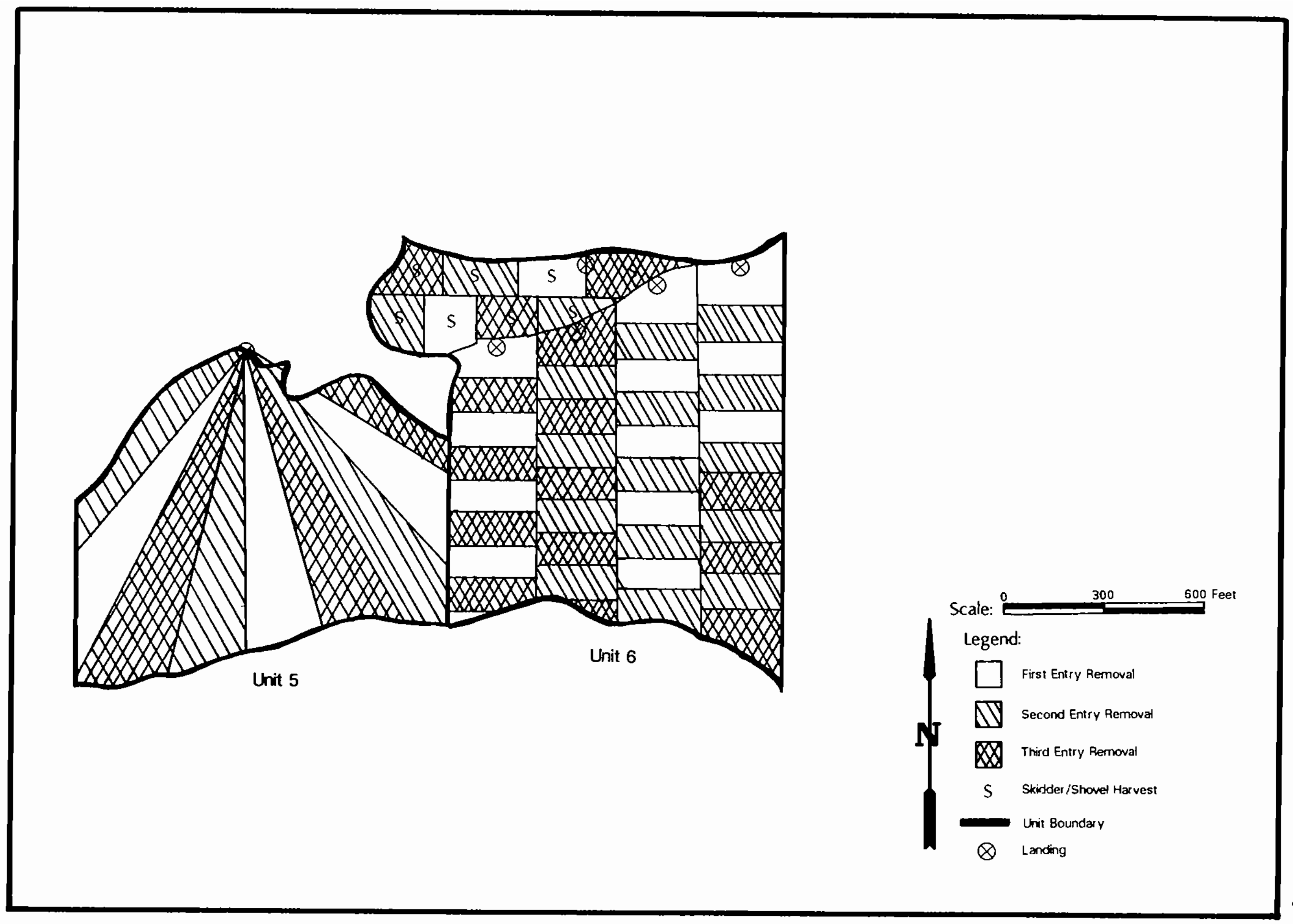


Figure 17: Planimetric map illustrating landing locations with three-entry harvest scenario for Units 5 (5-GSFW) and 6 (6-GSP.5P)

Table 8: Resulting map-based average and ranges of clearcut wildlife tree groups and first-entry group selection patches size/area

Unit-Rx	Wildlife tree group average size; range - acres (hectares)	Group selection patch average size; range - acres (hectares)
1-CCF	0.70; 0.54 - 0.86 (0.28; 0.22 - 0.35)	-
2-GSPS	-	2.5; 1.9 - 3.4 (1.0; 0.77 - 1.4)
3-GSF.5P	-	0.54; 0.41 - 0.70 (0.22; 0.17 - 0.28)
4-GSF1.5P	-	1.4; 1.0 - 1.8 (0.57; 0.40 - 0.73)
5-GSFW	-	2.4; 2.2 - 2.7 (0.97; 0.89 - 1.1)
6-GSP.5P	-	0.63; 0.54 - 1.1 (0.25; 0.22 - 0.45)

utilizing the contractor's equipment was merely verified using ground profile information and no skyline corridors were designated. Wildlife tree groups were marked and located on the back end of the unit and could thus serve as lift trees if needed, in addition to being in a relatively safe location. Downhill ground-based yarding with an FMC line skidder to a designated landing, although not included in this study, was required in the northern portion of the unit.

b). Unit 2-GSPS

Layout (shown in Figure 10) in this unit after ground profile data was collected and analyzed, initially consisted of locating parallel landings approximately 200 ft (61.0 m) apart for all three entries. After the mapping of three entries, taking care not to let adjacent strips in one entry overlap to create larger openings, skyline roads were then flagged in to designated lift trees within the unit. All guyline and tailhold tree/stumps in this and all other units were verified using the guidelines furnished in the Oregon Logging Safety Code (State of Oregon Department of Insurance and Finance, 1990).

Lift trees were used since the southern unit boundary was a road and no suitable timber was available across the road on which to anchor. On most of the corridors, a mobile tailhold was used on the south side of the road. After this procedure, the rectangular strips were boundary marked using flagged corridors, landings, and lift trees as frames of reference in several different relative strip location scenarios within the unit. These consisted of two strips where harvesting was performed on one side along the designated corridor. One strip was 100 ft (30.5 m) wide and 920 ft (280 m) in length; the other was 125 ft (38.1 m) wide and 890 ft (271 m) in length. Other strip layouts and sizes comprised one side and the middle of the strip harvested (150 ft (45.7 m) wide and 1020 ft (311 m) in length); and two staggered sides harvested (both 100 ft (30.5 m) wide and 440 and 470 ft (134 and 143 m) in length).

c). Unit 3-GSF.5P

Layout (shown in Figure 11) in this unit after the similar process above of ground profile//payload analysis, consisted first of locating one centralized landing. Mapping was next performed, with an effort made to use the least number of skyline roads per entry in order to harvest the required one-third of the volume. Care was taken, as was in all the patch (P) units, to prevent adjacent patches from combining together to create larger patches.

As in Unit 2, skyline roads were flagged in and lift trees were designated within the unit due to lack of suitable tail trees out of the unit. Stump tailholds were, however, available outside of the unit boundary in some cases; but leave trees were designated within the unit which could be used if needed. In some cases during logging, the lift tree was felled and one of the designated tailhold or guyline trees was used instead. This occurred when the hooktender determined that there were other options available that he preferred. Patches were cut tree marked starting from the back end of the skyline road (as a point of reference) and proceeding toward the landing. Corridors between first-entry patches were also cut tree marked using a 15 ft (4.6 m) designated corridor width. Lateral capabilities of the slackpulling carriage used (i.e. 125 ft (38.1 m) on either side of the skyline corridor) were not exceeded on any given patch.

d). Unit 4-GSF1.5P

Unit layout (shown in Figure 12) in this treatment consisted of locating two centralized fan setting landings due to the long, narrow shape of the unit. As a result of the two landings, a relatively higher number of ground profiles as compared to other units were necessary, although the profiles were shorter in length. Mapping of 1.5 acre (0.61 hectare) patches was constrained in this unit by areas of relatively small timber. Consequently, the first-entry patches had to be of a certain age/size of timber while also not being adjacent to another first-entry patch. In addition, due to the proximity of another group selection unit (3-GSF.5P), future guyline trees within this unit had to be left for the next two entries in Unit 3.

Skyline roads were flagged and lift trees designated in most of the patches which were located relatively far away from the given landing. For one of the patches close to the landing, a designated skyline road to another patch could be used to yard a portion of the patch. Another short skyline road was required (although two were planned for) and this road was merely verified for rigging feasibility. On the average, each patch required 1.4 skyline roads to harvest all of the volume contained in the patch. Only one skyline road necessitated a tailtree out of the unit. Patches located near landings were boundary marked from the top of the unit down and the reverse procedure was used for patches near the back end of the unit. The same criteria for designated corridor width between first-entry patches was used as above in Unit 3. Ground-based shovel yarding to a designated landing was utilized in the northeastern portion of the unit, although this was not studied.

e). Unit 5-GSFW

Layout (shown in Figure 13) in this unit, after similar ground profile/payload analysis as was performed in other units, consisted initially of locating one centralized landing. Mapping was next accomplished with the objective of removing one-third of the volume per entry in approximately equal size wedges separated spatially to prevent wedge overlap in a given entry. Back end unit widths of the wedges were planned in order to maximize the lateral capabilities of the skyline carriage (i.e. 250 ft (76.2 m)). Once mapping was finished, compass azimuths were followed in the middle of each wedge in order to verify tail/lift tree and/or stump tailhold availability and rigging feasibility. Skyline road corridors were not designated since the corridor would ideally be in the middle of the wedge.

In two of the wedges, trees were available for rigging in this entry out of the unit. One wedge sharing a common boundary with another group selection unit (6-GSP.5P) was identified and provisions were made during the mapping and tree marking of the 0.5 acre (0.20 hectare) patches in Unit 6 to leave third-entry timber to satisfy future rigging needs. Trees were boundary marked from the top of the unit/landing down on one side of the wedge following compass azimuths. Back end widths were then measured and the other side of the wedge was marked on the way back up to the landing.

f). Unit 6-GSP.5P

Unit layout (shown in Figure 14) in this treatment, after ground profile/payload analysis, consisted of first locating four landings for all three entries. Parallel landings approximately 200 ft (61.0 m) were attempted at first, however a fifth landing covering only a fraction of 200 ft would have resulted. Consequently, the extra lateral distance from the potential fifth skyline road was spread as equally as possible to the four landings mapped in and laid out. Lateral distance on either side of the designated corridor was kept under 125 ft (38.1 m) to prevent exceeding the capabilities of the slackpulling carriage. In addition, as in Unit 3, a similar standard of using the least number of skyline roads per entry in order to harvest the required one-third of the volume was followed.

Skyline roads from three of the landings were flagged in and stump tailholds out of the unit verified for two of the roads and a designated lift tree, tailhold, and guyline anchors in the unit were identified for one of the roads. Patches were cut tree marked from the top of the unit at the landing down. The same criteria for designated corridor width between first-entry patches was used as above in the other patch units. Ground-based yarding to a designated landing with a tractor line skidder was utilized in the northern portion of the unit, although this was not included in this study.

2). Time Requirements

The average time and relative frequency of area-wide logging planning time components for all treatments in this study and related ongoing research units in the project area by Tappeiner et al. (1991) is shown in Figure 18. Map/photo work and the flagging of unit boundaries were the most time demanding components and required 63 percent of the total 0.7095 hrs/acre (1.7532 hrs/hectare) for all time components. This time requirement per unit area is based on total unit area rather than area harvested in this entry.

In contrast to area-wide planning, the treatment specific time components (both randomized and non-randomized) were based on harvested area (i.e. first-entry). In order to compare the total logging planning time requirements for the different treatments, an equal basis on which to relate area-wide and treatment specific logging planning together was needed; Table 9 illustrates this procedure. For a detailed breakdown of treatment specific time required per unit area for each of the time components, see Appendix Q.

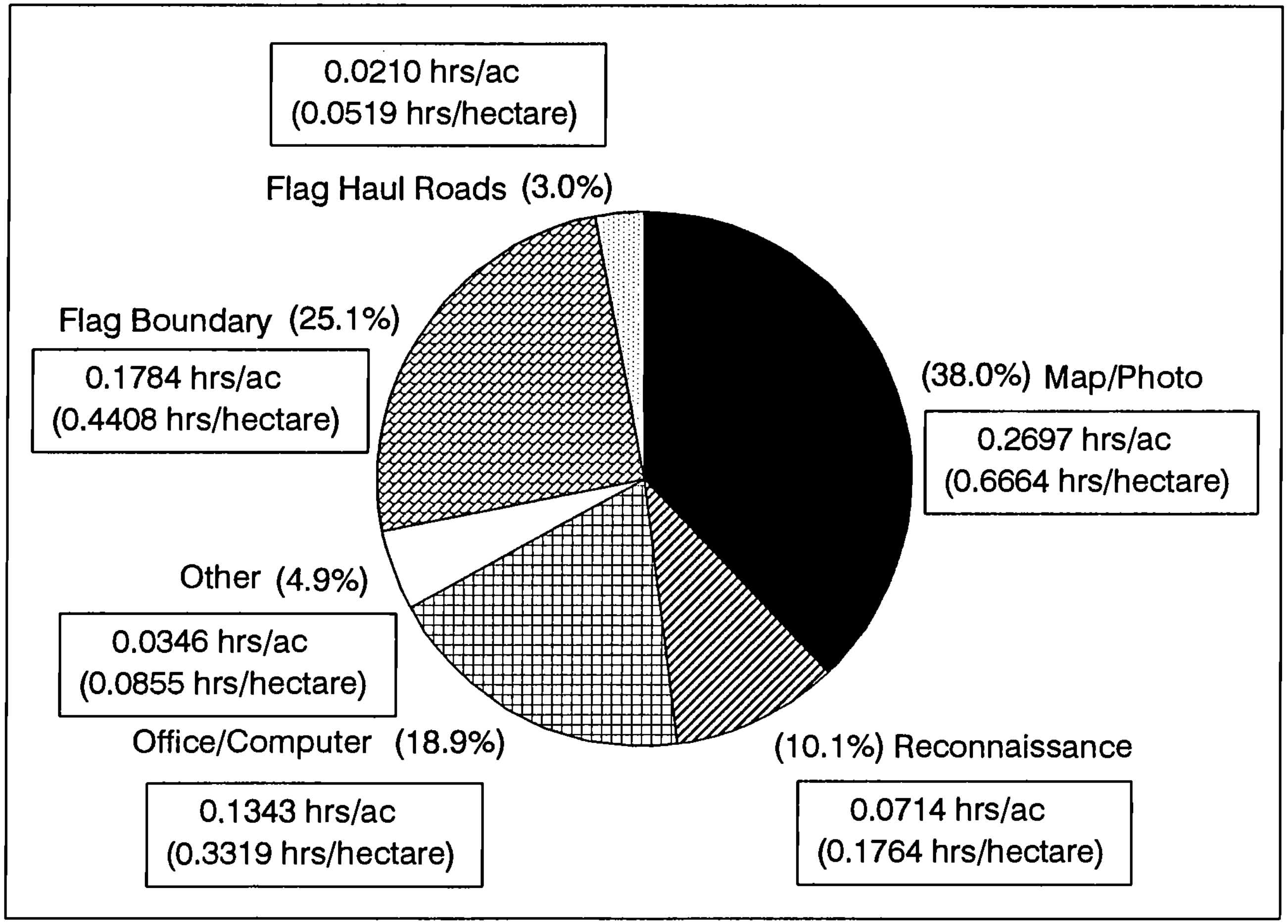


Figure 18: Area-wide pre-planning and logistics logging planning time component requirements and percentages of total area-wide planning time

Table 9: Logging planning time per treated unit area requirement comparisons (area-wide (PP+L), treatment specific, and total)

Unit-Rx	Study PP+L time per total unit area - hrs/acre (hrs/hectare)	PP+L for standardized unit (hours)	Standardized PP+L time per treated unit area - hrs/acre (hrs/hectare)	Percent difference over clearcut
1-CCF	0.7095 (1.7532)	17.7375	0.7972 (1.9699)	-
2-GSPS	"	"	2.0271 (5.0090)	154
3-GSF.5P	"	"	"	"
4-GSF1.5P	"	"	"	"
5-GSFW	"	"	"	"
6-GSP.5P	"	"	"	"

Table 9: (continued)

Unit-Rx	Treatment specific time per treated unit area - hrs/acre (hrs/hectare)	Percent difference over clearcut	Total planning requirements time per treated unit area - hrs/acre (hrs/hectare)	Percent difference over clearcut
1-CCF	0.8890 (2.1967)	-	1.6862 (4.1666)	-
2-GSPS	4.0909 (10.1086)	360	6.1180 (15.1176)	263
3-GSF.5P	9.6307 (23.7975)	983	11.6578 (28.8064)	591
4-GSF1.5P	9.6052 (23.7344)	980	11.6323 (28.7434)	589
5-GSFW	4.4366 (10.9628)	399	6.4637 (15.9718)	283
6-GSP.5P	7.4006 (18.2869)	732	9.4277 (23.2958)	459

Area-wide planning exhibited a 154 percent increase in all group selections over the clearcut due to the reduced amount of area harvested. Group selection treatment specific time per unit area requirements were highly variable (360-983 percent more time compared to the clearcut), and total planning time requirements displayed a smaller, yet still significant range of 263-591 percent more time for group selections versus the clearcut. On the average this amounted to 437 percent for all group selections.

3). Costs

Area-wide logging planning costs were \$0.52/Mbf (\$0.09/m^3) for the clearcut and \$1.32/Mbf (\$0.23/m^3) for all of the group selections. Area-wide, treatment specific, and total costs exhibited essentially the same percentage differences (i.e. some rounding errors detected) as they did on a time per treated unit area basis in Table 9. Figures 19 and 20 show graphically the differences in cost for all of the treatment specific time components measured. The most dramatic difference occurred in the Flag Skyline Roads time component, for which the clearcut did not require at all. It is relevant to note that planning costs did not decrease for any of the group selection time components over the clearcut treatment. Table 10 lists the relative percentage

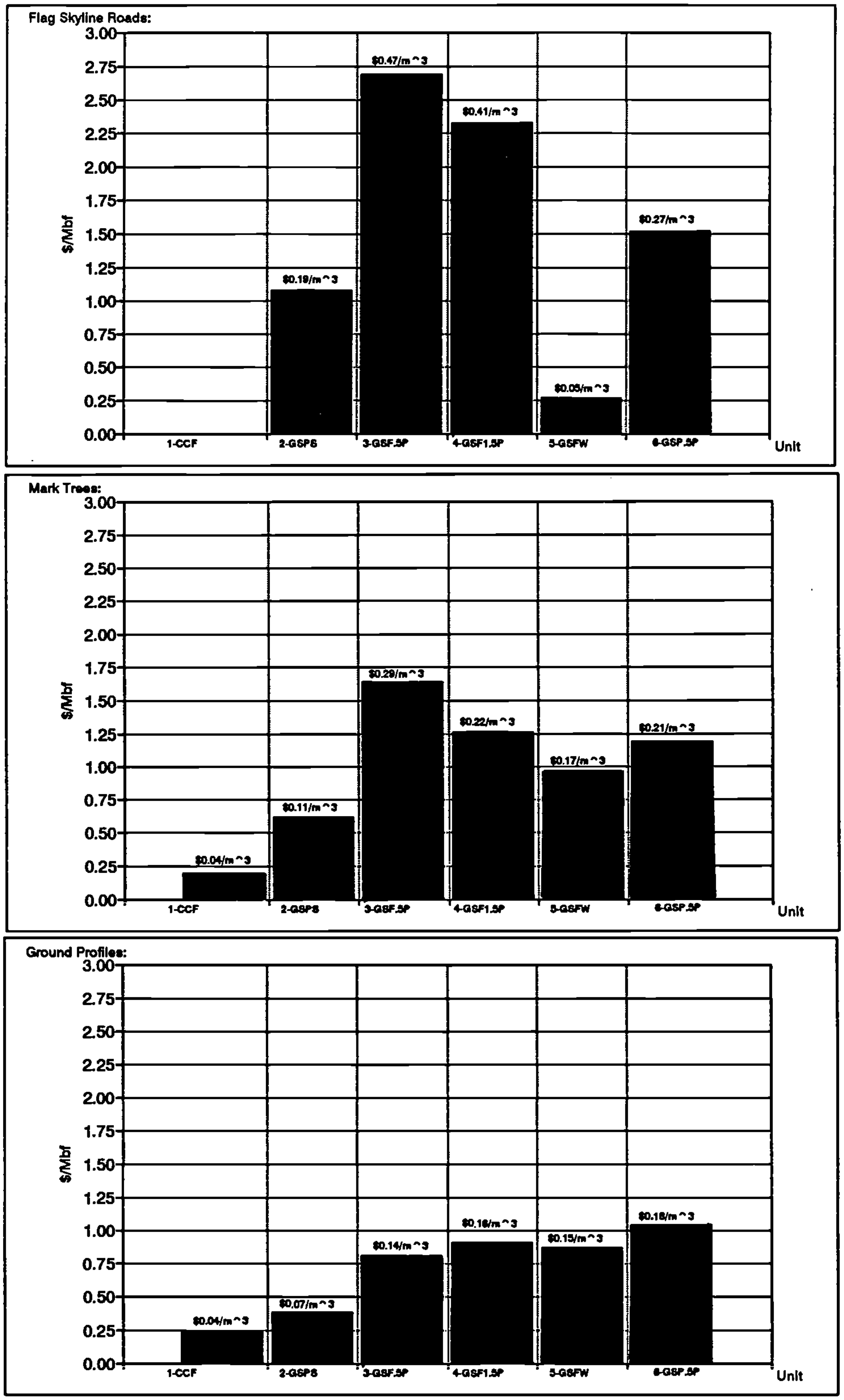


Figure 19: Randomized treatment specific logging planning time component costs per unit volume (US-graphic; SI-numeric).

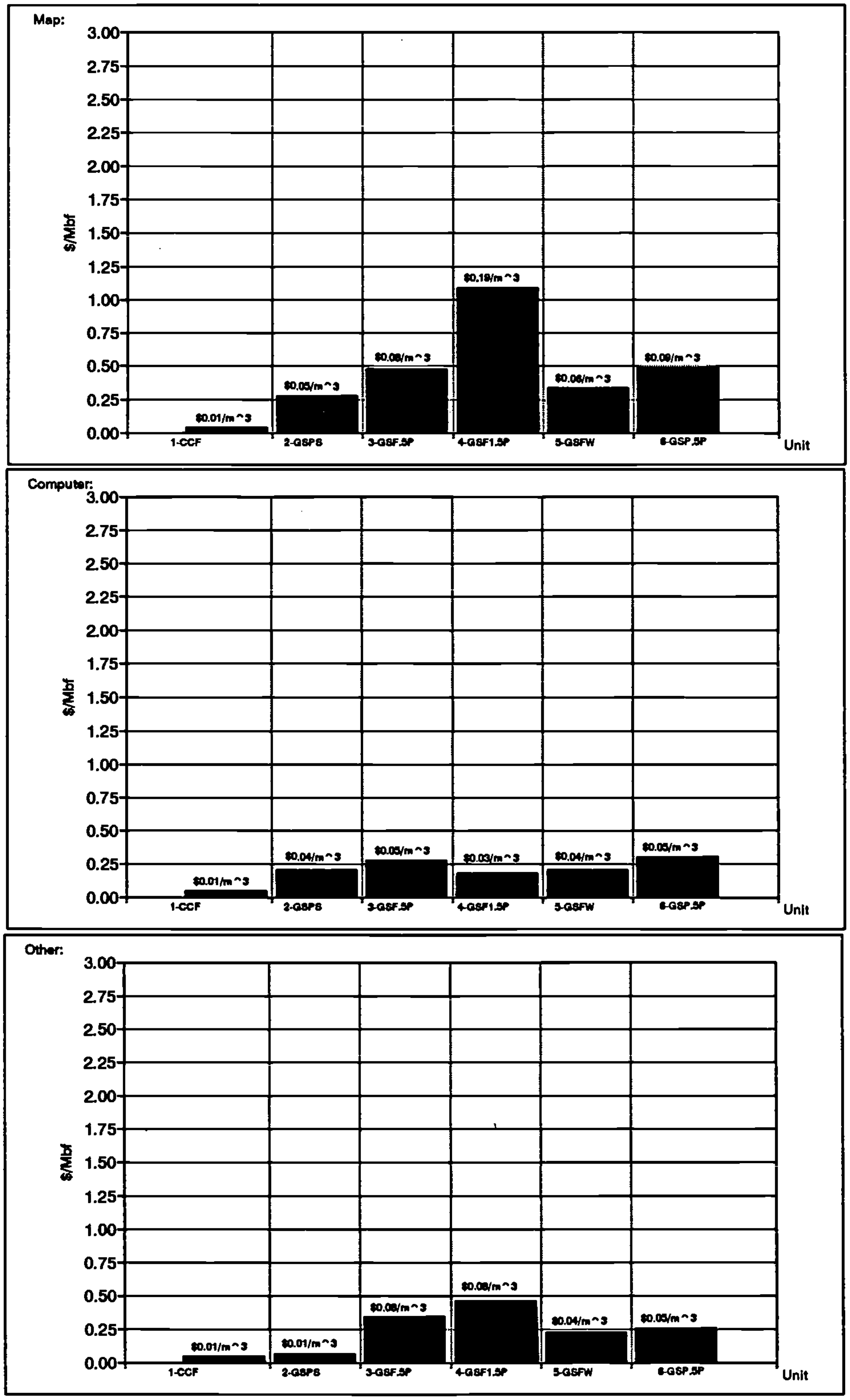


Figure 20: Randomized and other treatment specific logging planning time component costs per unit volume (US-graphic; SI-numeric).

Table 10: Relative percentage increase comparisons for treatment specific logging planning time components cost per unit volume (i.e. group selection versus clearcut treatment)

Unit-Rx	Flag Skyline Roads	Mark Trees	Ground Profiles	Map	Computer	Other
2-GSPS	\$1.08/Mbf (\$0.19/m^3) vs. 0	210%	63%	600%	320%	40%
3-GSF.5P	\$2.69/Mbf (\$0.47/m^3) vs. 0	720%	238%	1100%	460%	600%
4-GSF1.5P	\$2.33/Mbf (\$0.41/m^3) vs. 0	530%	279%	2625%	260%	840%
5-GSFW	\$0.27/Mbf (\$0.05/m^3) vs. 0	380%	263%	750%	320%	360%
6-GSP.5P	\$1.52/Mbf (\$0.27/m^3) vs. 0	495%	333%	1125%	520%	400%

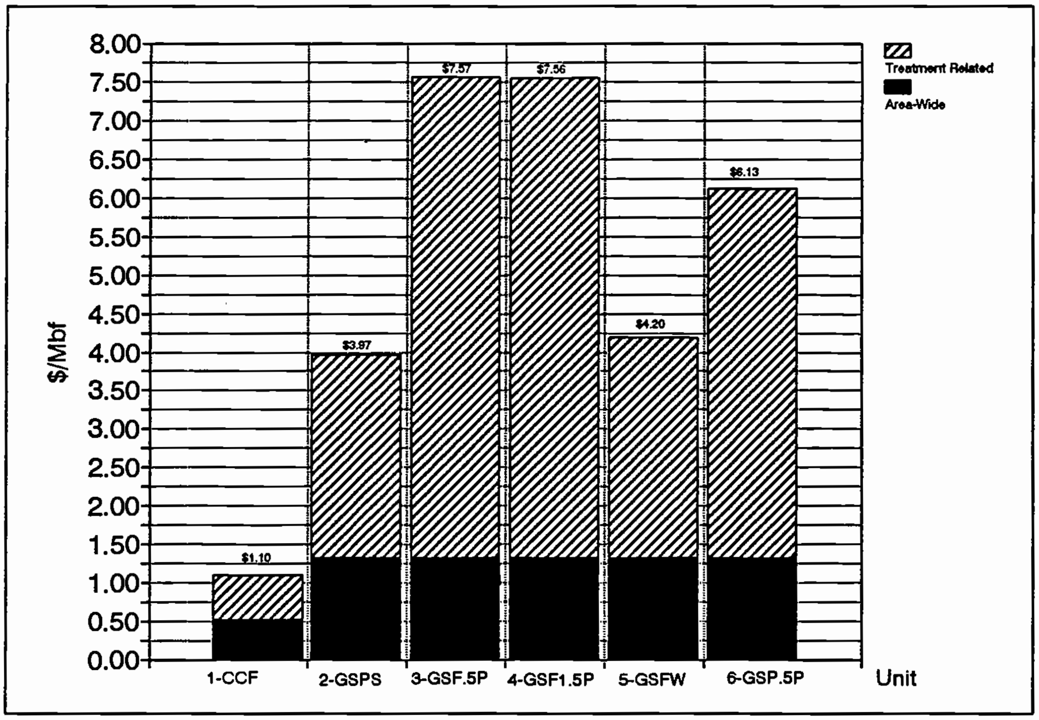
differences of the individual components (see Appendix Q for specific cost figures).

Total logging planning cost per unit volume for both area-wide and treatment specific components is shown in Figure 21. The clearcut unit, as suspected, was the most efficient in terms of unit layout costs. Alternatively, the fan patch group selections (3-GSF.5P and 4-GSF1.5P) nearly tied each other for least efficient as far as layout costs were concerned. The following increases in relative costs over the clearcut unit were calculated for total logging planning cost per unit volume:

2-GSPS	261%
3-GSF.5P	588%
4-GSF1.5P	587%
5-GSFW	282%
6-GSP.5P	457%

B. Felling Production and Costs

The average weighted time for felling cycle elements (both hardwood and softwood trees) and the relative frequency of each element is shown in Figure 22. Figure 23 further differentiates the comparison of felling cycle elements specifically into hardwood and softwood trees. As can be seen, bucking consumes the most time in the weighted and softwood felling cycle and hardwoods were not bucked (i.e. yarded whole tree). It should be noted that felling times reflect both wedged and non-wedged trees.



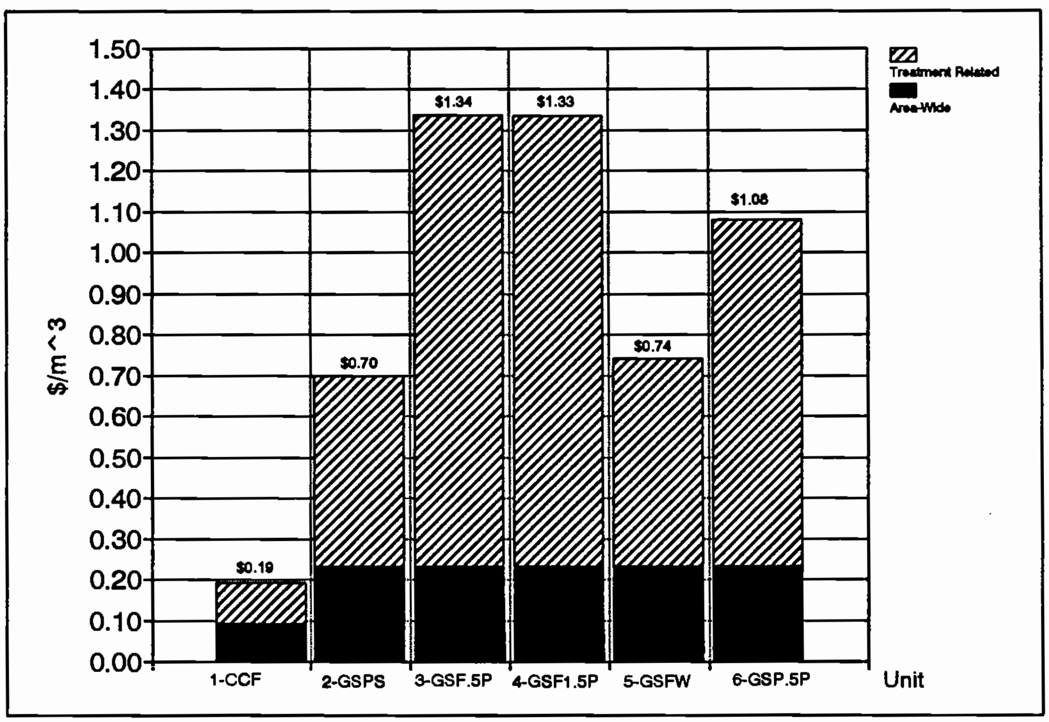


Figure 21: Total logging planning cost per unit volume (US and SI).

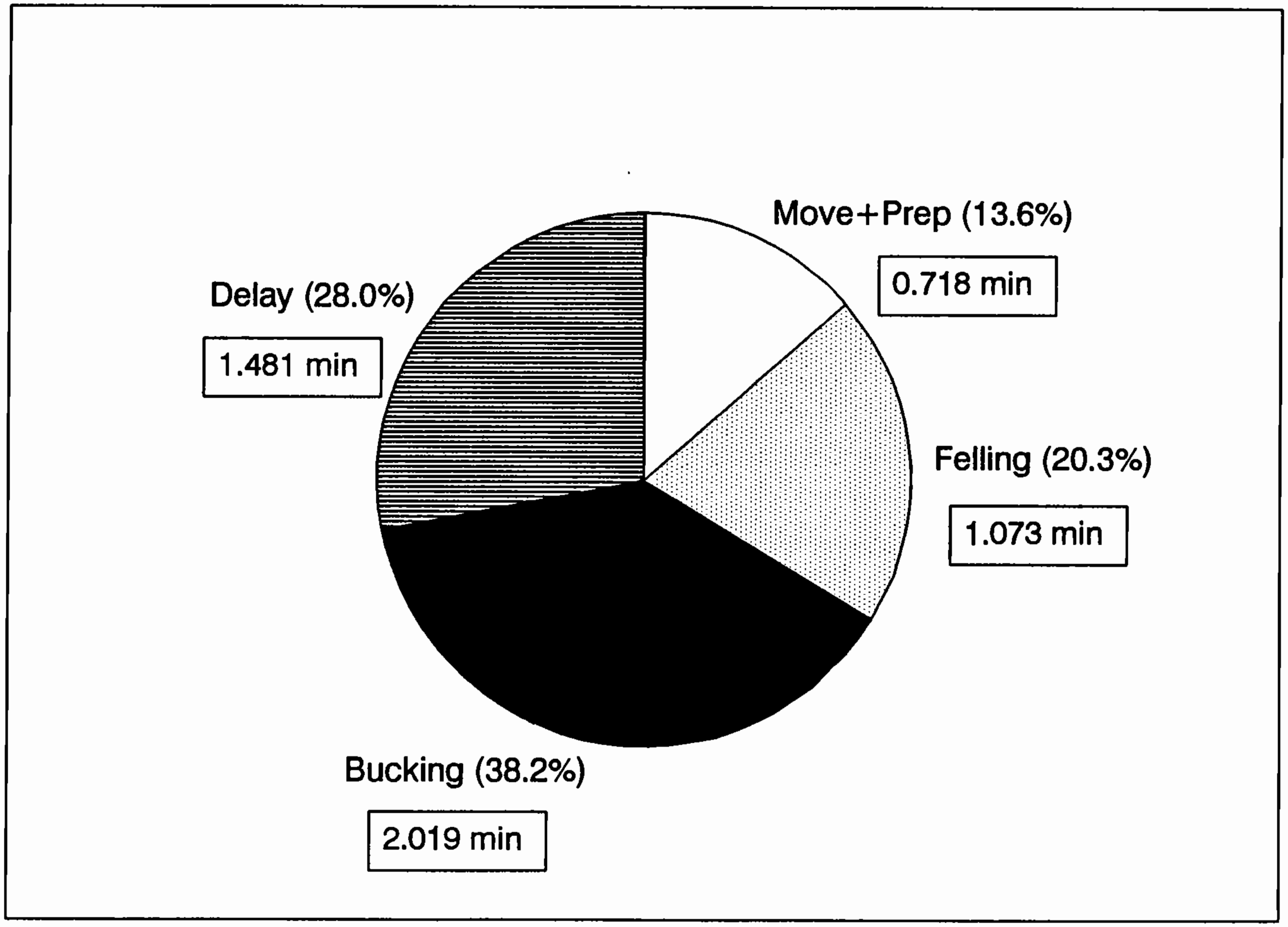
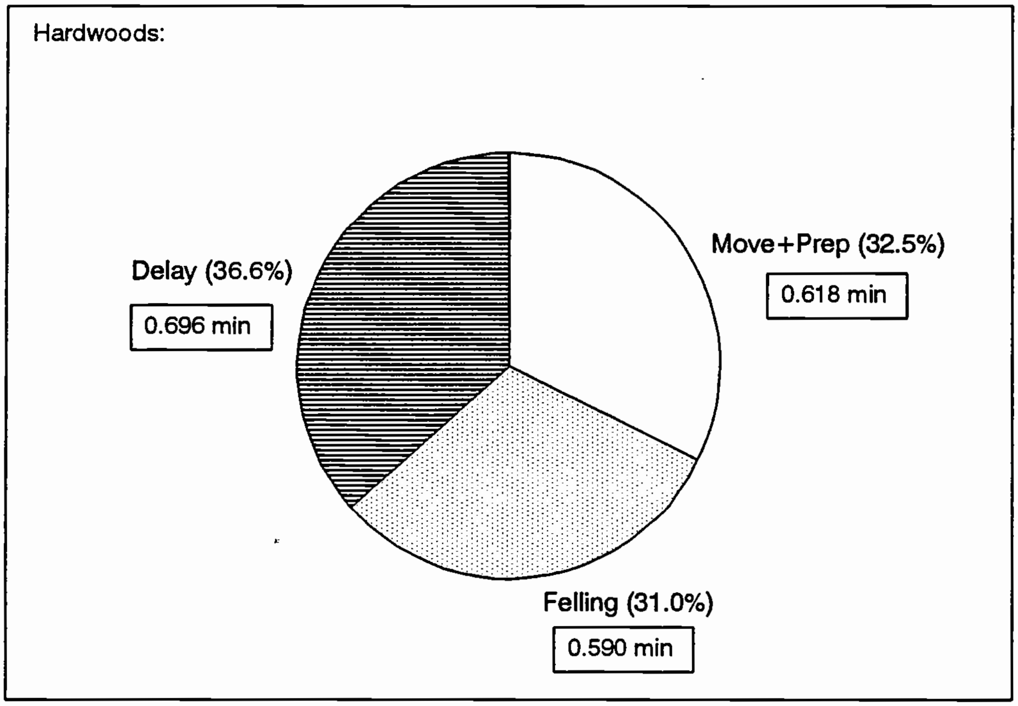


Figure 22: Felling time-study average time and relative frequency for felling cycle elements (all treatments). Percentages of total felling cycle time.



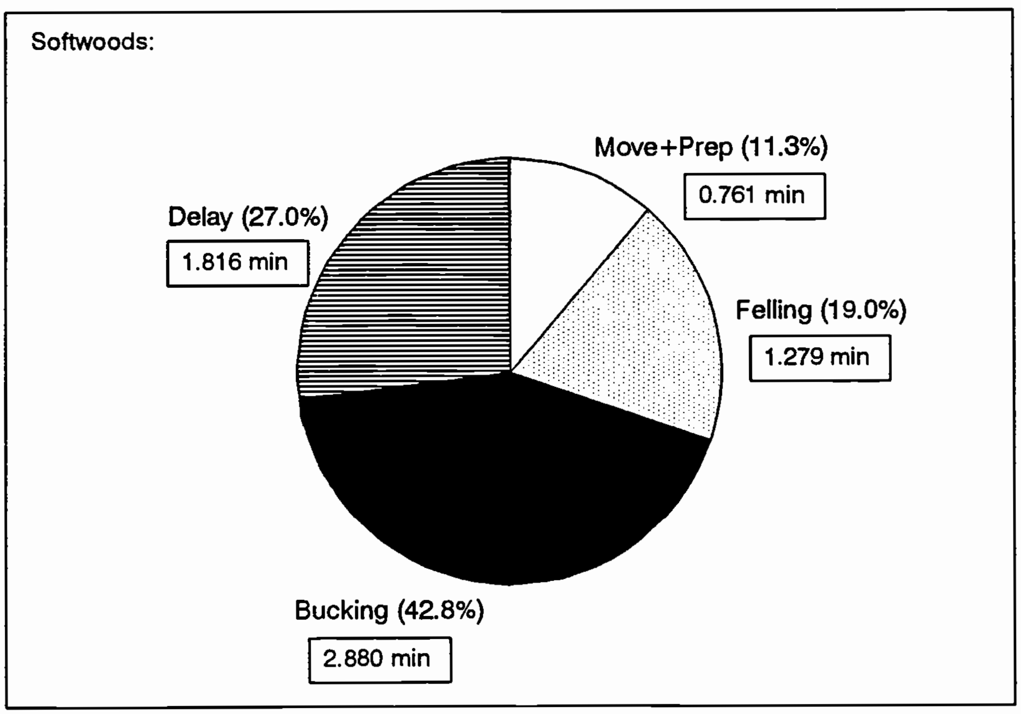


Figure 23: Felling time-study average time and relative frequency for hardwood and softwood felling cycle elements (all treatments). Percentages of total felling cycle time.

The preferred stepwise felling delay-free total cycle time prediction model selected and other relevant information is shown in Table 11. No statistically significant treatment differences were noted in the model selection process. However, a computer spreadsheet sensitivity analysis indicated that wedging should be handled as a treatment specific prediction parameter. Variables affecting the total delay-free felling cycle in order of importance are: inside bark butt diameter, Scribner board foot volume in the tree, whether or not the tree was wedged during felling, and number of logs in the tree. All selected explanatory variables were significant at the 99 percent confidence level. Appendix R lists summary statistics for all of the selected model parameters.

Felling delay and treatment specific activity categories are illustrated in Figure 24. Personal delays consumed most of the time; these for the most part consisted of water, food, and rest breaks. Operational, fuel, and felling non-merch trees contributed to account for most of the remaining delays. A more detailed summary of unit specific delays and activities is included in Appendix S. The only treatment specific activity, planning, accounted for very little of the recorded time. Figure 25 shows graphically on a unit and study basis the percentages of time in which planning was required for each unit. On a study basis, only one unit (4-GSF1.5P) required more

Table 11: Regression fit for delay-free felling time cycle (FTOB) prediction model

$$\text{Mean FTOB} = -\ 0.824261 + 0.181620 * (\text{DIAM}) + 0.002173 * (\text{BFVOL}) + 1.026032 * (\text{WDGE}) + 0.461181 * (\text{LOGS})$$

R-squared (adjusted for d.f.) = 0.8983
Standard error of estimate = 1.00401
Degrees of freedom (d.f.) = 764

Parameter	Standard error	Significance level
Constant	0.143202	0.0001
DIAM	0.011456	0.0001
BFVOL	0.000138	0.0001
WDGE	0.082028	0.0001
LOGS	0.061070	0.0001

Forward selection process:
(not adjusted for d.f.)

Step	Parameter	Partial R-squared	Model R-Squared
1	DIAM	0.8312	0.8312
2	BFVOL	0.0361	0.8673
3	WDGE	0.0240	0.8913
4	LOGS	0.0076	0.8988

Parameter definitions:

Response:

FTOB - Delay-free felling cycle (min)

Explanatories (with values used in analysis):

DIAM - Average inside bark butt diameter (in): 18.4
BFVOL - Average gross Scribner board foot volume (bf) per tree: 464
WDGE - 1 = wedged tree, 0 = otherwise: Treatment specific
LOGS - Average number of logs per tree: 2.38

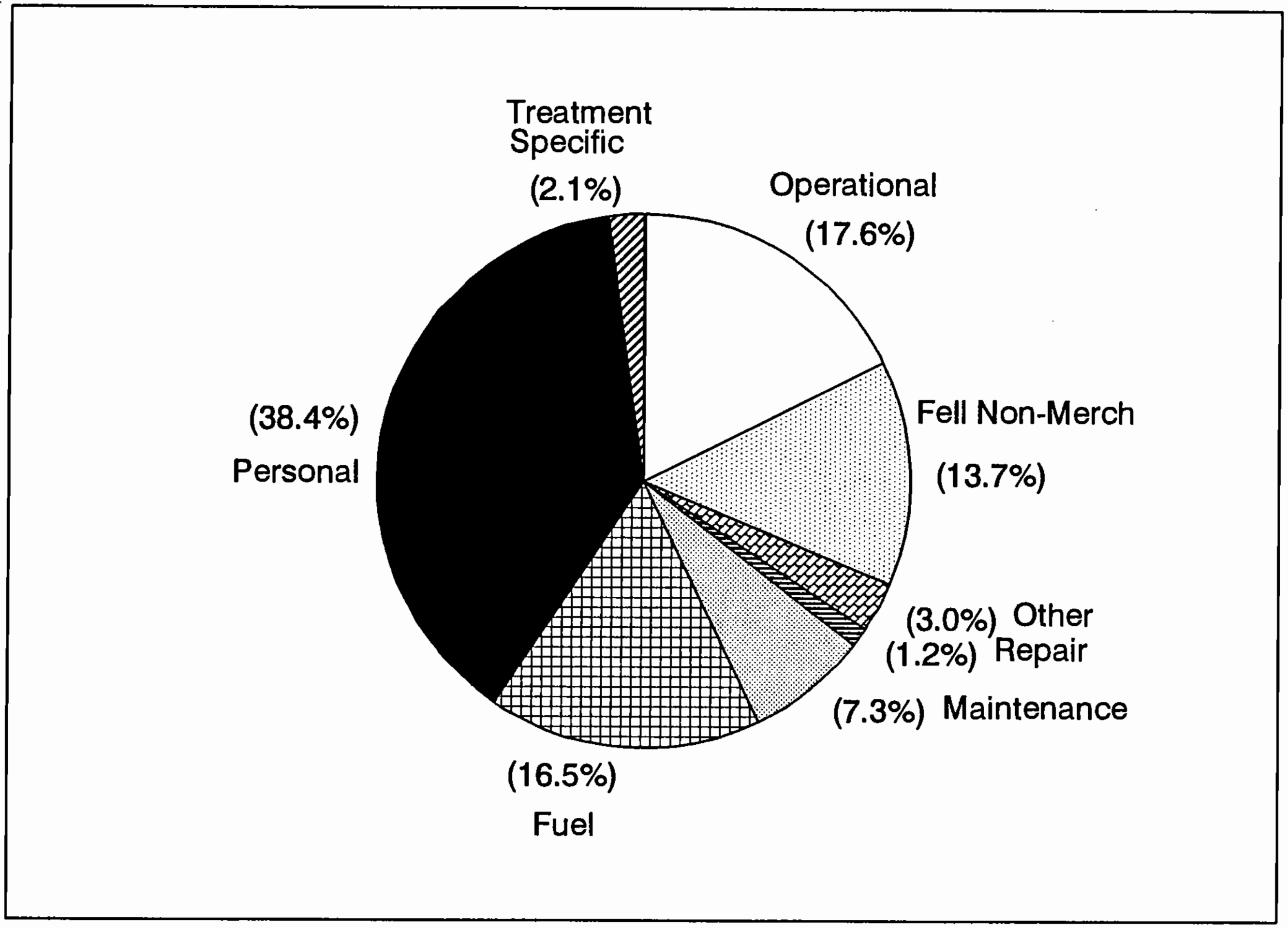


Figure 24: Felling time-study delay and treatment specific activity categories. Percentages of total felling delay and treatment specific activity time for all units.

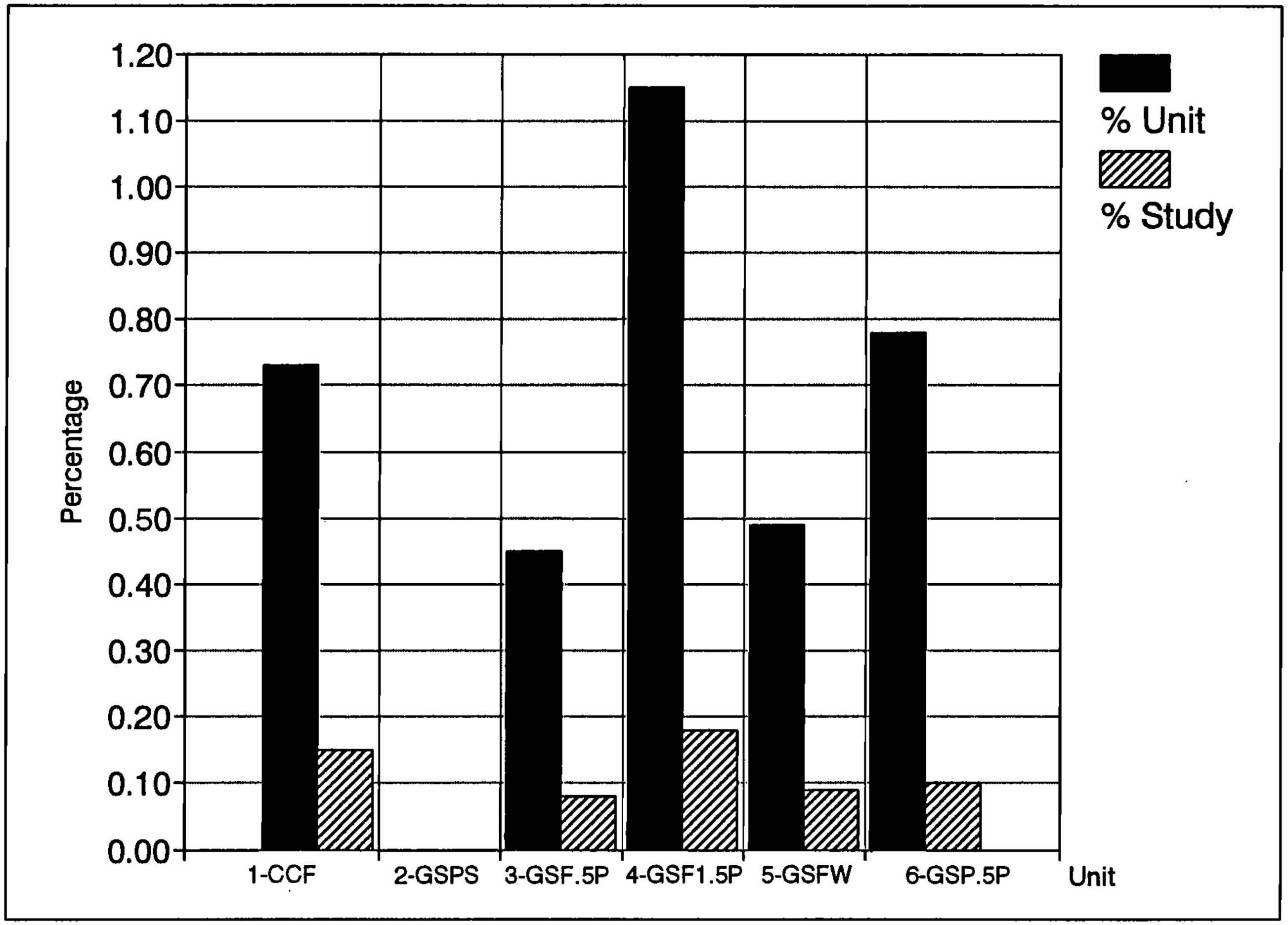


Figure 25: Felling treatment specific activities (i.e. planning). Percentages of total delay-free cycle + all recorded delays and treatment specific activities.

planning than the clearcut. Unit 2 (2-GSPS) required no planning at all on the part of the timber faller. As noted in the methods section of this paper, this component, originally in the delay-free cycle at the start of the study, was shown to statistically influence most of the observations it was originally included in. It was therefore removed and considered a treatment specific activity. As compared to the clearcut unit, the following planning percent differences were calculated based on the study percentage requirements for each group selection unit in Figure 25:

2-GSPS	-100%
3-GSF.5P	- 44%
4-GSF1.5P	19%
5-GSFW	- 44%
6-GSP.5P	- 31%

Average cycle time, from a sensitivity analysis for hardwood trees that were yarded, was 1.208 minutes per tree (standard deviation = 1.707 minutes; range = 0.392-28.811 minutes; sample size (N) = 328). Cycle times for the softwood trees were derived using the regression model in Table 11 with a unit specific tree wedging variable used. The remaining components used to calculate production and costs are listed in Table 12. Resulting production and cost differences for felling among the group selection units compared to the clearcut unit revealed very little variation. Unit 2 (2-GSPS) was revealed as the most costly in regards to felling by \$0.22/Mbf (\$0.04/m^3) over the

Table 12: Felling production and cost elements and results
(After Olsen, 1992)

Unit-Rx	Effective hour (min/hr)	Percent* trees wedged (dec %)	Weighted** total cycle time (min/tree)	Trees per hour
1-CCF	43.451	0.2377	3.773	11.5157
2-GSPS	43.517	0.3828	3.878	11.2228
3-GSF.5P	43.482	0.3000	3.818	11.3887
4-GSF1.5P	43.438	0.2263	3.765	11.5374
5-GSFW	43.479	0.3070	3.823	11.3729
6-GSP.5P	43.474	0.2627	3.791	11.4671

Notes:

* Decimal percent used in place of 0-1 indicator variable in regression equation; reflects weighted number of trees wedged for that particular unit.

** Calculated from average cycle time of 1.208 minutes per hardwood tree and calculated delay-free cycle time from regression equation; weighted by number of trees felled in study (i.e. 328 hardwood trees and 769 softwood trees).

Miscellaneous elements:

1). Average unit volume per log = 0.180 Mbf/log (1.02 m^3/log). See Appendix O.
2). Logs per tree calculated from average hardwood logs/tree = 1.5 and average softwood logs/tree = 2.38; weighted by number of logs of each type yarded (i.e. 902 hardwood logs and 3317 softwood logs). Result = 2.19 logs/tree. See Appendix R.
3). Calculated unit volume per tree = 0.359 Mbf/tree (2.03 m^3/tree).
4). Owning and operating cost per hour = $36.06/hr. See Appendix H.
5). Gross to net timber scale ratio = 0.927575. See Appendix O.

Table 12: (continued)

Unit-Rx	Gross production -Mbf/hr (m^3/hr)	Cost - \$/Mbf (\$/m^3)	Percent difference over clearcut
1-CCF	4.543 (25.75)	8.56 (1.51)	-
2-GSPS	4.428 (25.10)	8.78 (1.55)	2.6
3-GSF.5P	4.493 (25.47)	8.65 (1.53)	1.1
4-GS1.5P	4.552 (25.80)	8.54 (1.51)	-0.2
5-GSFW	4.487 (25.43)	8.66 (1.53)	1.2
6-GSP.5P	4.524 (25.64)	8.59 (1.52)	0.4

clearcut. Only Unit 4 (4-GSF1.5P) showed an improvement in felling cost as compared to the clearcut by only \$0.02/Mbf (< \$0.01/m^3).

C. Yarding Production and Costs

The average time for yarding cycle elements and the relative frequency of each element is shown in Figure 26. Delays consumed the most significant amount of time (20 percent), while Lateral In required the least time (9 percent). It should be noted that Hook times reflected both preset and hotset turns.

The preferred stepwise yarding delay-free total cycle time prediction model selected and other relevant information is presented in Table 13. Two statistically significant treatment differences (T4 and T5 in regression fit) resulted in Units 5 (5-GSFW) and 6 (6-GSP.5P). These treatment distinctions equated to a mean increase in cycle time of 8.6 seconds in Unit 5 and 9.6 seconds in Unit 6. Computer spreadsheet sensitivity analysis indicated that presetting should be utilized as a treatment specific prediction parameter.

Variables affecting the total delay-free yarding cycle in order of importance are: slope yarding distance, lateral yarding distance, whether or not the turn was preset during the hooking of logs, the total number of logs yarded in the

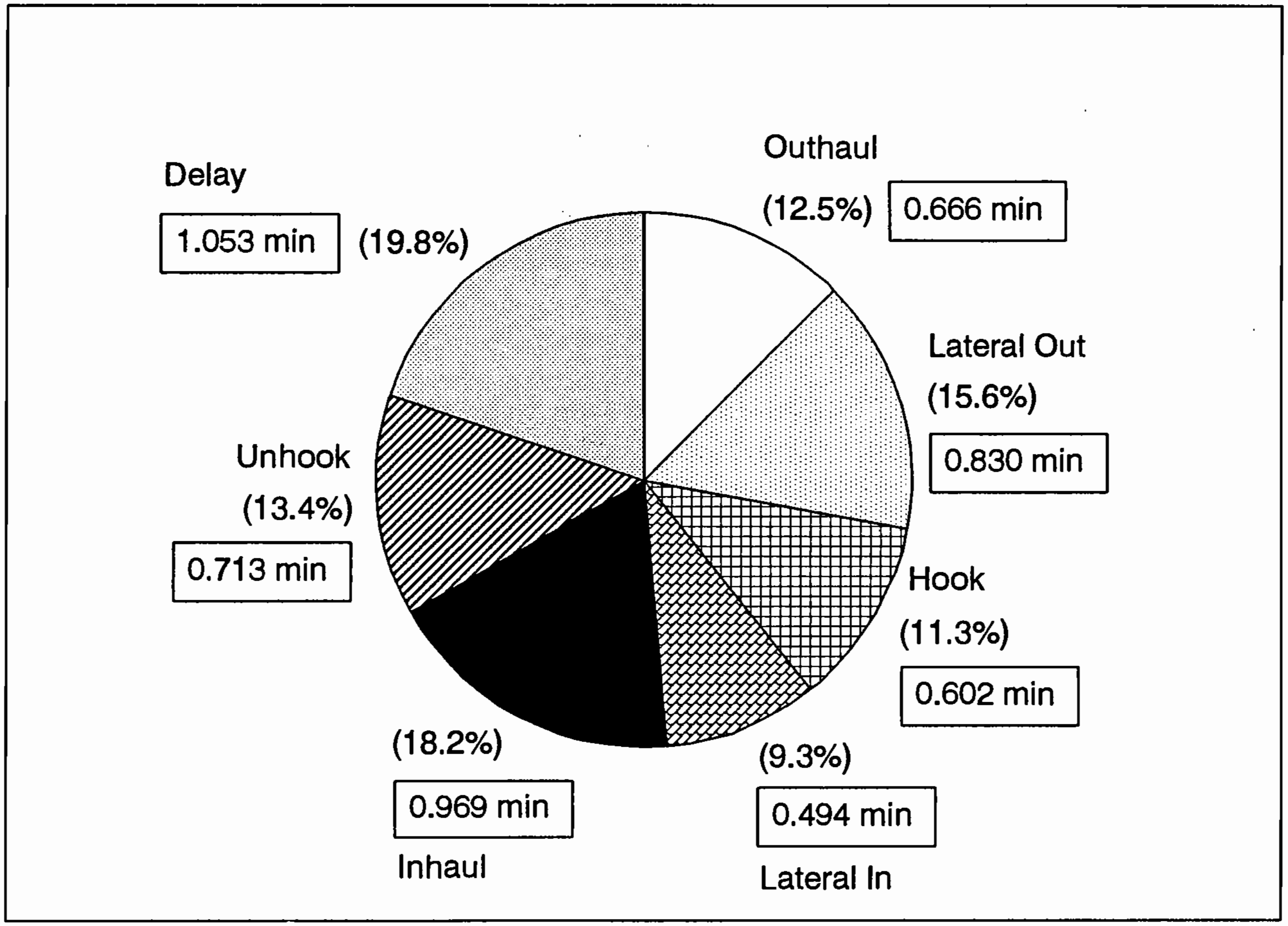


Figure 26: Yarding time-study average time and relative frequency for yarding cycle elements (all treatments). Percentages of total yarding cycle time.

Table 13: Regression fit for delay-free yarding time cycle (YTOB) prediction model

$$\text{Mean YTOB} = 238.377518 + 0.246527 * (\text{YDS}) + 1.030978 * (\text{LDS})$$
$$- 58.688900 * (\text{PR}) + 16.825105 * (\text{TLG})$$
$$+ 14.288477 * (\text{T4}) + 16.075758 * (\text{T5})$$

R-squared (adjusted for d.f.) = 0.5801
Standard error of estimate = 60.99849
Degrees of freedom (d.f.) = 1180

Parameter	Standard error	Significance level
Constant	7.455122	0.0001
YDS	0.007302	0.0001
LDS	0.062061	0.0001
PR	4.565671	0.0001
TLG	1.688173	0.0001
T4	5.236804	0.0065
T5	5.170656	0.0019

Forward selection process:
(not adjusted for d.f.)

Step	Parameter	Partial R-squared	Model R-squared
1	YDS	0.4272	0.4272
2	LDS	0.0763	0.5035
3	PR	0.0412	0.5446
4	TLG	0.0324	0.5770
5	T5	0.0025	0.5795
6	T4	0.0026	0.5822

Parameter definitions:

Response:

YTOB - Delay-free yarding cycle (centiminutes)

Explanatories (with values used in analysis):

YDS - Average slope yarding distance (ft): 534
LDS - Average lateral yarding distance (ft): 37
PR - 1 = preset turn, 0 = otherwise: Treatment specific
TLG - Average number of logs (hardwood and softwood) in turn: 3.55
T4 - 1 = yarding in Unit 5 (5-GSFW), 0 = otherwise
T5 - 1 = yarding in Unit 6 (6-GSP.5P), 0 = otherwise

turn, whether or not the yarding was performed in Unit 6 (6-GSP.5P), and whether or not the yarding was performed in Unit 5 (5-GSFW). All selected explanatory variables were significant at the 99 percent confidence level. Appendix T lists summary statistics for all of the selected model parameters except for treatment unit explanatories.

Yarding delay categories are illustrated in Figure 27. Operational delays accounted for well over half (54 percent) of the recorded delays. Repair and treatment specific delays represented most of the balance of delays (44 percent). Treatment specific delays during yarding are much more significant as compared to the felling time-study. A more detailed summary of unit specific delays is included in Appendix U.

Three treatment specific delays were identified for yarding during a computer spreadsheet delay analysis. Figure 28 illustrates graphically the three identified: reposition carriage/reset chokers, fell and buck, and clear corridor with carriage. The figure represents percentages of time required for each delay in each treatment unit, on a unit and study basis. Combined treatment specific delays are also shown graphically for all units in Figure 29. All group selection units exhibited higher percentages of treatment specific delays compared to the clearcut. The fan patch unit (3-GSF.5P) showed the highest percentages of delays, while the parallel strip unit (2-GSPS) displayed the lowest

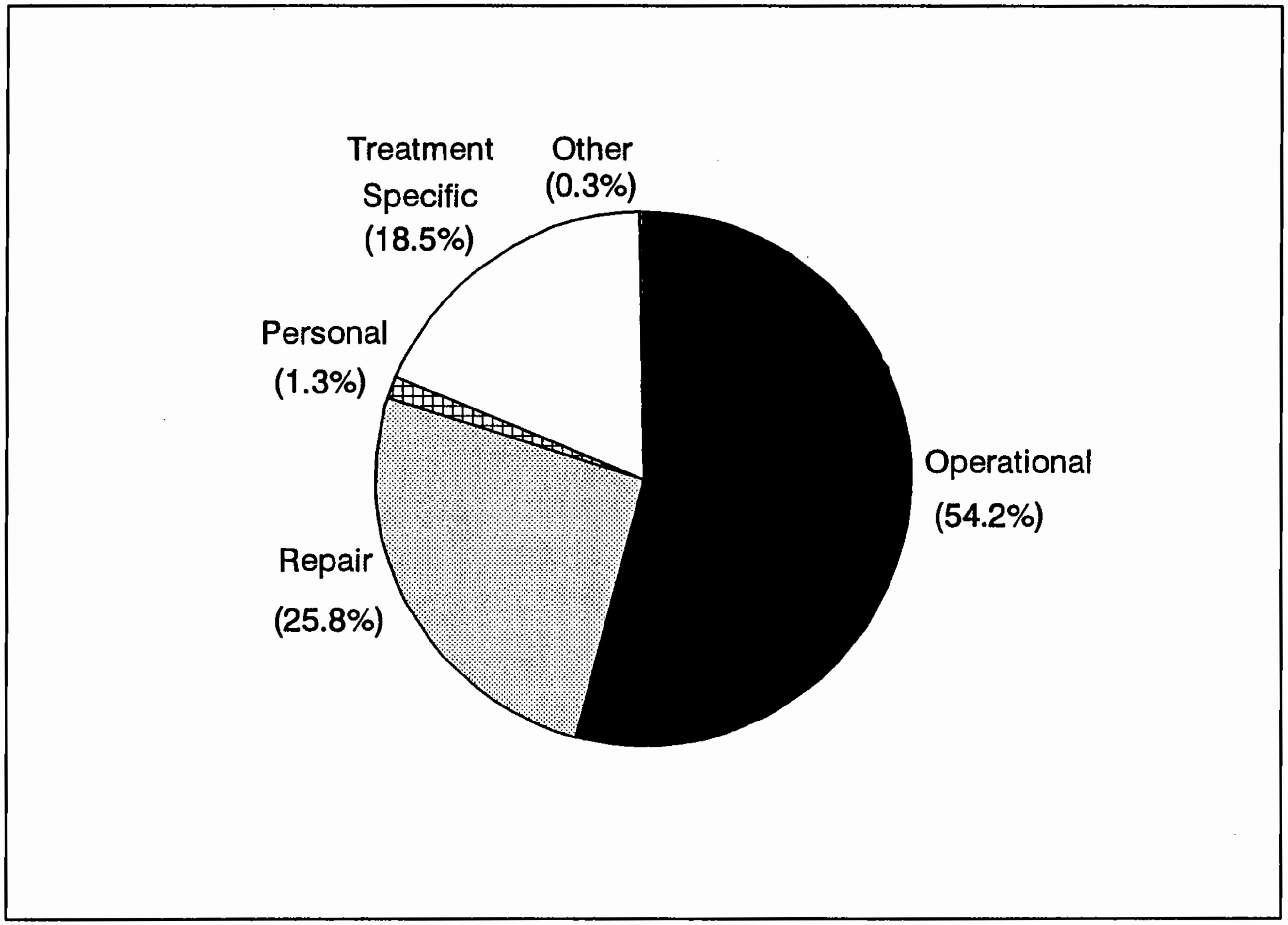


Figure 27: Yarding time-study delays. Percentages of total yarding delay time.

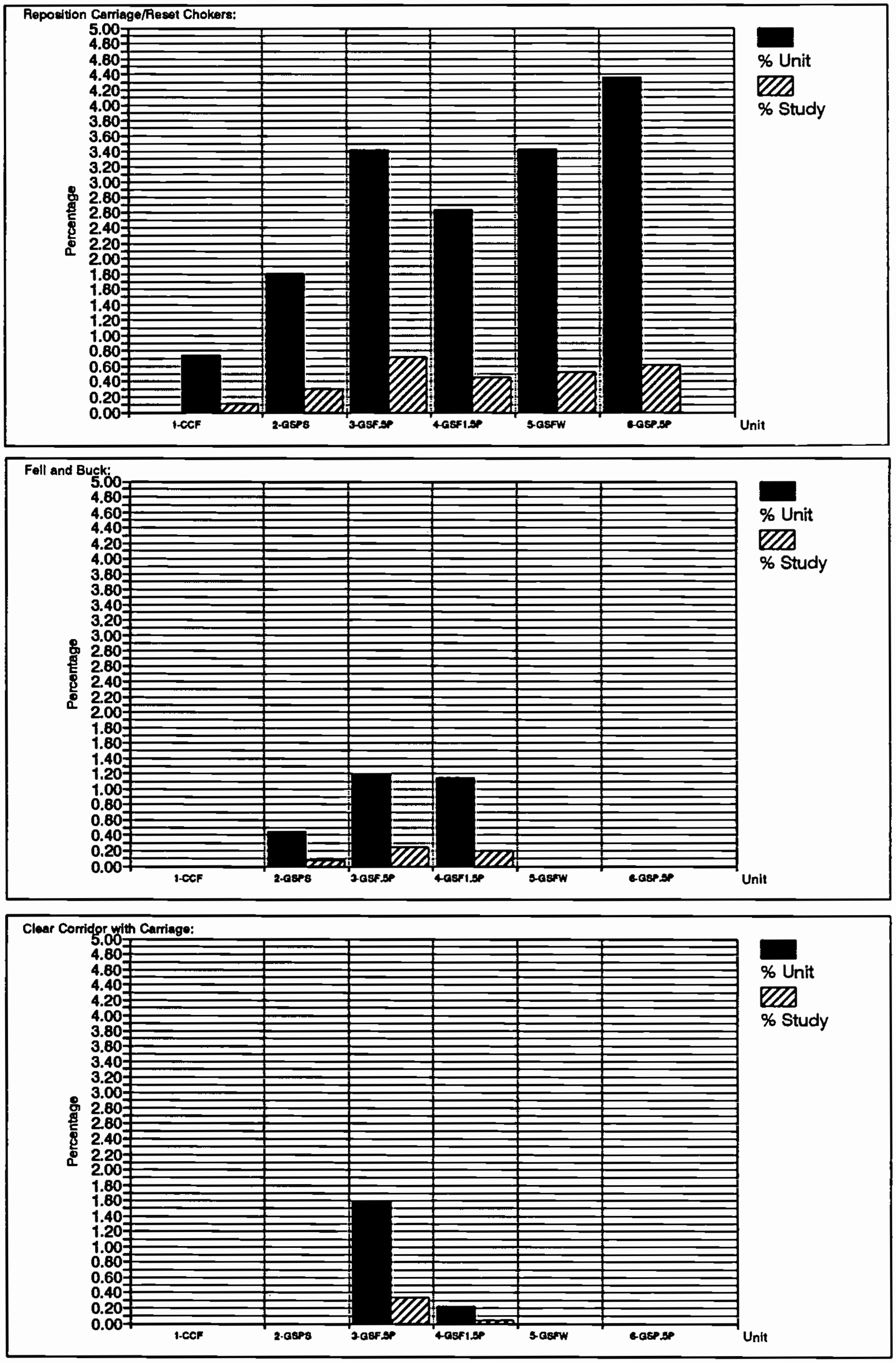


Figure 28: Yarding treatment specific delays. Percentages of total delay-free cycle time + all recorded delays.

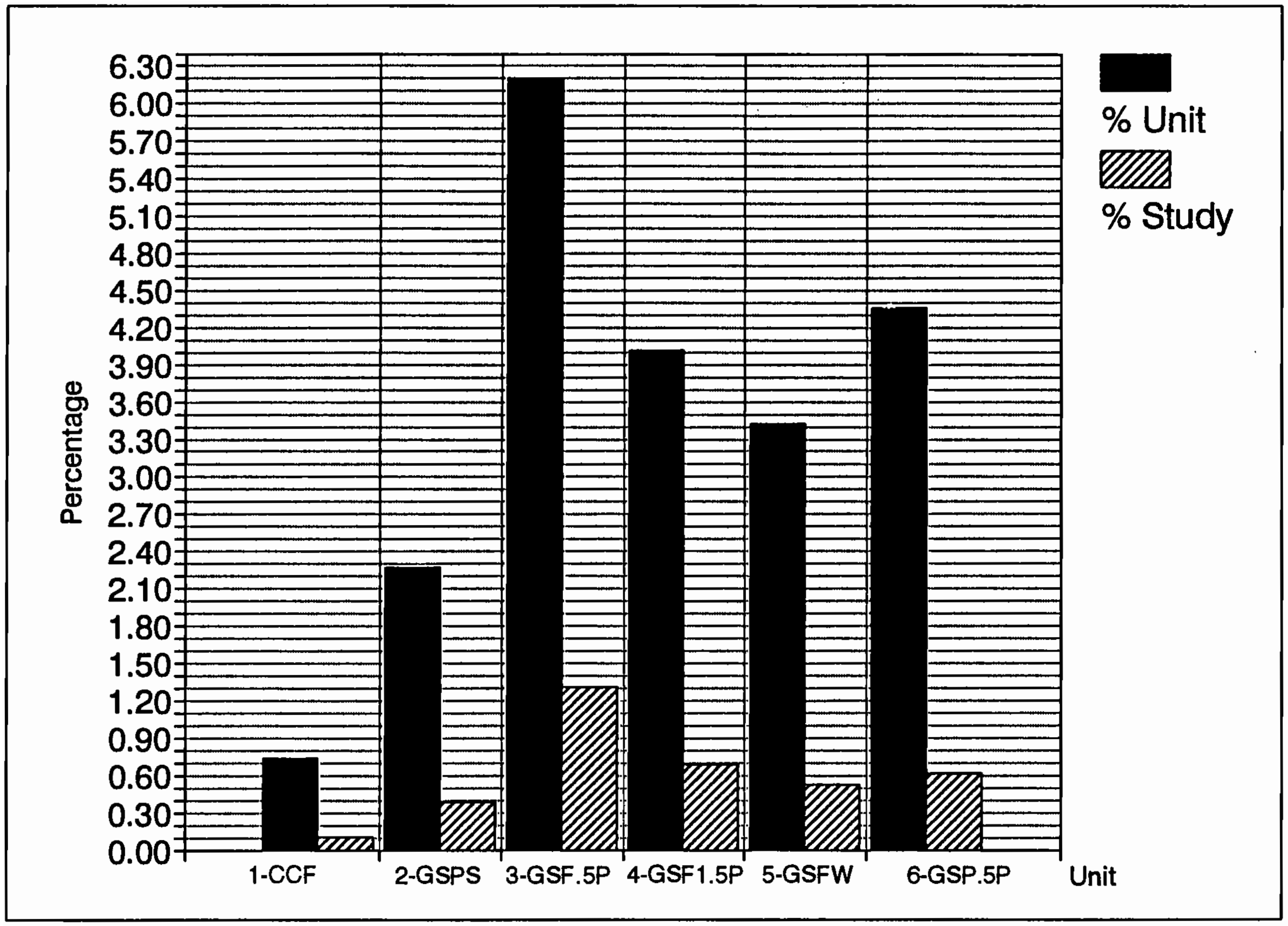


Figure 29: Total yarding treatment specific delays. Percentages of total delay-free cycle time + all recorded delays.

percentages. As compared to the clearcut unit, the following total percent differences for all treatment specific delays were calculated based on the study percentage requirements for each group selection unit in Figure 29:

2-GSPS	255%
3-GSF.5P	1090%
4-GSF1.5P	527%
5-GSFW	382%
6-GSP.5P	464%

Delay components were used to calculate the effective hour and cycle time was derived for each unit using the regression model in Table 13 with a unit specific turn presetting variable used. The remaining components used to calculate production and cost differences and the figures themselves are listed in Table 14. Resulting production and cost differences for yarding among the group selection units compared to the clearcut unit showed slightly more variation than did the felling costs. All group selections were revealed as being slightly more efficient and therefore less costly than the clearcut. Unit 2 (2-GSPS) was shown to be the least costly with respect to standard yarding cost by \$2.06/Mbf (\$0.36/m^3), whereas Unit 6 (6-GSP.5P) was nearly identical to the clearcut production/cost figures (i.e. \$0.11/Mbf (\$0.02/m^3) less standard yarding cost over the clearcut).

Table 14: Yarding production and cost elements and results (after Olsen, 1992)

Unit-Rx	Effective hour (min/hr)	Percent* turns preset (dec %)	Total cycle time (min/turn)	Turns per hour
1-CCF	49.911	0.4624	4.408	11.3238
2-GSPS	49.768	0.7980	4.211	11.8196
3-GSF.5P	49.297	0.8211	4.197	11.7455
4-GSF1.5P	49.611	0.7240	4.254	11.6620
5-GSFW	49.691	0.9667	4.255	11.6795
6-GSP.5P	49.645	0.7933	4.374	11.3496

Notes:

* Decimal percent used in place of 0-1 indicator variable in regression equation; reflects weighted number of turns preset for that particular unit.

Miscellaneous elements:

1). Average unit volume per log = 0.180 Mbf/log (1.02 m^3/log). See Appendix O.
2). Average logs per turn = 3.55; same as TLG average figure used in regression equation. See Appendix T.
3). Calculated unit volume per turn = 0.639 Mbf/turn (3.62 m^3/turn).
4). Owning and operating cost per hour = $328.60/hr. See Appendix K.
5). Gross to net timber scale = 0.927575. See Appendix O.

Table 14: (continued)

Unit-Rx	Gross production -Mbf/hr (m^3/hr)	Standard** cost - $/Mbf ($/m^3)	Percent difference over clearcut
1-CCF	7.236 (41.01)	48.96 (8.64)	-
2-GSPS	7.553 (42.81)	46.90 (8.27)	-4.2
3-GSF.5P	7.505 (42.54)	47.20 (8.33)	-3.6
4-GSF1.5P	7.452 (42.24)	47.54 (8.39)	-2.9
5-GSFW	7.463 (42.30)	47.47 (8.38)	-3.0
6-GSP.5P	7.252 (41.10)	48.85 (8.62)	-0.2

Notes:
** Yarding cost without road/landing change, move in and out, and set up and tear down costs.

D. Road/Landing Change Costs

The average total road/landing change time for all units is shown graphically in Figure 30. Figure 31 further graphically differentiates road/landing change time components for each unit. Appendix V contains more detailed road/landing time component information for each unit. The tabular analysis shown in Table 15 reveals only one treatment (4-GSF1.5P) more efficient, on the order of 31 percent, in road/landing change average time over the clearcut. Unit 6 (6-GSP.5P) exhibited the least efficient average time with 140 percent more time required. Parallel road setting treatments, in general, demanded a higher average time, as expected.

Figure 32 illustrates the average amount of time spent pre-rigging skyline cable roads in each unit. Unit 3 (3-GSF.5P) was the only unit in which any treatment related pre-rigging occurred (i.e. an average of 2.0833 hours per road). This pre-rigging occurred after regular operating hours during fire 1:00 pm (1300 hours) early closure of yarding operations and required extra personnel besides the hooktender. Since this activity occurred after hours, a labor rate for personnel involved was charged and added to the resulting road change cost for Unit 3 discussed below. Overall, compared to the clearcut unit, percent differences

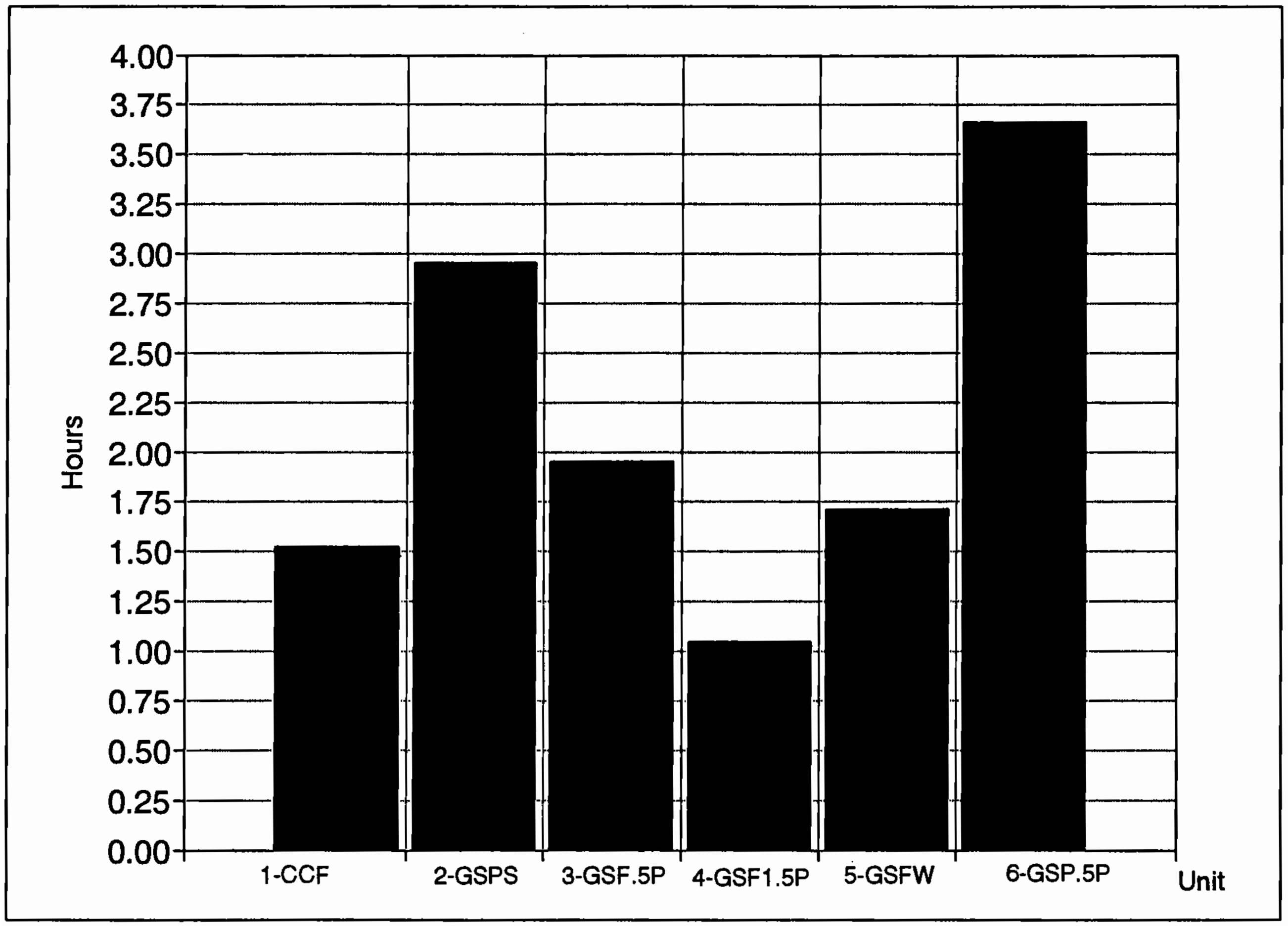


Figure 30: Average total road/landing change time without pre-rigging time.

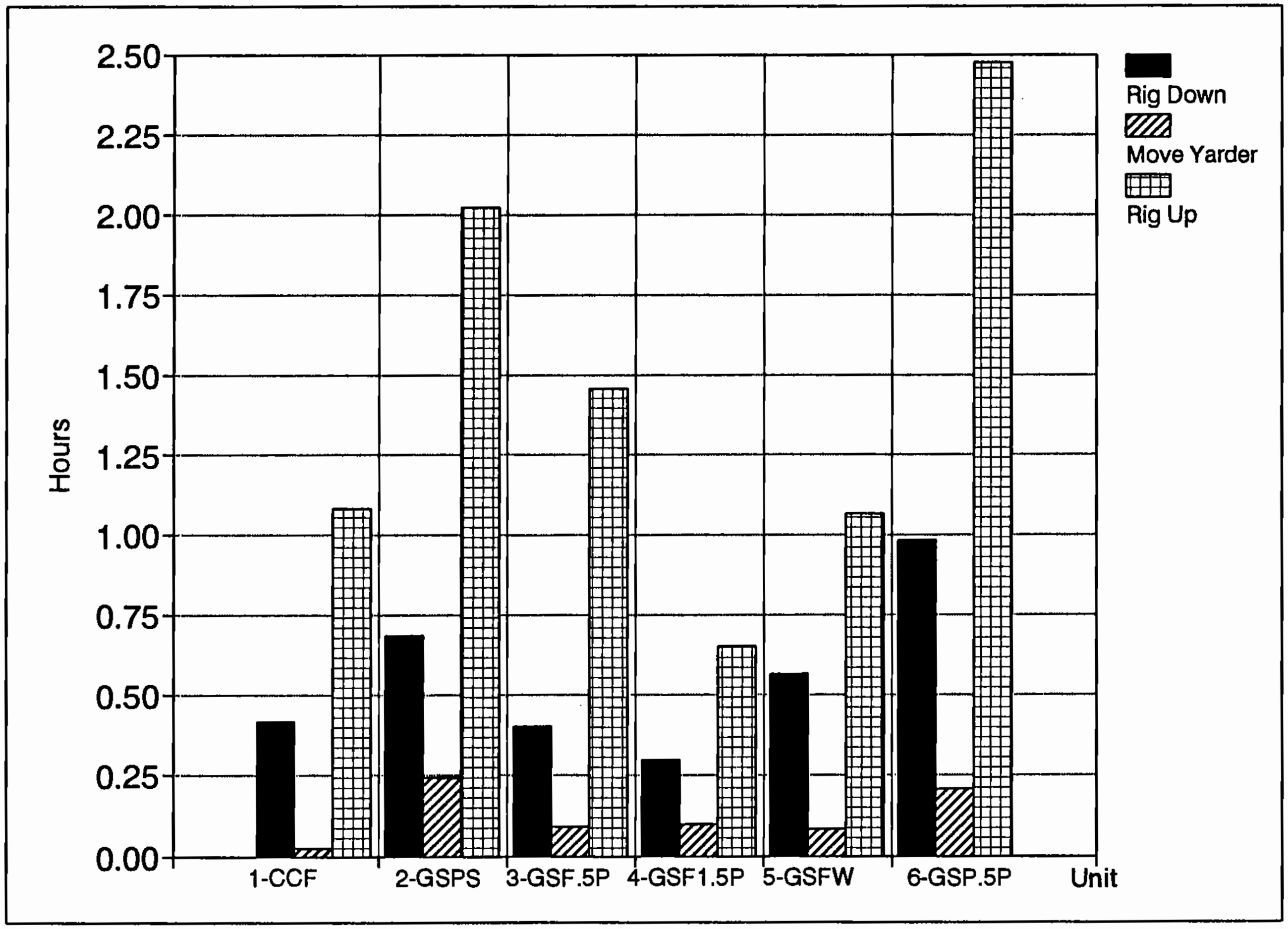


Figure 31: Average road/landing change time components (time per component).

Table 15: Total average time per road/landing change and percent differences over clearcut for total and individual time components.

Unit-Rx	Total average road/landing change time (hours)	Percent difference over clearcut	Road/landing change time components: Rig Down percent difference over clearcut	Move Yarder percent difference over clearcut	Rig Up percent difference over clearcut
1-CCF	1.5291	-	-	-	-
2-GSPS	2.9555	93.3	63.7	877.6	86.7
3-GSF.5P	1.9500	27.5	-4.3	266.8	34.4
4-GSF1.5P	1.0500	-31.3	-29.4	300.0	-39.7
5-GSFW	1.7167	12.3	34.7	233.2	-1.5
6-GSP.5P	3.6666	139.8	133.7	733.2	128.5

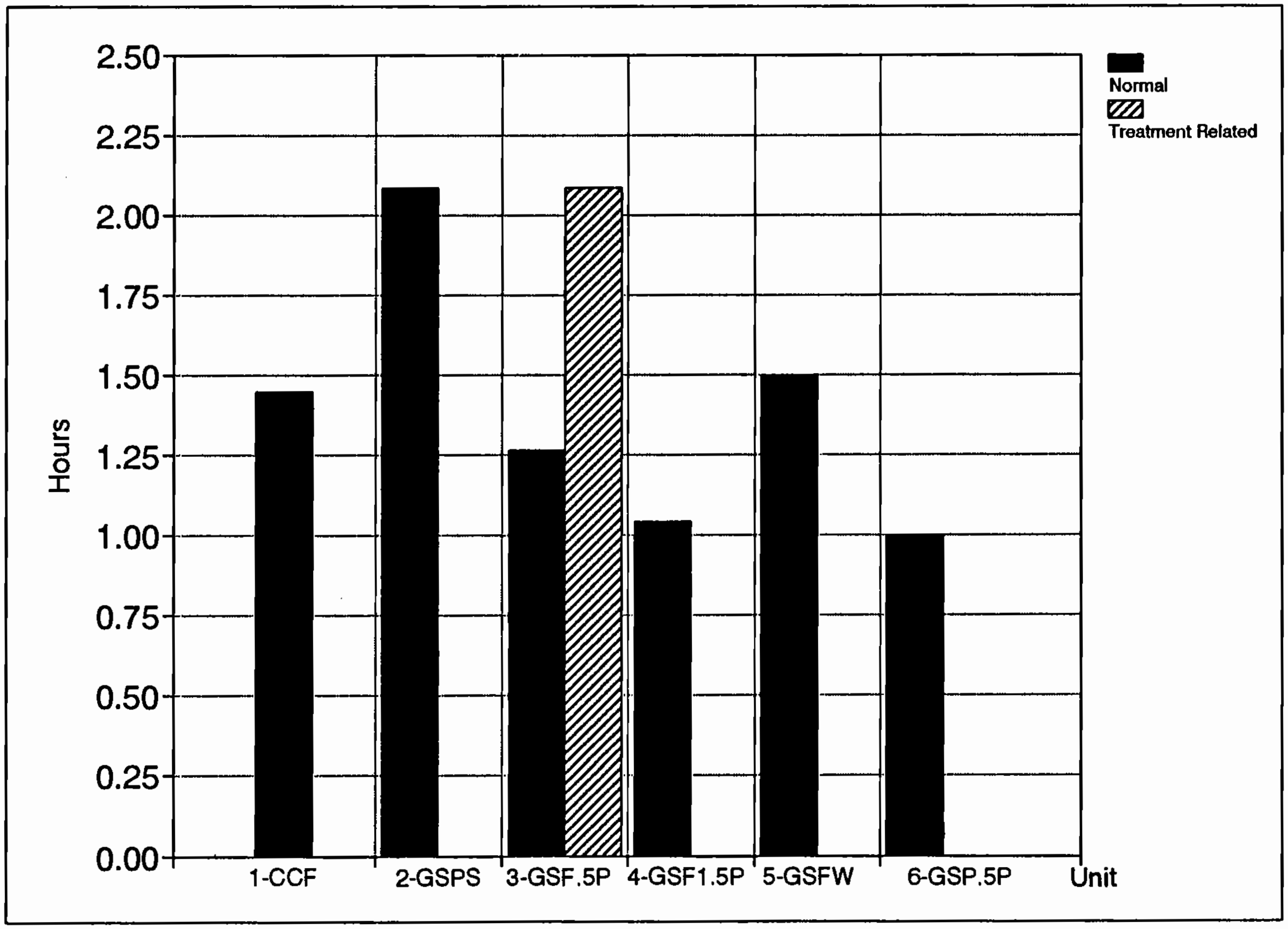


Figure 32: Average time spent pre-rigging for road/landing changes.

for pre-rigging requirements for group selections are as follows:

2-GSPS	44%
3-GSF.5P	131%
4-GSF1.5P	-28%
5-GSFW	4%
6-GSP.5P	-31%

Road/landing change delays are presented in Figure 33. Repair category delays accounted for most of the recorded delays (i.e. 64 percent). An effective hour of 52.987 minutes per hour was calculated from the delay analysis and used to derive an adjusted total time for cost calculations. Appendix W contains more specific information regarding delay types.

Table 16 shows the resulting analysis of cost per unit volume for each unit. The largest relative difference compared to the clearcut unit occurred in Unit 3 (3-GSF.5P) with an increase of 108 percent in costs. Alternatively, Unit 5 (5-GSFW) demonstrated a significant reduction of 52 percent in costs over the clearcut unit. All other costs for treatments were above the clearcut unit cost of \$9.16/Mbf (\$1.62/m^3).

In order to determine a final yarding cost, miscellaneous fixed costs such as road/landing changes, move in and out, and set up and tear down costs must be determined, totaled, and divided by the total volume harvested. These costs can then be added to the standard yarding cost (shown in Table 14). Figure 34 summarizes these

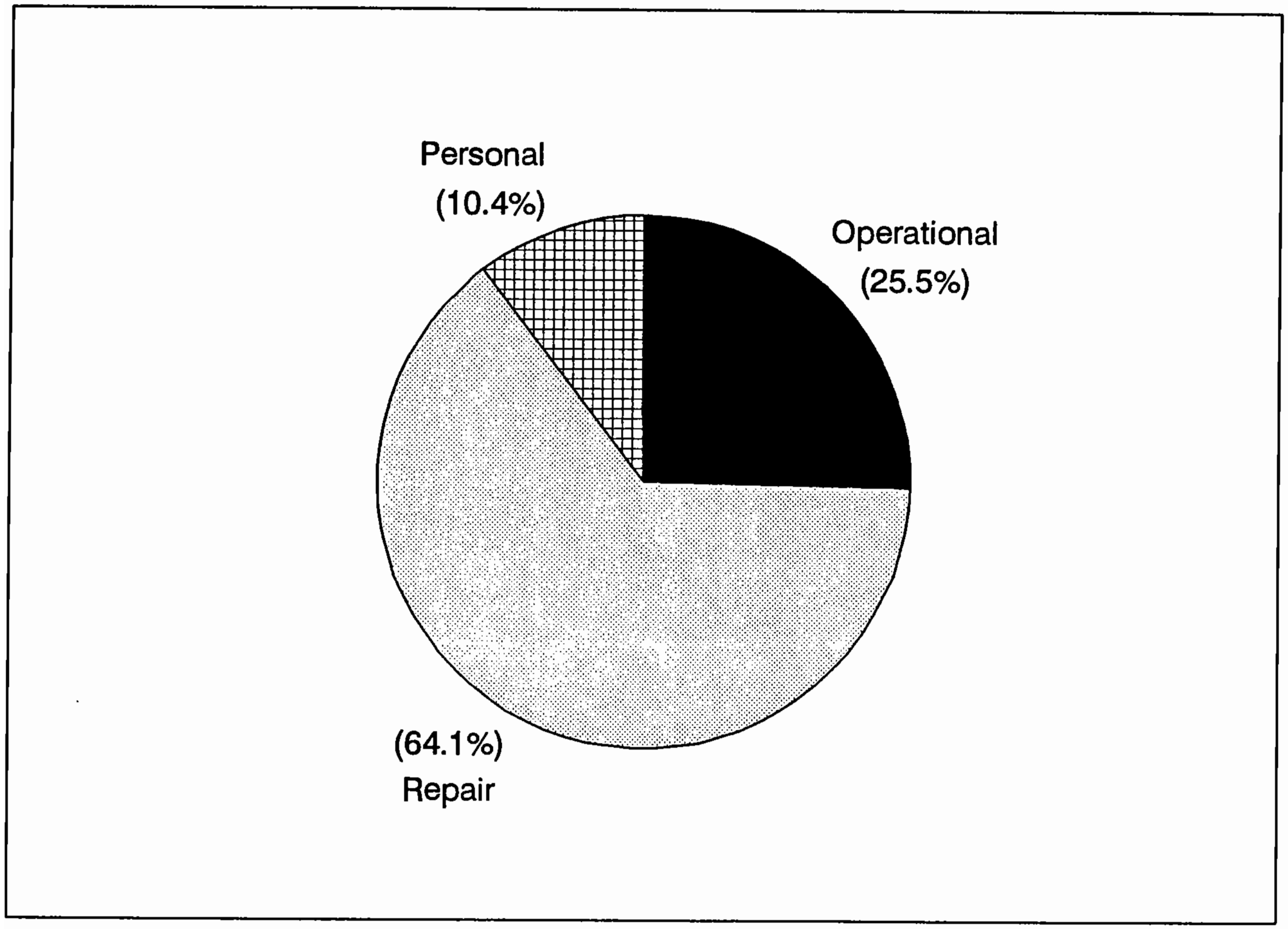


Figure 33: Road/landing change time-study delays. Percentages of total road change delay time.

Table 16: Road/landing change cost per unit volume

Unit-Rx	Average road/landing change time (hrs)	Number of road/ landing changes	Adjusted* total time (hrs)	Total cost ($)	Cost per unit volume - $/Mbf ($/m^3)	Percent difference over clearcut
1-CCF	1.5292	12	20.7787	6827.82	9.16 (1.62)	-
2-GSPS	2.9556	3	10.0402	3299.21	11.26 (1.99)	22.9
3-GSF.5P	1.9500	6	13.2485	5574.58**	19.03 (3.36)	107.8
4-GSF1.5P	1.0500	9	10.7007	3516.26	12.00 (2.12)	31.0
5-GSFW	1.7167	2	3.8877	1277.51	4.36 (0.77)	-52.4
6-GSP.5P	3.6667	2	8.3039	2728.67	9.31 (1.64)	1.6

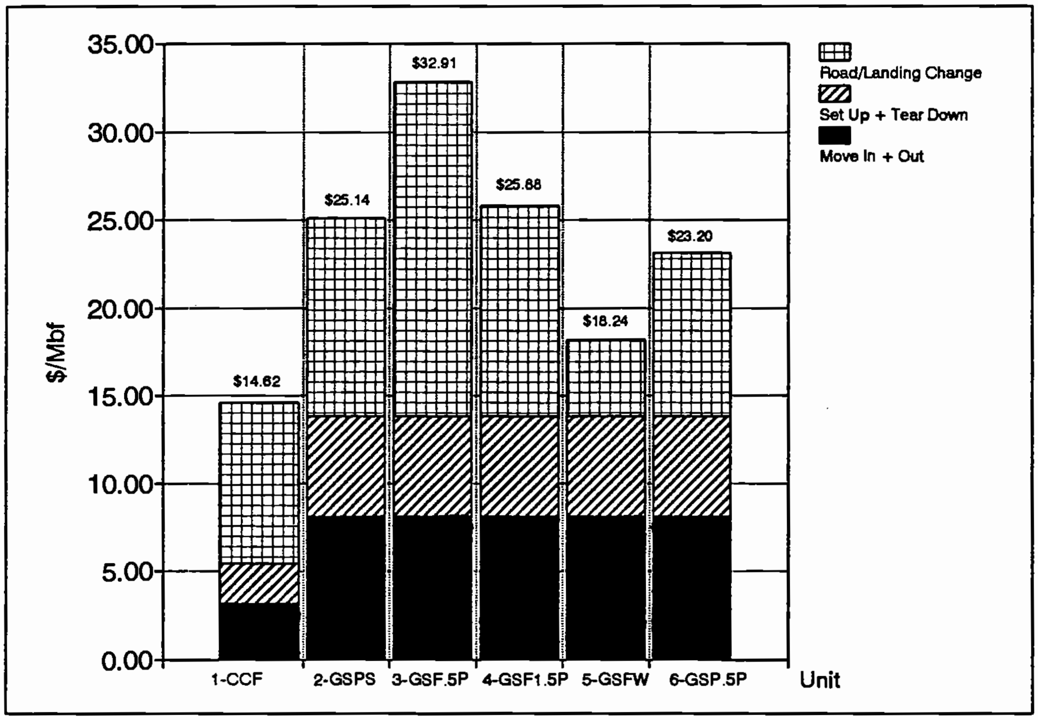
Notes:

* Adjusted total time = (Average road/landing change time) * (Number of road/landing changes) * (60 / Effective hour); Effective hour = 52.9874 min/hr.

** Reflects an added fixed cost for treatment specific pre-rigging of $1221.11.

Relevant figures:

1). Cost per scheduled hour = $328.60/hr. See Appendix K.
2). Standardized unit size = 25 acres (10.1 hectares). See Appendix A.
3). Gross Scribner volume per acre = 36.1 Mbf/acre (506 m^3/hectare). See Appendix A.
4). Gross to net timber scale = 0.927575. See Appendix O.
5). Percent area harvested in clearcut = 89%; in group selections = 35%. See Appendix N.



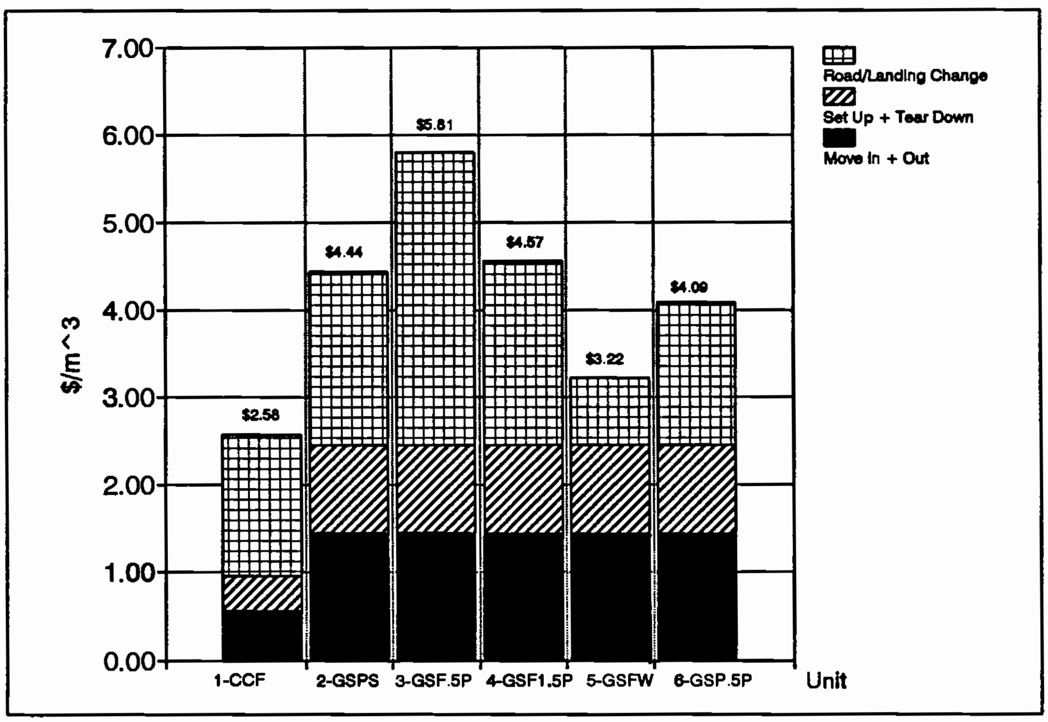


Figure 34: Total miscellaneous yarding costs per unit volume (US and SI).

miscellaneous fixed charges based on costs derived in Table 16 and figures from Appendix L. Group selection total miscellaneous cost calculated percent differences over clearcutting are:

2-GSPS	72.0%
3-GSF.5P	125.1%
4-GSF1.5P	77.0%
5-GSFW	24.8%
6-GSP.5P	58.7%

Table 17 illustrates the resulting final yarding cost after adding miscellaneous costs to the standard yarding cost and percent differences for the group selection units compared to the clearcut. Appendix X exemplifies a yarding cost tree developed by Olsen (1992) with components used to calculate the final yarding cost in the analysis for the clearcut unit (1-CCF). Unit 3 (3-GSF.5P) exhibited the highest final yarding cost at 26 percent above the clearcut cost. Alternatively, Unit 5 (5-GSFW) displayed the most productive final yarding cost of only 3.4 percent above the clearcuts' cost. Interestingly, the two parallel road setting units (2-GSPS and 6-GSP.5P), had nearly identical costs (i.e. only \$0.01/Mbf (<\$0.01/m^3) difference).

Similarly, Table 18 presents a comparison adjusted total production rates for all treatments. This rate takes into account standard yarding production (see Table 14) and the effect of road/landing changes on unit volume per hour. On the basis of total production, the fan wedges (5-GSFW) are 12.1 percent more efficient than the clearcut and the

Table 17: Final yarding cost per unit volume

Unit-Rx	Final yarding cost - \$/Mbf (\$/m^3)	Percent difference over clearcut
1-CCF	63.58 (11.22)	-
2-GSPS	72.05 (12.71)	13.3
3-GSF.5P	80.11 (14.13)	26.0
4-GSF1.5P	73.42 (12.95)	15.5
5-GSFW	65.71 (11.59)	3.4
6-GSP.5P	72.04 (12.71)	13.3

Table 18: Adjusted total production rate; standard production rate with road/landing changes

Unit-Rx	Time spent* yarding standardized unit (hrs)	Time spent** performing road/ landing changes (hrs)	Adjusted total gross production rate - Mbf/hr (m^3/hr)	Percent difference over clearcut
1-CCF	111.00	20.78	6.095 (34.55)	-
2-GSPS	41.82	10.04	6.091 (34.52)	-0.1
3-GSF.5P	42.09	13.25	5.708 (32.35)	-6.3
4-GSF1.5P	42.39	10.70	5.950 (33.72)	-2.4
5-GSFW	42.33	3.89	6.834 (38.74)	12.1
6-GSP.5P	43.56	8.30	6.091 (34.52)	-0.1

Notes:
* Calculation using standard yarding production rate from Table 14 and total gross volume harvested in 25 acre (10.1 hectare) standardized unit.
** Calculation using adjusted total time for road/landing change from Table 16.

most productive of the group selection treatments. Alternatively, Unit 3 (3-GSF.5P) was shown to be the least efficient by 6.3 percent under the clearcut figure. The remaining group selection units showed intermediate values less productive than the clearcut treatment.

E. Total Harvest Costs

Figure 35 shows graphically a comparison of the relative magnitude of each type of harvest cost studied for each treatment: logging planning, felling, and yarding. A combined stacked bar graph in Figure 36 illustrates the resulting summarized harvest costs for the treatments studied. It should be noted at this point that a profit and risk margin was not included in this study. The final total harvest cost analysis suggests that the fan wedge treatment (5-GSFW) is the most efficient and the fan 0.5 acre (0.20 hectare) patches are the least efficient of the group selection units studied as compared to the clearcut unit. Final total harvest cost percentage differences for the group selections as compared to the clearcut are as follows:

2-GSPS	15.8%
3-GSF.5P	31.5%
4-GSF1.5P	22.2%
5-GSFW	7.3%
6-GSP.5P	18.5%

Figure 37 illustrates the effect of average yarding distance on the total harvest cost for each of the

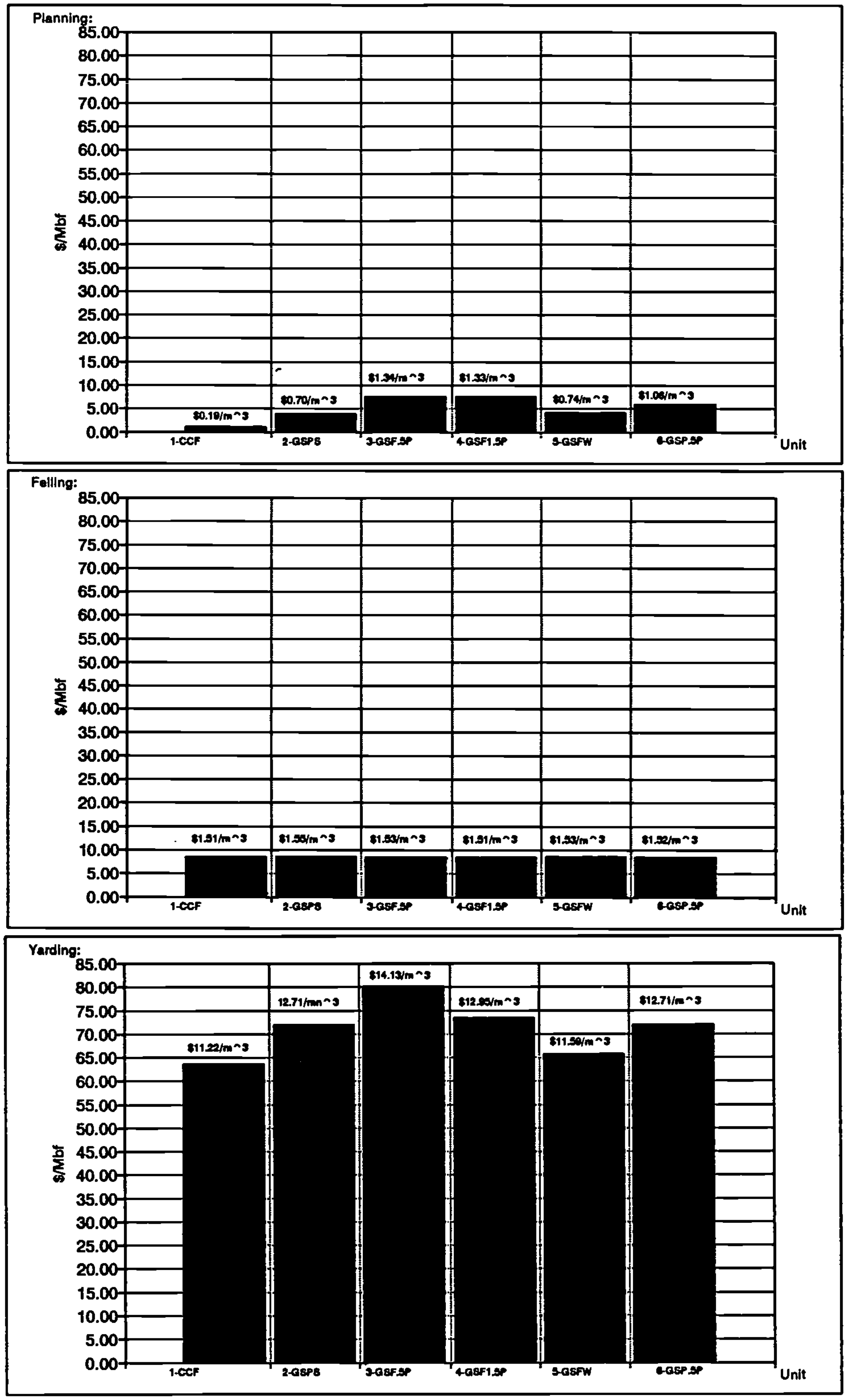


Figure 35: Planning, felling, and yarding component costs per unit volume (US-graphic; SI-numeric).

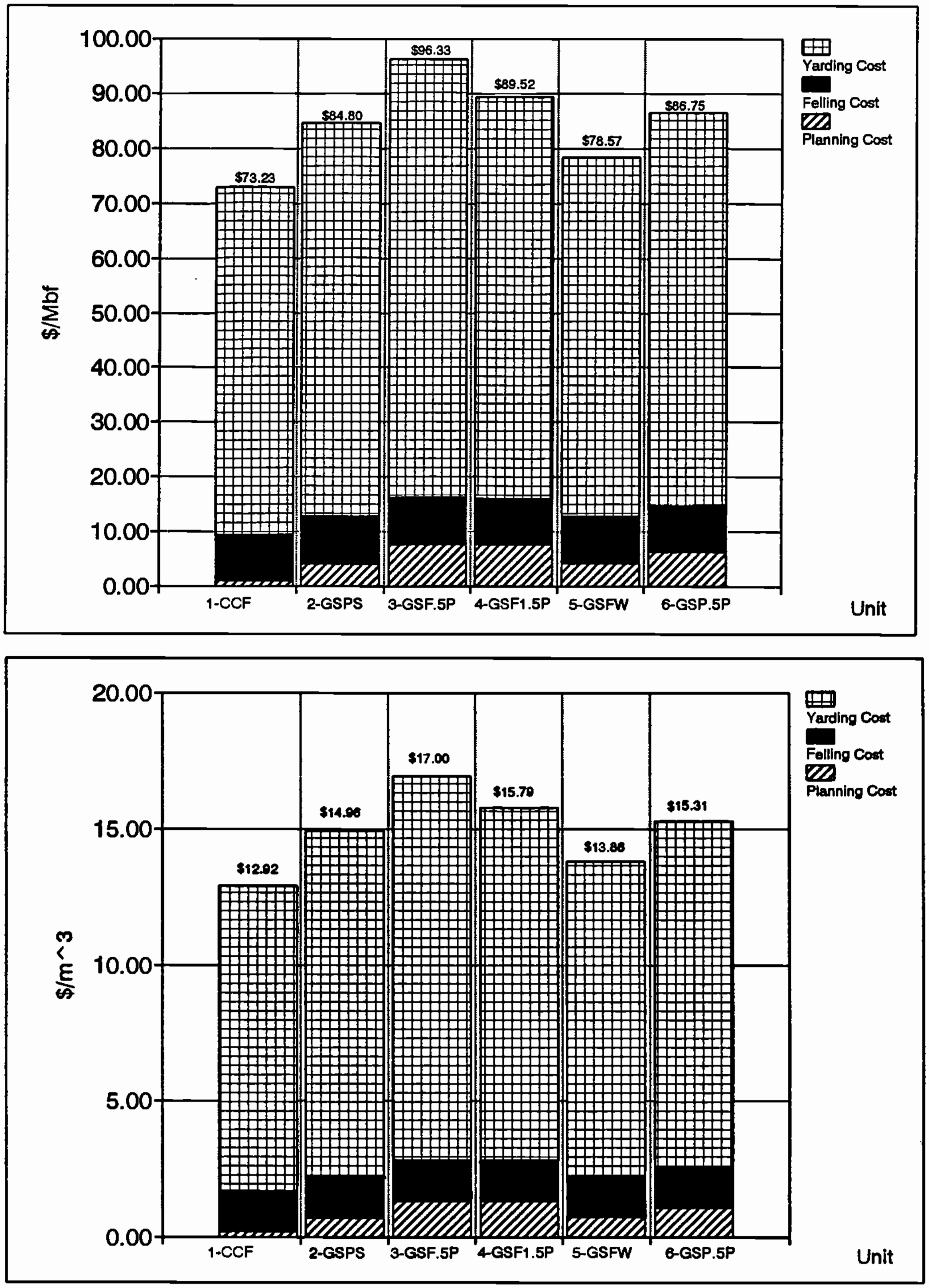


Figure 36: Total harvest cost per unit volume (US and SI).

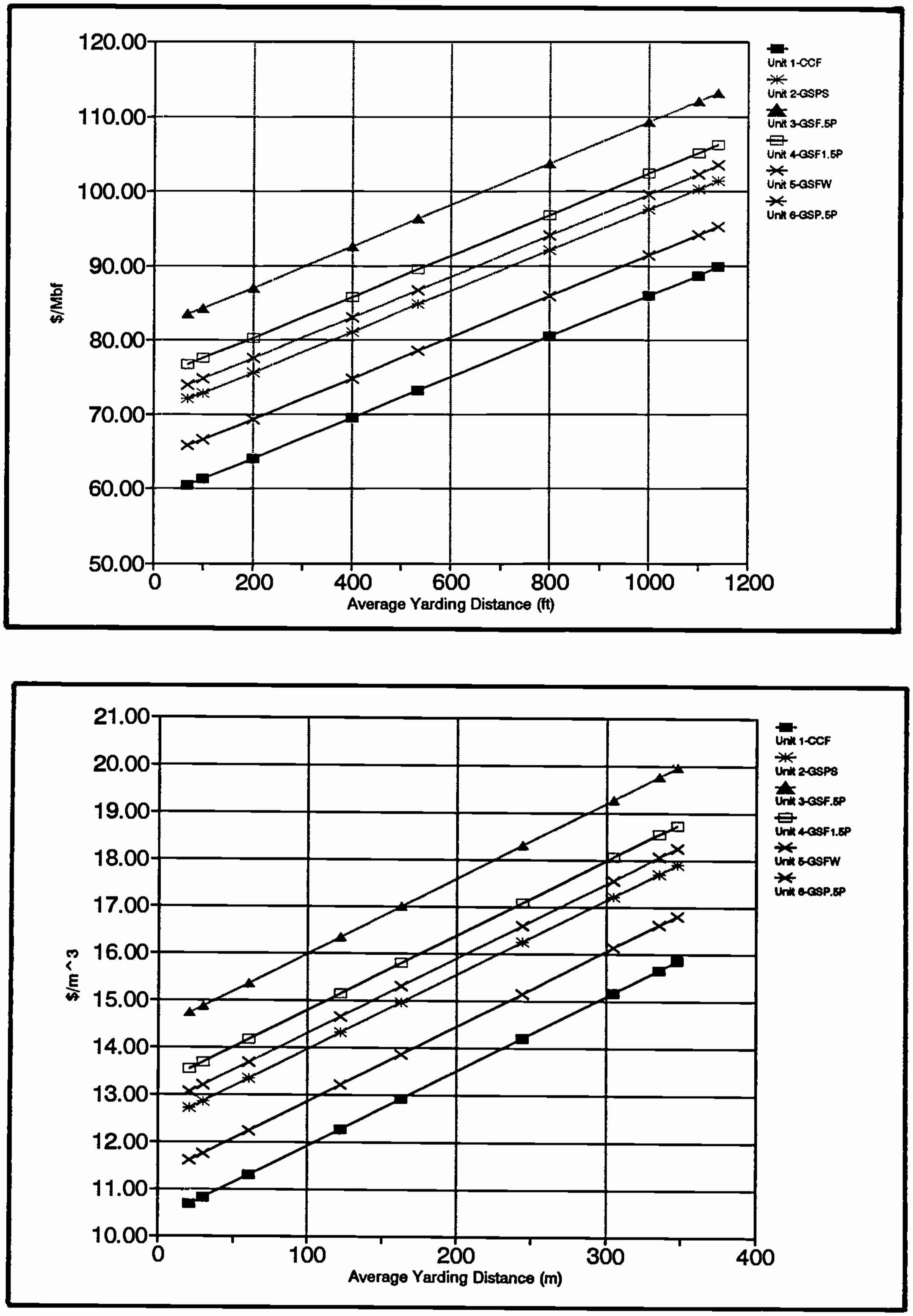
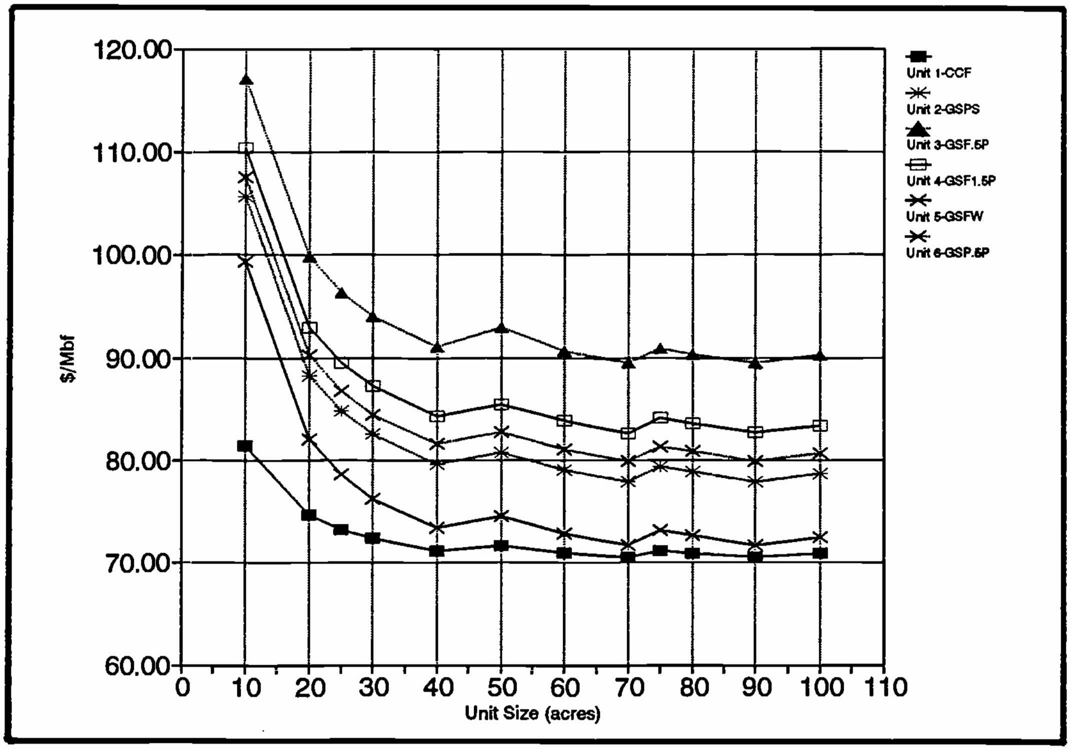


Figure 37: Total harvest cost per unit volume as a function of average yarding distance (US and SI).

treatments. Similarly, Figure 38 relates total harvest cost as affected by the unit size/area. Discontinuities in the function illustrated occurring at 50, 75, and 100 acres (20, 30, and 40.5 hectares) reflect an added fixed cost for an additional yarder set up and tear down in order to harvest an added 25 acre (10 hectare) area. Lastly, Figure 39 shows the effect on total harvest cost for the clearcut treatment unit of two different clearcut rigging and yarding procedure scenarios versus the method used in the study (i.e. 13 roads and approximately 46 percent of the turns preset).

One alternative that could be implemented in order to increase productivity/decrease costs in the clearcut treatment would be to reduce the number of roads rigged in the setting. This would be accomplished by maximizing the lateral capabilities of the slackpulling carriage used, which in turn would be achieved by increasing the back end skyline cable road width to 250 ft (76.2 m) versus the 175 ft (53.3 m) average road width used by the hooktender in the study. The result of this type of rigging procedure would be to increase the average lateral yarding distance (similar to Unit 5's (5-GSFW) average) and decrease the number of road changes, thus reducing the original total harvest costs by approximately 3.0 percent.

The other alternative would be to use the same procedures as above and have the rigging crew preset most of the turns (also similar to Unit 5's (5-GSFW) percentage of



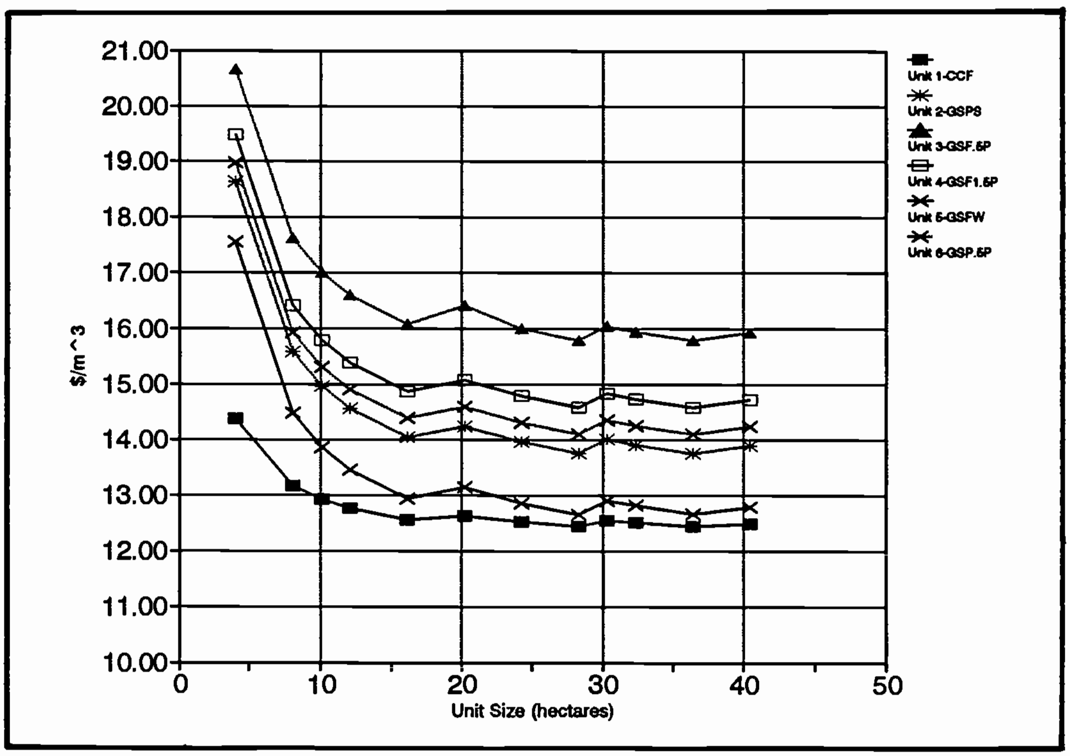
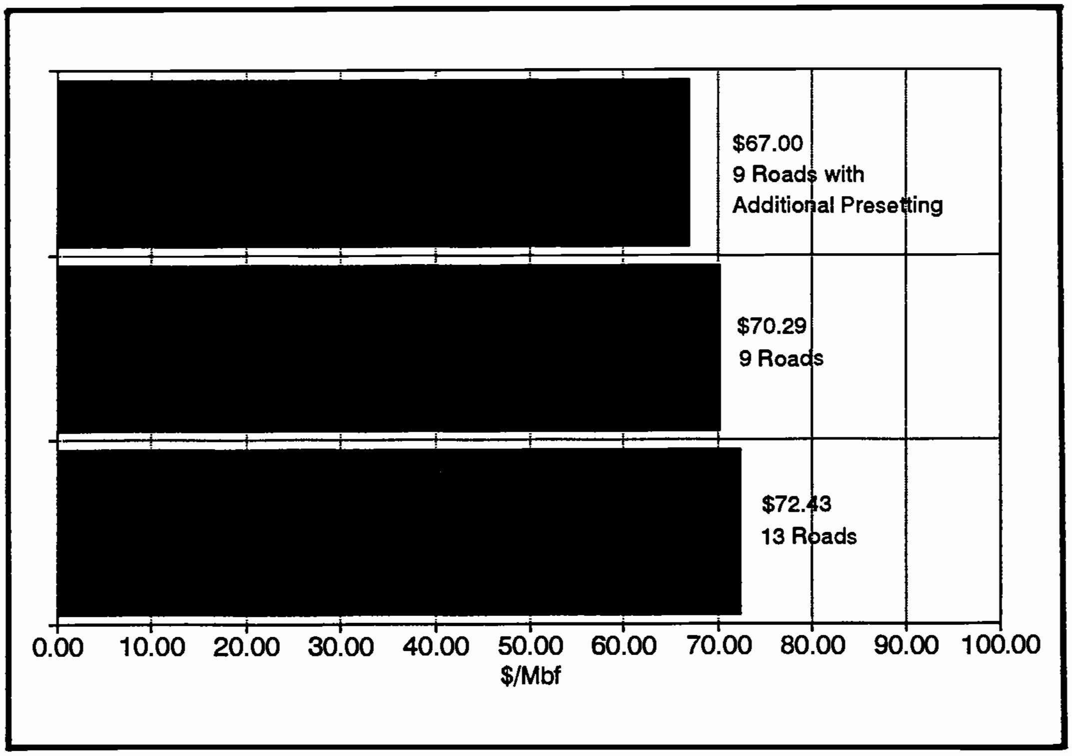


Figure 38: Total harvest cost per unit volume as a function of unit size/area (US and SI).



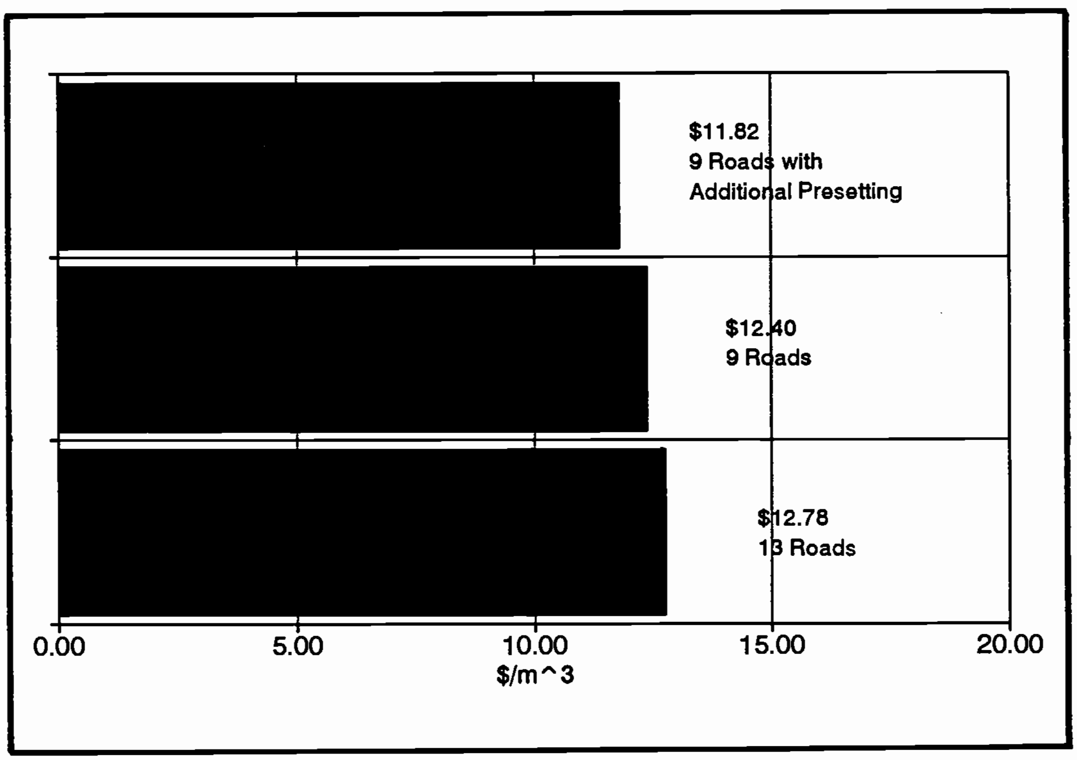


Figure 39: Unit 1 (1-CCF) total harvest cost per unit volume for three alternative yarding scenarios (US and SI).

turns preset). This would reduce the original total harvest costs by approximately 7.5 percent. Table 19 shows the results of this sensitivity analysis in terms of the effects on group selection percentage differences of total harvest costs compared to the clearcut for the three scenarios investigated.

Table 19: Three alternative clearcut yarding scenarios (see Figure 39); percent differences of total harvest costs for group selection treatments over clearcut treatment scenario

Unit-Rx	13 road alternative percent difference over clearcut	9 road alternative percent difference over clearcut	9 road with additional presetting alternative percent difference over clearcut
2-GSPS	15.8	20.6	26.6
3-GSF.5P	31.5	37.0	43.8
4-GSF1.5P	22.2	27.4	33.6
5-GSFW	7.3	11.8	17.3
6-GSP.5P	18.5	23.4	29.5

VI. DISCUSSION

A. Logging Planning

Planning time requirements (hrs/unit area) and costs ($/unit volume) for any given group selection treatment unit in this study exhibited the same relative percent increases over clearcutting (i.e. approximately 2.6 to 5.9 times longer time requirements and higher costs). A previous study by Kellogg et al. (1991) showed these elements to be different due to an alternate method of calculating time requirements. The previous process involved using total unit area for time requirements and volume harvested in the first-entry (i.e. treated area) for costs. Results from this previous study indicated that layout time (hrs/unit area) for skyline group selections increased by approximately 2 times over clearcutting with resulting layout cost ($/unit volume) increases of 6 times.

In this current investigation, the time requirements and costs are both based on treated area in the first-entry. No attempt was made to account for first-entry planning that would be used in future entries. In addition, the previous research mentioned above did not include area-wide planning in the analysis. As a result, comparisons of cost magnitudes between this study and the previous study show significant differences for clearcutting and group selection. Other factors that may have influenced an increase in logging planning time requirements and cost per unit volume in this study over the previous research include:

1). Smaller trees.
2). Poorer timber site conditions.
3). Use of more difficult rigging techniques such as more lift tree rigging requirements.
4). Previous study costs based on two aggregated treatments (i.e. parallel and fan setting road plan 0.5 acre (0.20 hectare) treatments).

Two of the fan setting treatments, 3-GSF.5P and 4-GSF1.5P, were shown to be the least efficient overall as far as logging planning was concerned. The difficulty of flagging skyline roads to a centralized landing in the fan skyline road settings versus one road per landing in the parallel road settings (Units 2-GSPS and 6-GSP.5P) was indicated in the results. Overall, flagging skyline roads was shown to be the principal time consuming planning component.

In addition, locating and marking the patches in both of the fan setting patch units was comparatively more difficult when compared with the parallel setting patch unit (6-GSP.5P) due to a more dispersed group selection patch location. Consequently parallel setting patches were easier to mark since relative patch locations were much easier to locate on the ground. Strips and wedges (2-GSPS and 5-GSFW) required significantly less time with regards to both of these major time components.

In general, Unit 4 (4-GSF1.5P) required more time to lay out and thus a higher cost per unit volume than was originally hypothesized. It was assumed that with larger patches economies of scale would dictate, thus making this unit relatively more efficient than Unit 3 (3-GSF.5P). However, this aspect of the study was essentially observational and with the exception of randomizing most of the treatment specific planning time components, was confounded by many terrain and operational variables. Further research and/or personal time records over a longer period of time for agencies or firms involved in these types of treatments would be necessary to "fine tune" requirements and costs.

The parallel strip unit (2-GSPS) was found to be the most overall efficient in regards to planning of the group selections with the fan wedges a close second. As mentioned above, this was due to the relative ease of flagging skyline roads and boundary marking large areas of first-entry timber to be harvested. Mapping time was also proportionally less since larger harvest areas simplified the three-entry scenario map design process. Overall, group selection patch size was found to have the largest effect on planning time/cost with the setting road plan having a relatively minor role.

Of worthy mention is the process of wildlife tree (i.e. snags and green recruitment trees) group location in the clearcut unit (1-CCF). In general, the time spent locating these groups was time well spent. In the first replication of a study of this type (Kellogg et al., 1991), it was found that improper location of these groups caused an inordinate amount of administrative and operational difficulties and a resultant loss in yarding and road change production as well as creating potential safety hazards. During location of these groups, it is essential that a person or persons familiar with logging planning practices, equipment capabilities, and logging safety codes in addition to wildlife requirements, be present.

It was also found, in this study and in previous research by Kellogg et al. (1991), that the development and distribution of detailed first-entry logging plan maps was essential to the success of the whole operation, especially for the group selection harvest units. In addition, a three-entry scenario logging plan base map with detailed overlays was created and considered requisite to successful implementation of subsequent entries in the cutting cycle for the group selections. Laminated copies of the first-entry logging plan map were given to owners of the logging contracting firm and felling sub-contractor, hooktender, yarder operator, and to the lead faller. Smaller copies of specific group selection units printed on water resistant paper were distributed to individual fallers assigned to the given treatment units throughout the harvest process.

Initial walk-through of all treatment units with the felling sub-contractor bullbuck was also found to be beneficial.

B. Felling

Although felling production/cost exhibited only small relative differences when compared to the clearcut (i.e. average 1.0 percent less efficient over clearcut for all group selections), some pertinent conclusions are worth mentioning. The two least efficient treatments, the strips (2-GSPS) and wedges (5-GSFW), required the most amount of wedging, although their effective hours were among the highest (i.e. very little planning required). This extra amount of wedging and resultant additional time was probably the direct result of the larger openings and the need not to fell trees along the outside of patches into adjacent standing timber. This occurred along the entire width of the strip unit (2-GSPS) and in the bottom of the wedge unit (5-GSFW) where the opening reached its' maximum width of 250 ft (76.2 m).

The 0.5 acre (0.20 hectare) patches (3-GSF.5P and 6-GSP.5P), on the other hand, allowed more options for the faller and painted cut trees were easier to identify. This was also concluded in the 0.5 acre (0.20 hectare) units in the first replication shift-level study by Kellogg et al.

(1991) where felling production in group selections was actually 3.4 percent superior to clearcut production.

The fan 1.5 acre (0.61 hectare) unit (4-GSF1.5P) was found to be the most efficient by 0.2 percent as compared to the clearcut. Although this unit required the most amount of planning treatment-specific delay time, the amount of tree wedging was the lowest. The 1.5 acre (0.61 hectare) patch size for the most part was similar in width to the actual width of the fallers' normal cutting strip width observed in the skyline clearcut unit (1-CCF). This may have allowed for comparatively more tree lay options and consequently less wedging.

C. Yarding

Standard yarding cost for all group selections turned out to be more efficient as compared to the clearcut unit (1-CCF). This result was not hypothesized prior to the study. Treatment-specific delays, although playing a role in reducing the group selection treatments' effective hour (i.e. 255-1090 percent more delays in group selection units over the clearcut unit), were overshadowed by the amount of presetting performed in some of the units. Thus, despite the fact that more delays can be anticipated in the group selections, these delays were, and can be, compensated for during yarding by an increase in the amount of presetting of turns. This was documented in the study with 46 percent of the turns being preset in the clearcut unit (1-CCF), and 72 to 97 percent of the turns preset in the group selection units. Treatment-specific delays were the highest in the 0.5 acre (0.20 hectare) and 1.5 acre (0.61 hectare) fan patch units (3-GSF.5P and 4-GSF1.5P), although the percentage of turns preset was moderate (72 and 82 percent respectively).

The amount of presetting in group selections increased due to the fact that all skyline roads were planned and designated during the layout process. In contrast to the clearcut, where the amount of area covered by skyline corridors was left up to the discretion of the hooktender, the group selection harvested areas were laid out in order to maximize the lateral yarding capabilities of the carriage used. Longer average lateral yarding distances in the group selections (i.e. 33 to 41 ft (10.1 to 12.5 m) in group selections versus 30 ft (9.1 m) in the clearcut) encouraged the rigging crew to preset more turns in order to reduce hooking time.

The most efficient unit with respect to yarding turned out to be the parallel strip unit (2-GSPS). This unit exhibited a standard yarding cost 4.2 percent lower than the clearcut unit (1-CCF). Very few delays due to the open, non-obstructed nature of the strip layout and a moderate percentage of preset turns combined to produce this result. It should also be noted that residual stand damage was lowest in the larger group opening units (2-GSPS and 5-GSFW) as compared to the other fan and parallel patch units.

In contrast, the fan wedge group selection (5-GSFW) may have been as productive as the parallel strips (2-GSPS) if not for its' statistically significant treatment effect. Relatively large lateral yarding distances on the back ends of the wedges required the largest percentage of presetting in the study (i.e. 97 percent). The only plausible explanation for the treatment effect in this unit lies in the relatively long average lateral yarding distances required to yard a given turn which was a direct result of the maximization of back end wedge group width. These long lateral distances, in turn, increased total delay-free yarding cycle time.

The least efficient treatment was the parallel 0.5 acre (0.20 hectare) patches (6-GSP.5P) with a standard cost of 0.2 percent above the clearcut unit (1-CCF). A moderate amount of delay time spent solely on repositioning the carriage and resetting chokers due to yarding through the standing timber of adjacent leave patches was one cause of this result. Other causal factors included: only a moderate percentage of preset turns (79 percent) and a statistically significant treatment effect reducing overall yarding productivity. This unit exhibited the highest average lateral yarding distance of all the treatments, thus increasing delay-free yarding cycle time as the treatment effect above in Unit 5 (5-GSFW) did.

The lesson that can be learned from these results is that turn presetting should be used on all group selection treatments to its' fullest advantage, especially in units where excessive delays are anticipated. These treatment specific delays, on the other hand, may have been more significant without the detailed logging planning and unit layout used in this study. In this case, it is believed that the flagging and marking of cable corridors is of the utmost importance in partial cutting operations of this type. The extra expense involved in a logging engineer's planning efforts and costs seem to be superior (i.e. more efficient and economical) to the hourly owning, operating, and labor cost of a large logging crew fighting the additional hang-ups and obstacles, and increased residual stand damage that would probably appear as a result of little or no planning.

D. Road/Landing Changes

As expected, average time per landing change in the parallel road setting group selections (Units 2-GSPS and 6-GSP.5P) was higher than in the fan setting clearcut and group selection road changes. This was due to the fact that in a landing change, in addition to pulling in the operating lines, guylines must be pulled in, the tower lowered, and all lines pulled out in order for yarding to commence again. The longest average total time occurred in the parallel setting 0.5 acre (0.20 hectare) patch unit (6-GSP.5P). The shortest average total time was recorded in Unit 4 (4-GSF1.5P).

In Unit 4's case, it was felt that the average time was affected somewhat by the shorter average yarding distances in this unit. However this unit also required a large number of roads (10) to harvest the required 35 percent of the area. These figures could therefore be a function of the resulting unit layout characteristics, especially larger resulting patch size and proximity of patches to the landing.

The number of road/landing changes required, rather than average time, was the determining factor in deciding which of the units was the most efficient. In addition, smaller patch sizes had a negative effect on productivity due to corridor obstructions and yarder tower to tailtree/tailhold alignment problems. The fan wedge unit (5-GSFW) turned out to be 52 percent more cost-efficient based on volume removed than the clearcut, since it only required two road changes at a moderate average time per road change. On the other hand, Unit 3 (3-GSF.5P) was the most costly (108 percent more than the clearcut) due to a large number of road changes (6), some treatment related pre-rigging, and a moderate average time per road change.

On the basis of final yarding cost, the fan wedge unit (5-GSFW) is shown to be vastly superior to any of the other group selection treatments with a cost only 3.4 percent above the clearcut unit (1-CCF) cost. Of all the units, this treatment has the most similar attributes as compared to clearcutting in terms of yarding efficiency. Alternatively, Unit 3 (3-GSF.5P) exhibited the highest final yarding cost, 26 percent above clearcutting, as a result of its' overall operationally difficult yarding layout. The other three group selection units were shown to be intermediate in terms of their yarding production/cost.

The biggest surprise is that the parallel treatments (2-GSPS and 6-GSP.5P) are nearly identical in their final yarding costs, a fact that was not hypothesized and only borne out by the analysis. In these units, average skyline road lengths of 930 ft (283 m) in Unit 2-GSPS and 810 ft (247 m) in Unit 6-GSP.5P; and average area harvested per road of 2.5 acres (1.0 hectares) in Unit 2-GSPS and 2.6 acres (1.1 hectares) in Unit 6-GSP.5P are fairly comparable. However, the parallel strip unit (2-GSPS) required 3 relatively time efficient landing changes, while the parallel patch unit (6-GSPS) required 2 landing changes to yard similar volumes along similar skyline road lengths. Larger strips in Unit 2 (2-GSPS) with less resulting landing changes would increase efficiency and reduce costs since standard yarding production and cost was superior on the order of 4 percent in the parallel strips (2-GSPS) versus the parallel patches (6-GSP.5P).

Final yarding costs, including all miscellaneous costs, averaged for two units (3-GSF.5P and 6-GSP.5P) that were similar to units in the first replication shift-level study (Kellogg et al., 1991), yield a 19.7 percent increase in cost over the clearcut unit (1-CCF). In contrast, the shift-level study showed a 23.6 percent increase. It should also be noted that the shift-level study did not include a move in and out and set up and tear down cost.

The final yarding cost figures in this study indicate that there is a range of increases in costs for the different group selection treatments and in general they are relatively moderate to high in scale (i.e. 3.4 to 26.0 percent). Using these figures as a "bottom line" exemplify the individual treatment efficiencies and inefficiencies. The addition of fixed yarding miscellaneous costs per total volume harvested (i.e. costs for move in and out, set up and tear down, and road/landing changes) illustrates the importance of not relying strictly on standard yarding production/cost figures to answer questions of interest in a comparison of alternative silviculture/harvesting systems.

E. Total Harvest Costs

As can be surmised by examining the data for each of the total harvest cost components, a large amount of variation occurs between and within treatments. In the end, total harvest cost offers the best means for comparisons between the group selection treatments themselves. It also serves well to compare the group selections to a more conventional fan shaped setting clearcut.

These total costs are based on the foundation of adequate logging planning. Although the clearcut required only 1.5 percent of it's total harvest cost for planning, the group selections' percentage of total cost ranged from a low of 4.7 percent in the parallel strip unit (2-GSPS) to a high of 8.4 percent in the fan 1.5 acre (0.61 hectare) patch unit (4-GSF1.5P). It cannot be overemphasized that felling, yarding, and road/landing change production and costs would be greatly influenced, in a negative fashion, by the lack of good logging planning. The degree of influence, at this point, is unknown.

Although Figure 36 in the Results shows graphically the relative differences between the treatments, some general conclusions and guidelines for the group selection treatments studied can be made. Larger group sizes were shown to be the most efficient, given that adequate wedging of trees is used during felling and presetting of turns is employed during yarding. Lack of standing trees near the designated skyline roads in these types of treatments also contributed to fewer delays and thus a higher effective hour.

Specifically, for the group selection units, the fan wedge treatment (5-GSFW) was the most efficient and the parallel strips (2-GSPS) were second. These were originally hypothesized to be the most efficient, although the magnitude and order of efficiency was unknown. The fan wedge unit was superior to the parallel strip unit mainly due to the fact that only two relatively rapid <u>road</u> changes were required. Alternatively, the parallel strip unit demanded three relatively longer <u>landing</u> changes.

The parallel 0.5 acre (0.20 hectare) patch unit (6-GSP.5P) was intermediate in it's total harvesting costs. Compared to the fan 0.5 and 1.5 acre (0.20 and 0.61 hectare) units, this treatment exhibited a slightly lower planning and final yarding cost. The reduction in planning requirements and costs can be attributed to the relative ease of unit layout, especially in flagging skyline roads and marking trees, for smaller group patches on a parallel skyline road plan setting design. Similarly, the decrease in yarding costs is associated specifically with the number of <u>landing</u> changes (2) since the average landing change time was the highest of all treatments.

The least efficient group selections, the fan patch units 3-GSF.5P and 4-GSF1.5P, illustrate in a total harvest cost fashion what would appear to be an economies of scale effect. Although logging planning requirements were essentially the same, felling cost was slightly superior in the 1.5 acre (0.61 hectare) patches, and standard yarding cost was higher in the larger patches. Final yarding costs were revealed as the most significant difference between the two treatments. 1.5 acre (0.61 hectare) patches, although requiring a larger number of road changes, did not demand as long of an average time per road change. This can be attributed to the fact that one group patch in Unit 4 (4-GSF1.5P) contained, on the average, three times the amount of harvestable area as a group patch in Unit 3 (3-GSF.5P) and a larger proportion of patches were close to the landing in Unit 4.

Interestingly, average percentages of total harvest cost above clearcutting, in this detailed time-study, of two of the group selection treatments (3-GSF.5P and 6-GSP.5P) examined previously by Kellogg et al. (1991) utilizing a shift-level time-study are nearly identical. Although different yarding equipment and felling techniques were used in the previous study, a total increased harvest cost for the group selections over clearcutting was found to be 24.7 percent. As a comparison, in this present study, the average increase in total harvest cost for two similar units was 25.0 percent.

Sensitivity analysis for the six treatments yielded an intuitively obvious linear increase in total harvest cost as a function of increasing average yarding distance. Another analysis, total harvest cost as a function of unit size, indicated that clearcuts were not as sensitive to size/area of the unit as were group selections. This unit size analysis suggests that clearcuts should be a minimum of 20 acres (8.1 hectares) in size, whereas group selection units should be a minimum of 30 acres (12.1 hectares) in size in order to minimize total harvest costs. In addition, clearcut treatment sensitivity analysis indicates that there is room for reducing total clearcut harvest cost, in the neighborhood of 3 to 7.5 percent, via improvements in rigging procedures and yarding techniques.

VII. SUMMARY AND CONCLUSIONS

This study has considered logging planning, felling, and yarding costs in a clearcut harvest unit and five alternative group selection harvest units in U.S. Pacific Northwest second growth timber. All of these units were harvested utilizing manual felling techniques and an uphill skyline Thunderbird TMY 70 mobile yarder logging system rigged in a slackline configuration. Group selection units varied by size and shape of patch and skyline road plan (i.e. fan versus parallel). The clearcut possessed a fan setting skyline road plan with wildlife tree groups. Time records, shift-level summaries, and detailed stopwatch time-study techniques were used to derive summary statistics and predictive regression equations in order to determine production and cost information.

Logging planning time requirements per unit area and cost per unit volume for group selection treatments varied from 263 to 591 percent greater than the clearcut treatment. Size of patch affected requirements most significantly, with larger patches being more cost effective to lay out. In addition, parallel setting skyline road plans appeared to be easier to lay out and thus less costly.

Felling production and costs for group selections were similar to the clearcut and varied from 0.2 percent more efficient to 2.6 less efficient. Delay-free felling cycle time was found from stepwise regression to be a function of diameter of tree, the board foot volume contained in the tree, whether or not the tree was directionally wedged, and the number of logs bucked from the tree. The amount of wedging which was required in the given treatment affected the felling production/cost most significantly. This in turn was most likely due to the opening size in relation to the skyline road. Large strip and wedge shaped patches reduced the number of potential tree lays for the faller, thus requiring more time consuming directional wedging along outer patch boundaries. Treatment specific delays had little effect on production and costs in all units.

Yarding production and costs were also relatively less variable, although group selection treatments were all found to be more productive and less costly than the clearcut treatment. Group selection treatment standard yarding production/cost varied from 0.2 to 4.2 percent more efficient than the clearcut treatment. Delay-free yarding cycle time was found from stepwise regression to be a function of the slope yarding distance, lateral yarding distance, whether or not the turn of logs was preset, the total number of logs in the turn, and whether or not the yarding was performed in two of the five statistically significant group selections. The percentage of turns that were preset in a given treatment had the most substantial effect on yarding production and cost. Larger group opening sizes required the more time efficient presetting method due to longer average lateral yarding distances, making these units more productive. In addition, treatment specific delays were found to play a much larger role in the group selection treatments during yarding, especially in the small 0.5 and 1.5 acre (0.20 and 0.61 hectare) patch units. These delays involved mainly yarding hang-ups on the edge of patches and in the skyline road corridors.

Road change costs for fan settings and landing change costs for parallel settings, in general, were substantially different due to the difference in time required for the two types of road plan changes (i.e. parallel settings necessitated longer average time). Smaller group openings were shown to demand relatively longer average times within setting road plan types. This was mainly due to problems with corridor and inter-patch obstructions and aligning the yarder tower with the tailtree/tailhold. However, number of road/landing changes was more relevant in determining the total road/landing change cost.

Resulting differences in road/landing change cost for group selection treatments ranged from 52 percent more efficient to 108 percent less efficient than the clearcut treatment. No units exhibited any treatment specific delays, although one fan patch unit did require additional treatment specific pre-rigging for some of the road changes. Total miscellaneous fixed costs (i.e. road/landing change, move in and out, and set up and tear down costs) per unit volume ranged from 25 to 125 percent higher cost in the group selections over the clearcut, mainly due to the lower volume harvested. In addition, final yarding cost (i.e. standard yarding cost plus miscellaneous costs) ranged from 3.4 to 26 percent higher in the group selection units.

Total harvest cost differences for the group selection treatments ranged from 7.3 to 31.5 percent greater than the clearcut. Units with larger group sizes (both fan and parallel setting road plans) were shown to be the most efficient overall, and units with fan settings and smaller group sizes were shown to be the least efficient. Parallel setting units with small group sizes were intermediate in production and cost efficiency. Sensitivity analysis indicated that harvest costs in both the clearcut and group selections could be minimized by a minimum unit size of 20 acres (8.1 hectares) for the clearcut and 30 acres (12.1 hectares) for the group selections. Similarly, improvements in rigging procedures and yarding techniques in clearcuts has the potential to reduce overall harvest cost on the order of 3 to 7.5 percent.

Of utmost importance, in this study and in any future implementation of the group selection treatments studied or other alternative silvicultural systems, is the foundation of adequate logging planning carried out by competent personnel. The results described and discussed in this study would not apply to first or subsequent entry treatment units (clearcut or group selection) with minimal logging planning.

It is hypothesized that as the level of logging planning decreases, the resultant felling and final yarding cost would increase. Choices of which type of group selection patch size/shape and setting skyline road plan to be utilized would depend on economic, silvicultural, terrain, visual, and wildlife considerations and objectives. This in turn would necessitate close coordination with other disciplines involved in timber harvest (i.e. an interdisciplinary approach). The conclusions, figures, and management implications from this study should, however, enable land management personnel associated with timber harvesting to make sound resource management and operational decisions based on economics and physical feasibility.

VIII. FUTURE RESEARCH

In the process of designing this study, collecting and compiling data, and the resultant analysis, several problem areas were identified where additional research could be completed. These topic areas include the following:

1). Safety and location considerations for wildlife trees (snags and green retention trees) in clearcuts (grouped and scattered); and for wildlife topped snags in group selections (grouped and scattered). In this study and a previous study by Kellogg et al. (1991), group selection snags were left in the residual future entry groups. This practice specifically may be creating more safety problems in the future as compared to locating snags in the first-entry groups.

2). Group selection second and third entry logging planning, felling, and yarding production and costs. It was felt by many of the logging personnel and researchers (both involved in the study and outside sources) that production and economics may be drastically different in subsequent entries. The conclusions in this study would especially change with regards to pre-commercial and intermediate stand improvement thinnings after the first initial entry and first complete cutting cycle.

3). Group selection first, second, and third entry residual stand damage (i.e. seedling, sapling, pole, and sawtimber differentiated). This is especially of concern in the smaller group patch treatments. In addition, it would pertain to areas with a large concentration of phototrophic hardwoods (i.e. maple). These trees tend to grow/bend outward on edges of groups toward harvested patches with a high potential for residual stand damage.

4). Group selection small patch shape effects on productivity and costs. There may be some opportunities to increase productivity and lessen potential current entry stand damage by varying patch shapes. This may include tear-drop shaped openings at the top (i.e. toward yarder in uphill yarding) of small group selection patches.

5). Effect of level of logging planning on any or all alternative silvicultural systems harvest productivity and costs. These effects may be of interest to agencies or firms who may not have the economic, time, or personnel resources that were available in this study.

6). Logging contract administration costs for any or all alternative silvicultural systems. From observation during this study, this may be another economical aspect of alternative silvicultural systems which could be significantly different depending on the system used and that warrants further investigation.

Scientists working in other disciplines (i.e. recreation, silviculture, and wildlife) have more than likely identified further needed research to pursue in alternative silvicultural systems. Many of these suggested areas for further study could easily be imbedded in several projects and accomplished in an interdisciplinary framework. Without additional research into subsequent harvest entries for group selections, long term economics for these treatments can only be conjectured.

REFERENCES AND LITERATURE CITED

Aubuchon, Richard R. 1982. Compendium of Cable Yarding Production Equations. Master of Forestry paper; Department of Forest Engineering, School of Forestry, Oregon State University; Corvallis, OR. 136 pp.

Avery, Thomas Eugene and Harold E. Burkhart. 1983. Forest Measurements, 3rd ed. McGraw-Hill Book Company; New York, NY. 331 pp.

Bell, John F. and J.R. Dilworth. 1988. Log Scaling and Timber Cruising. Oregon State University Book Stores, Inc.; Corvallis, OR. 396 pp.

Bennett, Marvin. 1992. Lead Faller, Wischnofske Timber Falling, Inc.; Philomath, OR. Personal Communication; 12 August.

Bettinger, Pete. 1991. Husky Hunter 2 and SIWORK3 User's Guide. Unpublished. Department of Forest Engineering, College of Forestry, Oregon State University; Corvallis, OR. 27 pp.

Bushman, Stephen P. and Eldon D. Olsen. 1988. Determining Costs of Logging-Crew Labor and Equipment. Oregon State University College of Forestry Forest Research Lab, Research Bulletin 63; Corvallis, OR. 22 pp.

Campbell, Tom and Jim Sherar. 1991. A Skyline Group Selection Logging Study. Unpublished USDA Report, Southern Region. USDA Forest Service; Asheville, NC. 43 pp.

Canham, Charles D.; Julie S. Denslow; William J. Platt; James R. Runkle; Tom A. Spies; and Peter S. White. 1990. Light regimes beneath closed canopies and tree-fall gaps in temperate and tropical forests. Canadian Journal of Forestry Research, Vol. 20. p. 620-631.

Carvell, Kenneth L. 1984. A Silvicultural Evaluation of Cable Yarding for Partial Cuts. In: Peters, Penn A. and John Luchok, eds. Proceedings of the Mountain Logging Symposium; June 5-7; West Virginia University; Morgantown, WV. p. 133-141.

Conway, Steve. 1982. Logging Practices: Principles of Timber Harvesting Systems, Revised ed. Miller Freeman Publications, Inc.; San Francisco, CA. 432 pp.

Daniel, Theodore W.; John A. Helms; and Frederick S. Baker. 1979. Principles of Silviculture, 2nd ed. McGraw Hill Publishing Company; New York, NY. 500 pp.

Dykstra, Dennis P. 1975. Production Rates and Costs for Cable, Balloon, and Helicopter Yarding Systems in Old-Growth Douglas-fir. Oregon State University College of Forestry Forest Research Lab, Research Bulletin 18; Corvallis, OR.

Dykstra, Dennis P. 1976. Production Rates and Costs for Yarding by Cable, Balloon, and Helicopter Compared for Clearcuttings and Partial Cuttings. Oregon State University College of Forestry Forest Research Lab, Research Bulletin 22; Corvallis, OR. 44 pp.

Erickson, Michael D.; Curt C. Hassler; and Chris B. LeDoux. 1992. Group-Selection Harvests: Influence of Group Size on Harvesting Costs and Productivity. In: Proceedings of the 15th Annual Meeting of the Council on Forest Engineering, Total Engineering in the Managed Forest; August 10-13; Hot Springs, AR. Council on Forest Engineering; Corvallis, OR. 11 pp.

Fight, Roger D.; Chris B. LeDoux; and Tom L. Ortman. 1984. Logging Costs for Management Planning for Young-Growth Coast Douglas-Fir. USDA Forest Service Pacific Northwest Forest and Range Experiment Station; Portland, OR. General Technical Report PNW-176. 10 pp.

Food and Agriculture Organization of the United Nations. 1992. Cost control in forest harvesting and road construction. FAO Forestry Paper No. 99; Rome, Italy. 106 pp.

Franklin, J.F. and Richard T.T. Forman. 1987. Creating landscape patterns by forest cutting: Ecological consequences and principles. Landscape Ecology; SPB Academic Publishing; The Hague. 1:1, p. 5-18.

Franklin, J.F. 1989. Toward a New Forestry. American Forests; American Forestry Association; Washington, DC. 95:11&12, p. 37-44.

Freund, Rudolf J. and Ramon C. Littell. 1991. SAS System for Regression, 2nd ed. SAS Institute, Inc.; Cary, NC. 210 pp.

Gardner, Rulon B. 1980. Skyline Logging Productivity under Alternative Harvesting Prescriptions and Levels of Utilization in Larch-Fir Stands. USDA Forest Service, Intermountain Forest and Range Experiment Station; Ogden, UT; Research Paper INT-247. 35 pp.

Gibson, David F. and John H. Rodenberg. 1975. Time Study Techniques for Logging Systems Analysis. USDA Forest Service Intermountain Forest and Range Experiment Station General Technical Report, INT-25. 32 pp.

Gregg, N. Taylor. 1991. Will "New Forestry" Save Old Forests? American Forests; American Forestry Association; Washington, DC. 97:9&10, p. 49-53 & 70.

Halme, Tim. 1990. Designing cutting patterns to balance New Forestry concepts with traditional forest management objectives on cable logging settings. Unpublished Speech Abstract; Plum Creek Timber Company, Columbia River Unit; Kelso, WA. 6 pp.

Halme, Tim. 1991. Some First Year Test Results of Various Leave Tree Patterns in Second Growth Timber. Unpublished Speech Abstract; Plum Creek Timber Company, Columbia River Unit; Kelso, WA. 7 pp.

Hansen, A.J.; T.A. Spies; F.J. Swanson; and J.L. Ohmann. 1991. Conserving Biodiversity in Managed Forests: Lessons from natural forests. BioScience 41:6. p. 382-392.

Hartman, David A.; William A. Atkinson; Ben S. Bryant; and Richard O. Woodfin, Jr. 1976. Conversion Factors for Pacific Northwest Forest Industry: Converting Forest Growth to Forest Products. Institute of Forest Products, College of Forest Resources, University of Washington; Seattle, WA. 112 pp.

Hicks, Lorin L. 1991. Plum Creek Timber Company's New Forestry Experiments: Lessons Learned and Future Directions. Forest Perspectives; World Forestry Center; Portland, OR. 1:3, p. 9-10.

Howard, Andrew F. 1988. Development and Use of Production Functions for Harvesting Operations. In: Proceedings of the International Mountain Logging and Pacific Northwest Skyline Symposium; December 12-16; Portland, OR. Oregon State University Department of Forest Engineering; Corvallis, OR. p. 97-102.

Kellogg, Loren D.; Eldon D. Olsen; and Michael A. Hargrave. 1986. Skyline Thinning a Western Hemlock-Sitka Spruce Stand: Harvesting Costs and Stand Damage. Oregon State University College of Forestry Forest Research Lab, Research Bulletin 53; Corvallis, OR. 21 pp.

Kellogg, Loren D.; Stephen J. Pilkerton; and Richard M. Edwards. 1991. Logging Requirements to Meet New Forestry Prescriptions. In: Proceedings of the 14th Annual Meeting of the Council of Forest Engineering, Forest Operations in the 1990's: Challenges & Solutions; July 22-25; Nanaimo, BC; Canada. Council on Forest Engineering; Corvallis, OR. p. 43-49.

Kluender, Richard A. and Bryce J. Stokes. 1992. Harvesting Productivity and Costs of Three Harvesting Methods. In: Proceedings of the 15th Annual Meeting of the Council on Forest Engineering, Total Engineering in the Managed Forest; August 10-13; Hot Springs, AR. Council on Forest Engineering; Corvallis, OR. 17 pp.

LeDoux, Chris B.; John E. Baumgras; James Sherar; and Tom Campbell. 1991. Production Rates and Costs of Group Selection Harvests with a Christy Cable Yarder. In: Proceedings of the Forestry and Environment National Forest Engineering Conference; June 5-6; New Orleans, LA. American Society of Agricultural Engineers, Forest Engineering Group; St. Joseph, MI. p. 75-84.

Lockner, Jerry. 1992. Salesman, Hessel Tractor and Equipment Co.; Tangent, OR. Personal Communication; 22 January.

Mann, John; Bill Atkinson; and Steve Tesch. 1989. Operational Challenges of Uneven-aged Management. Speech Manuscript; Abstract In: Proceedings of the Western Forestry Conference, Forestry and the World Around It; December 3-6; Sacramento, CA. Western Forestry and Conservation Association; Portland, OR. p. 38.

McArdle, Richard E.; Walter E. Meyer; and Donald Bruce. 1961. The Yield of Douglas Fir in the Pacific Northwest. United States Department of Agriculture Technical Bulletin No. 201; Washington, DC. 74 pp.

Mendenhall, William. 1979. Introduction to Probability and Statistics, 5th ed. Duxbury Press; North Scituate, MA. 594 pp.

Miyata, Edwin S. 1980. Determining Fixed and Operating Costs of Logging Equipment. USDA Forest Service, North Central Forest Experiment Station; St. Paul, MN; General Technical Report NC-55. 16 pp.

Muir, Bob. 1992. Sales, Timber Supply Company, Inc.; Philomath, OR. Personal Communication; 4 August.

National Research Council, Committee on Forestry Research. 1990. Forestry Research: A Mandate for Change. National Academy Press; Washington, DC. 84 pp.

Neter, John; William Wasserman; and Michael H. Kutner. 1989. Applied Linear Regression Models, 2nd ed. Irwin Publishers; Homewood, IL. 667 pp.

Oldham, Wayne. 1992. Co-owner, J.F. Oldham and Son, Inc.; Eugene, OR. Personal Communication; 11 August.

Olsen, Eldon D. 1983. Avoiding Two Errors in Estimating Logging Costs. TRANSACTIONS of the ASAE; American Society of Agricultural Engineers; St. Joseph, MI. 26:5, p. 1324- 1326 & 1331.

Olsen, Eldon D. and Loren D. Kellogg. 1983. Comparison of Time-Study Techniques for Evaluating Logging Production. TRANSACTIONS of the ASAE; American Society of Agricultural Engineers; St. Joseph, MI. 26:6, p. 1665-1668 & 1672.

Olsen, Eldon D. 1992. Class Notes; Forest Operations Analysis, FE 440/540. Department of Forest Engineering, Oregon State University; Corvallis, OR. 260 pp.

Oregon State University Department of Forest Engineering. 1991. LOGGER PC (Version 2.0) User's Guide. Oregon State University; Corvallis, OR. 34 pp.

Riggs, James L. and Thomas M. West. 1986. Engineering Economics, 3rd ed. McGraw-Hill Publishing Company; New York, NY. 879 pp.

Renoud, Dick. 1992. Co-owner, More Logs, Inc.; Foster, OR. Personal Communication; 5 February.

Sedlak, Jerry. 1992. Logging Engineer, ESSI Logging; Philomath, OR. Personal Communication; 26 August.

Sherar, James R. and Chris B. LeDoux. 1989. Shift Level Analysis of Cable Yarder Availability, Utilization, and Productive Time. In: Proceedings of the 12th Annual Meeting of the Council on Forest Engineering, Implementing Techniques for Successful Forest Operations; August 27-30; Coeur d'Alene, ID. Council on Forest Engineering; Corvallis, OR. p. 37-40.

Sherar, Jim; Jack Swanner; and Tom Campbell. 1991. Skyline Shelterwood Logging Study. Unpublished USDA Report, Southern Region. USDA Forest Service; Asheville, NC. 11 pp.

Smith, David M. 1986. The Practice of Silviculture, 8th ed. John Wiley and Sons, Inc. New York, NY. 527 pp.

Society of American Foresters. 1981. Choices in Silviculture for American Forests. Society of American Foresters; Washington, DC. 80 pp.

Spies, Thomas A. and Jerry F. Franklin. 1989. Gap Characteristics and Vegetation Response in Coniferous Forests of the Pacific Northwest. Ecology, 70:3. p. 543-545.

Spies, Thomas A.; Jerry F. Franklin; and Mark Klopsch. 1990. Canopy gaps in Douglas-Fir forests of the Cascade Mountains. Canadian Journal of Forestry Research, Vol. 20. p. 649-658.

Spies, Thomas A. and Jerry F. Franklin. 1991. The Structure of Natural Young, Mature, and Old-Growth Douglas-Fir Forests in Oregon and Washington. In: Wildlife and Vegetation of Unmanaged Douglas-Fir Forests; USDA Forest Service Pacific Northwest Research Station; Portland, OR. General Technical Report PNW-285. p. 91-109.

Spies, Thomas A.; John Tappeiner; Jim Pojar; and Dave Coates. 1991. Trends in Ecosystem Management at the Stand Level. In: Transactions of the 56th North American Wildlife and Natural Resources Conference. p. 628-639.

Spurr, Stephen H. and Burton V. Barnes. 1980. Forest Ecology, 3rd ed. John Wiley and Sons; New York, NY. 687 pp.

State of Oregon Department of Insurance and Finance Accident Prevention Division. 1990. Draft Oregon Occupational Safety and Health Code; OAR Chapter 437 Division 06, Forest Activities; Effective June 1990. Salem, OR. 208 pp.

Statistical Graphics Corporation. 1991. STATGRAPHICS version 5 User Manual. STSC; Rockville, MD. ≈ 300 pp.

Stenzel, George; Thomas A. Walbridge, Jr.; and J. Kenneth Pearce. 1985. Logging and Pulpwood Production, 2nd ed. John Wiley and Sons; New York, NY. 358 pp.

Studier, Donald D. and Virgil W. Binkley. 1974. Cable Logging Systems. Oregon State University Book Stores, Inc.; Corvallis, OR. 211 pp.

Swanson, Frederick J.; Jerry F. Franklin; and James R. Sedell. 1990. Landscape Patterns, Disturbance, and Management in the Pacific Northwest, USA. In: Zonneveld, I.S. and R.T.T. Forman; eds. Changing Landscapes: An Ecological Perspective. Springer-Verlag; New York, NY. p. 191-213.

Swanson, Fred and Dean Berg. 1991. The Ecological Roots of New Approaches to Forestry. Forest Perspectives; World Forestry Center; Portland, OR. 1:3, p. 6-8.

Tappeiner II, John; William C. McComb; Loren Kellogg; and Becky Johnson. 1991. Comparisons Among Three Silviculture Systems on McDonald-Dunn Research Forests: Harvesting Strategies, Tree Regeneration, Vertebrate Communities, and Public Responses. In: Proceedings of the First Biannual Regional Alternative Silviculture Conference; November 25-26; Vancouver, WA. Olympic Natural Resources Center and Coastal Oregon Productivity Enhancement. Oregon State University; Corvallis, OR. p. 45-49.

Tesch Steven D.; John W. Mann; and David H. Lysne. 1989. Coordinating Timber Harvest Activities with Silvicultural Objectives in the West. In: Proceedings of the Society of American Foresters National Convention, Foresters on the Frontier; September 24-27; Spokane, WA. Society of American Foresters; Bethesda, MD. p. 198-202.

Thomas, Jack Ward. 1979. Wildlife Habitats in Managed Forests: the Blue Mountains of Oregon and Washington. USDA Forest Service Agriculture Handbook No. 553. 512 pp.

Thompson, Michael A. 1988. An Analysis of Methods Used to Report Machine Performance. Presented at the 1988 International Winter Meeting of the ASAE; December 13-16; Chicago,IL. American Society of Agricultural Engineers; St. Joseph, MI. 56 pp.

Troup, R.S. 1928. Silvicultural Systems. Oxford University Press; London, UK. 199 pp.

USDA Forest Service. 1978. Logging Systems Guide. USDA Forest Service Alaska Region Report Number 21; Juneau, AK. ≈ 400 pp.

USDA Forest Service, Region 6. 1990. Cost Guide for Empirical Appraisal, revision 18. USDA Forest Service Regional Office; Portland, OR. 27 pp.

Van Dehey, Dick. 1992. Salesman, Ross Corporation; Eugene, OR. Personal Communication; 26 August.

Van Winkle, Denis J. 1976. An Analysis of Road Changing on Several Cable Logging Operations. Master of Forestry paper; Department of Forest Engineering, School of Forestry, Oregon State University; Corvallis, OR. 99 pp.

Weigand, J. 1991. Costs and Benefits of New Perspectives; Blue River Ranger District, Willamette National Forest. Unpublished USDA Report; PNW Research Station, USDA Forest Service; Portland, OR. 4 pp.

Weigand, James F. and Richard W. Haynes. 1991. Economic Considerations for Green Tree Retention. Forest Perspectives; World Forestry Center; Portland, OR. 1:3, p. 11-12.

Wells, G.C. 1981. Costing Handbook for Logging Contractors. New Zealand Logging Industry Research Association, Inc.; Rotorua, New Zealand. 79 pp.

Workers' Compensation Board of British Columbia. 1981. Yarding and Loading Handbook, 2nd ed. WCB of British Columbia; Richmond, BC. Canada. 188 pp.

APPENDICES

APPENDIX A:
Study Area Unit Specific Site and Timber Statistics

Unit-Rx	Total Area - acres (hectares)	Area Cable Yarded - acres (hectares)	Volume per Unit Area - Scribner gross Mbf volume/acre (m^3/hectare)*
1-CCF	24.5 (9.9)	19.1 (7.7)	41.6 (583)
2-GSPS	25.9 (10.5)	9.9 (4.0)	34.3 (480)
3-GSF.5P	25.0 (10.1)	8.8 (3.6)	30.9 (433)
4-GSF1.5P	25.3 (10.2)	7.1 (2.9)	27.2 (381)
5-GSFW	20.4 (8.3)	7.1 (2.9)	39.2 (549)
6-GSP.5P	28.0 (11.3)	7.8 (3.2)	35.7 (500)
	Average:		Weighted Average:
	24.9 (10.1)		36.1 (506)

Unit-Rx	Basal Area - ft^2/acre (m^2/hectare)	Average Age - years	Average Height - ft (m)
1-CCF	240 (55.1)	111	102 (31.1)
2-GSPS	230 (52.8)	92	90 (27.4)
3-GSF.5P	220 (50.5)	68	93 (28.3)
4-GSF1.5P	200 (45.9)	66	87 (26.5)
5-GSFW	280 (64.3)	90	90 (27.4)
6-GSP.5P	290 (66.6)	77	86 (26.2)
	Weighted Average:		
	240 (55.1)	90	94 (28.7)

* A conversion factor of 5.668 m^3 per Mbf was utilized, calculated from: 177 bf = 35.43 ft^3 for an 18 and 11 in large and small end dib and 29.2 ft scaling length (see Appendices A and O) using Smalian's formula (Hartman et al., 1976).

Unit-Rx	Average Dbh - in (cm)	Average Trees per Unit Area - trees/acre (trees/hectare)	Average Slope - % (Range)
1-CCF	20 (51)	77 (190)	30 (0-67)
2-GSPS	18 (46)	64 (158)	29 (0-40)
3-GSF.5P	17 (43)	90 (222)	34 (0-60)
4-GSF1.5P	16 (41)	79 (195)	33 (0-55)
5-GSFW	17 (43)	87 (215)	31 (0-73)
6-GSP.5P	16 (41)	107 (264)	34 (0-73)
	Weighted Average:		
	18 (46)	82 (203)	31 (0-73)

Unit-Rx	Average Aspect - Azimuth (Quadrant)
1-CCF	117 (SE)
2-GSPS	159 (S)
3-GSF.5P	348 (N)
4-GSF1.5P	317 (NW)
5-GSFW	165 (S)
6-GSP.5P	164 (S)
	Weighted Average:
	192 (S)

Weighted Average (Range) McArdle Site Index for all Units:

157 (146-168; Site Class II-III)

Weighted Average and Range of Elevations for all Units; ft (m):

Average: 730 (223)
Range: 380-1100 (116-335)

Unit-Rx	Percent Hardwood	Percent Grand Fir
1-CCF	11.13	1.24
2-GSPS	16.14	1.08
3-GSF.5P	20.80	1.59
4-GSF1.5P	23.88	2.70
5-GSFW	10.50	3.29
6-GSP.5P	13.12	2.02
	Weighted Average:	
	16.07	1.95

APPENDIX B:
Logging Planning Time Records Form

Dunn Tract Harvesting Component Study

	A	B	C	D	E	F	G	H	I
1	Date	Activity Code	Start	Finish	Time	# People	Total Time	Unit #	Comments
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									
31									
32									
33									
34									
35									
36									

APPENDIX C:
Logging Planning Equipment Costs and Labor Rate

Scheduled hours/year (SH) = 2,000

EQUIPMENT OWNERSHIP COSTS $/hr

1. Depreciation

Straight-line method = $\dfrac{P - S - RC}{N}$

Average annual investment (AAI) =

$$\frac{\underset{\text{(Depreciable value)}}{(P - S)}\ \underset{\text{(Depreciation period + 1)}}{(N + 1)}}{2\ \underset{(N)}{\text{(Depreciation period)}}} + \underset{\text{Salvage value}}{(S)}$$

Crew truck, 1/2 ton 4WD pickup; Ford F-150.
Purchase price (P) = $14,400
Salvage value (S) = 10% x P
Replacement Cost (RC) = $480 (tires)
Estimated life (N) = 8 years 0.78
Average annual investment (AAI) = $8,730

2. Interest, Insurance, and License Fees (After Kellogg et al., 1986; and Bushman and Olsen, 1988)

Interest Rate = 12.00%
Insurance = 0.88%
License Fees = 1.00%
Total = 13.88%

(13.88%) (AAI) ÷ SH
(0.1388%) ($8,730) ÷ 2,000 hrs/yr 0.61

Total Equipment Ownership Cost 1.39

EQUIPMENT OPERATING COSTS $/hr

3. Direct Labor
(Includes a fringe benefit and burden factor of 1.40)

Logging Engineer 16.80

4. Supervision

(5%) (Direct labor cost)
(0.05) ($16.80) 0.84

5. Maintenance and Repair (After Kellogg et al., 1986)

Crew truck:
(50%) (depreciation) + one set of
tires every 1.5 years @ $480 .... 0.55

6. Crew Truck Operation

$\frac{(100 \text{ mi/day}) (\$1.21/\text{gal})}{(15 \text{ mi/gal}) (8 \text{ hrs/day})}$ x 1.07 lube and oil adj. ... 1.08

7. Forestry Supplies

Cruiser's vest
Logger's tapes (3)
Tape refills (9)
Hip chain
Clinometer
Compass
Boxes of flagging (24)
Cases of paint (40)
Paint gun
Other

$4,335 ÷ 4,000 hrs 1.08

Total Equipment Operating Cost 20.35

TOTAL COST PER SCHEDULED HOUR $21.74

APPENDIX D:
Felling Shift-Level Form
(After Kellogg et al., 1991)

OREGON STATE UNIVERSITY
FOREST ENGINEERING DEPARTMENT

DAILY PRODUCTION -- GENERAL INFORMATION

DATE: ____________________ SHIFT START TIME ________

NAME: ____________________________ END TIME ________

BREAK TIME USED: ________
(ie. LUNCH, 20 MIN)

UNIT NUMBER: _____ SETTING TYPE: CC ____ (CLEARCUT)
SW ____ (SHELTERWOOD)
PA ____ (PATCH)

FELLING PRODUCTION INFORMATION

NUMBER OF FELLERS: ____

	HOURS WORKED	# OF TREES (LOGS)
FELLER #1	____________	__________
FELLER #2	____________	__________
FELLER #3	____________	__________

FELLING DELAY TIME --- DELAY TIME GREATER THAN 10 MINUTES

MECHANICAL ----- TIME (MINUTES) & EXPLANATION
1) ____
2) ____
3) ____

OTHER DELAY ----- TIME (MINUTES) & EXPLANATION
1) ____
2) ____
3) ____

SPECIAL EQUIPMENT USED (ie, TREE JACKS) and TOTAL TIME FOR THE DAY
FELLER #1 ____
FELLER #2 ____
FELLER #3 ____

COMMENTS ---

APPENDIX E:
Summary of Specific Felling Delays Used in Detailed Stopwatch Time-Study

Delay Type:	Code
Operational:	
* Move Fuel/Saw	10
* Consult with Other Faller	20
* Consult with Administrator	30
* Bar Hang-Up	40
* Cut Other Faller Out of Hang-Up	50
Other	100
Repair	200
Maintenance:	
* Install/ Sharpen Chain	310
* Adjust Bar Tension	320
* Adjust Idle	330
* Clean Air Filter	340
Fuel	400
Personal:	
* Water/Food Break	510
* Urinate/Defecate	520
* Rest Break	530

APPENDIX F:
Felling Detailed Time-Study Form
(After Kellogg et al., 1991)

FELLING TIME STUDY FORM

Unit #: ________ Date: ________

Start: ________ Feller: ________

Tree #	Non-Merch Tree	Planning	Move + Prep	Felling	Bucking	Inside Bark Butt Diameter	# Logs	# Cuts	Used Jacks?	Delay	Delay Code

Comments (Slope %, Weather, etc.): ________

APPENDIX G: Model Parameter Summary Statistics and Regression Fit for Board Foot Volume (BFVOL) Prediction Model

I. Summary Statistics:

Parameter	Average	Standard Deviation	Range	Sample Size
BUTTDIAM	20.2 in (51 cm)	7.9 (20)	8-41 (20-104)	150
NMBRLOGS	2.57	1.05	1-6	"
NMBRCUTS	2.80	1.35	1-8	"

II. Regression Fit:

$$\text{Mean } \ln \text{(BFVOL)} = 1.865112 + 0.092594 \text{ (BUTTDIAM)} + 0.734101 \text{ (NMBRLOGS)} + 0.364438 \text{ (NMBRCUTS)} - 0.10527 \text{ (NMBRLOGS) (NMBRCUTS)}$$

R-squared (adjusted for d.f.) = 0.953652

Standard Error of Estimate = 0.270399

Degrees of Freedom (d.f.) = 145

Parameter	Standard Error	Significance Level
Constant	0.095528	< 0.0001
BUTTDIAM	0.00469	"
NMBRLOGS	0.071493	"
NMBRCUTS	0.072521	"
NMBRLOGS* NMBRCUTS	0.0118	"

APPENDIX H: Felling Equipment Costs and Labor Rate

Scheduled hours/year (SH) = 1,600

EQUIPMENT OWNERSHIP COST	$/hr
1. Depreciation	
Chainsaws (2); Stihl 064 w/ 36" bar.	
Purchase price (P) = $1,430	
Salvage value (S) = 40% x P	
Replacement cost (RC) = $70 (bar and chain)	
Estimated life (N) = 1.5 years	0.33
Average annual investment (AAI) = $1,287	
Crew truck, 1/2 ton 4WD pickup; Ford F-150.	
Purchase price (P) = $14,400	
Salvage value (S) = 10% x P	
Replacement cost (RC) = $480 (tires)	
Estimated life (N) = 8 years	0.98
Average annual investment (AAI) = $8,730	
Total AAI = $10,017	
Total Depreciation	1.31
2. Interest, Insurance, and License Fees (After Kellogg et al., 1986; and Bushman and Olsen, 1988)	
Interest rate = 12.00%	
Insurance = 0.88%	
License fees = 1.00%	
Total 13.88%	
(13.88%) (AAI) ÷ SH	
(0.1388) ($10,017) ÷ 1,600 hrs/yr	0.87
Total Equipment Ownership Cost	2.18

EQUIPMENT OPERATING COSTS $/hr

3. Direct labor (Bennett, 1992)
(Includes a fringe and burden factor of 1.40)

Timber Faller 26.25

4. Supervision

(15%) (Direct labor cost)
(0.15) ($26.25) 3.94

5. Maintenance and Repair (After Miyata, 1980; and Kellogg et al., 1986)

Chainsaws:
(90%) (depreciation) + one bar every
400 hrs @ $50 and one chain every
80 hrs @ $20 .... 0.62

Crew truck:
(50%) (depreciation) + one set of
tires every 1.5 years @ $480 .... 0.69

Total Maintenance and Repair 1.31

6. Equipment Operation

Chainsaw fuel mix:
(0.23 gal/hr) ($1.46/gal) 0.34

Chainsaw bar oil:
(0.10 gal/hr) ($5.00/gal) 0.50

Crew truck fuel and oil:
$\frac{(100 \text{ mi/day}) (\$1.21/\text{gal})}{(15 \text{ mi/gal}) (8 \text{ hrs/day})}$ x 1.07 lube and oil adj. ... 1.08

Total Equipment Operation 1.92

EQUIPMENT OPERATING COSTS (continued) $/hr

7. Miscellaneous Felling Supplies

Felling axe
Axe handles (2)
Shovel and fire kill
Wedges (15)
Logger's tapes (2)
Tape refills (20)
Gas cans (2)
Bar wrenches (2)
Boxes of files (2)
Bench grinder (8 year life; $0.04/hr)
Grinding stones (12)
Protective chaps
Ear plugs
First Aid supplies (2 year life; $0.03/hr)
Other

$619 ÷ 1,600 hrs + $0.07/hr	0.46
Total Equipment Operating Cost	33.88
TOTAL COST PER SCHEDULED HOUR	$36.06

APPENDIX I:
Yarding and Loading Shift-Level Form
(After Kellogg et al., 1991)

OREGON STATE UNIVERSITY -- FOREST ENGINEERING DEPARTMENT

LOADING AND YARDING DAILY PRODUCTION -- GENERAL INFORMATION

DATE: ____________________
NAME: ____________________

SHIFT START TIME ________
END TIME ________
BREAK TIME USED: ________
(ie. LUNCH, 20 MIN)

UNIT NUMBER: _____
LANDING # : _____
SKYLINE ROAD(S) #: _____

SETTING TYPE: CC ____ (CLEARCUT)
SW ____ (SHELTERWOOD)
PA ____ (PATCH)

==

LOADER: ____________________

TOTAL NUMBER OF LOADS: _____
APPROXIMATE TIME SPENT LOADING: _____
APPROXIMATE TIME SPENT DECKING: _____
APPROX. TIME SHOVEL LOGGING: _____
TIME SPENT OTHER: _____

TRIP TICKET NUMBERS	
________	________
________	________
________	________
________	________
________	________
________	________

LOADING DELAY TIME --- DELAY TIME GREATER THAN 10 MINUTES
MECHANICAL ----- TIME (MINUTES) & EXPLANATION
1) ____
2) ____
3) ____

OTHER DELAY -----
1) ____
2) ____
3) ____

==

YARDER: ____________________

TOTAL # OF TURNS ______
TOTAL # OF LOGS ______

MANPOWER
(HOURS)
LOADER OPERATOR: _____
YARDER ENGINEER: _____
CHASER: _____
HOOK TENDER: _____
SECOND RIGGER: _____
RIGGING SLINGER: _____
CHOKER SETTER #1: _____
CHOKER SETTER #2: _____

YARDING DELAY TIME --- DELAY TIME GREATER THAN 10 MINUTES
DELAY TYPE ----- TIME (MINUTES) & EXPLANATION
1) ____
2) ____
3) ____

ROAD and / or LANDING CHANGES --- TIME and IDENTIFY (by #, etc)
1) ____
2) ____
3) ____

==

OTHER COMMENTS -----

APPENDIX J:
Summary of Specific Yarding Delays Used in Detailed Stopwatch Time-Study

Delay Type:	Code
Operational:	
* Landing Logs	5
* Reposition Carriage/Reset Chokers	10
* Planning	15
* Felling and Bucking	20
* Rigging Chainsaw Cuts	25
* Pulled Anchor Stump or Tailtree/Stump Tailhold	30
* Yarder Adjustments/Wait Yarder	35
* Line/Rigging Adjustments and/or Checks	40
* Wait Loader	45
* Wait Chaser	50
* Wait Log Truck	55
* Put On/Take Off Extra Chokers	60
* Transfer of Rigging, Equipment, Chainsaws, Lunches, etc. Along Skyline	65
* Clear Corridor Obstacles with Carriage	70
* Fuel	75
* Pick Up Logs	80
* Miscellaneous	85
Repair:	
* Yarder	100
* Loader	110
* Line/Carriage	120
* Block	130
* Miscellaneous	140
Personal:	
* Food, Water	200
* Discussion	210
* Miscellaneous	220
Other:	
* Researcher in Way	300
* Miscellaneous	310

APPENDIX K:
Yarding and Loading Equipment Costs and Labor Rates
(After Kellogg et al.,1986)

Scheduled hours/year (SH) = 2,000

EQUIPMENT OWNERSHIP COSTS $/hr

1. Depreciation (USDA Forest Service, 1990; Lockner, 1992; Renoud, 1992; and Van Dehey, 1992)

Equipment	P($)	S(%)	RC($)	N(yrs)	AAI($)	$/hr
Yarder (T-Bird TMY70)	465,000	20	4,100 (tires)	8	302,250	22.99
Carriage (Danebo S35DL)	15,000	10	0	3	10,500	2.25
Loader (JD 892D-LC)	289,000	20	14,900 (tracks)	8	187,850	13.52
Crew truck (Ford 12 pass. Cabin Chassis)	23,000	10	780 (tires)	8	13,944	1.25
Communications (3 Talkie Tooters; 3 Walkie Talkies)	8,831	20	1,787 (1 of each unit)	8	5,740	0.33
Used landing cat (JD 550)	30,000	20	0	4	21,000	3.00
Used tailhold cat (CAT D7G)	75,000	20	0	4	52,500	7.50
Used fuel truck (Ford 1,250 gal)	10,000	10	0	4	6,625	1.13

Total AAI 600,409

Total Depreciation 51.97

EQUIPMENT OWNERSHIP COSTS (continued) $/hr

2. Interest, Insurance, and Taxes (After Bushman and Olsen, 1988)

Interest rate	=	12.00%
Insurance	=	0.88%
Taxes	=	1.45%
Total		14.33%

(14.33%) (Total AAI) ÷ SH
(0.1433) ($600,409) ÷ 2,000 hrs/yr 43.02

Total Equipment Ownership Cost 94.99

EQUIPMENT OPERATING COSTS $/hr

3. Direct Labor
(Includes a fringe benefit and burden factor of 1.40 on straight time wages; 1.15 on overtime wages. 10 hours overtime per 40 hours straight time assumed and a travel allowance of $0.80/hr. After Kellogg et al.,1986; Bushman and Olsen, 1988; and USDA Forest Service, 1990)

Hooktender 20.84
Loader Operator 18.42
Rigging Slinger 17.87
Yarder Operator 17.74
2 Chasers 33.98
2 Chokersetters 29.28

Total Direct Labor 138.13

4. Supervision

(15%) (Direct labor cost)
(0.15) ($138.13) 20.72

5. Maintenance and Repair (After Miyata, 1980)

Yarder:
(50%) (depreciation) + one set of
tires every 4 years @ $4,100 .... 12.01

Carriage:
(70%) (depreciation) 1.58

EQUIPMENT OPERATING COSTS (continued) $/hr

5. Maintenance and Repair (continued)

Loader:
(65%) (depreciation) + one set of tracks every 4 years @ $14,900 .... 10.65

Crew truck:
(50%) (depreciation) + one set of tires every 1.5 years @ $780 .... 0.88

Communications:
(60%) (depreciation) + one Talkie Tooter and walkie-talkie transmitter every 3 years @ $1,787 .... 0.50

Used landing cat:
(65%) (depreciation) 1.95

Used tailhold cat:
(40%) (depreciation) 3.00

Used fuel truck:
(30%) (depreciation) 0.34

Total Maintenance and Repair 30.91

6. Equipment Operation (After USDA Forest Service, 1990)

Yarder:
(17 gal/hr) ($0.84/gal) x 1.07 lube and oil adj. 15.28

Loader:
(8 gal/hr) ($0.84/gal) x 1.07 lube and oil adj. 7.19

Crew truck:
$\frac{(100\ \text{mi/day})\ (\$1.21/\text{gal})}{(10\ \text{mi/gal})\ (10\ \text{hrs/day})}$ x 1.07 lube and oil adj. ... 1.29

Used landing cat:
$\frac{(3.3\ \text{gal/hr})\ (2\ \text{hrs/day})\ (\$0.84/\text{gal})}{10\ \text{hrs/day}}$ x 1.07 lube and oil adj. ... 0.59

Used tailtree cat:
$\frac{(8.5\ \text{gal/hr})\ (0.5\ \text{hrs/day})\ (\$0.84/\text{gal})}{10\ \text{hrs/day}}$ x 1.07 lube and oil adj. ... 0.38

EQUIPMENT OPERATING COSTS (continued) $/hr

6. Equipment Operation (continued)

Used fuel truck:

$\frac{(10\ \text{mi/day})\ (\$1.11/\text{gal})}{(8\ \text{mi/gal})\ (10\ \text{hrs/day})}$ x 1.07 lube and oil adj. ... 0.15

Total Equipment Operation 24.88

7. Wire Rope, Rigging, and Landing Supplies (USDA Forest Service, 1990; and Muir, 1992)

Wire Rope (Domestic):

Skyline:
1 1/8" swaged x 2,000′ @ $2.31/ft
+ $225 labor ÷ 2,000 hrs 2.42

Mainline:
7/8" IPS x 2,100′ @ $2.14/ft
+ $150 labor ÷ 2,000 hrs 2.32

Haulback:
3/4" IPS x 4,400′ @ $1.72/ft
+ $225 labor ÷ 2,000 hrs 3.90

Slackpulling line:
1/2" IPS x 3,100′ @ $0.94/ft
+ $120 labor ÷ 2,000 hrs 1.52

Strawline:
3/8" IPS x 4,500′ @ $0.83/ft
+ $350 labor ÷ 2,000 hrs 2.04

Dropline (for carriage):
3/4" IPS x 250′ @ $1.72/ft
+ $70 labor ÷ 500 hrs 1.00

Guylines:
(7/8" IPS x 300′ @ $2.14/ft
+ 2 swaged ferrules @ $9.20
each) x 5 + $150 labor ÷ 3,000 hrs 1.15

Chokers:
(5/8" x 12′ @ $35.40 each)
x 24 ÷ 2,000 hrs 0.42

Tailtree guylines:
(3/4" IPS x 150′ @ $1.72/ft)
x 4 ÷ 4,000 hrs 0.26

EQUIPMENT OPERATING COSTS (continued) $/hr

7. Wire Rope, Rigging, and Landing Supplies (continued)

Guyline taglines:
(7/8" IPS x 100′ @ \$2.14/ft
+ 2 swaged ferrules @ \$9.20
each) x 3 ÷ 3,000 hrs 0.23

(7/8" IPS x 50′ @ \$2.14/ft
+ 2 swaged ferrules @ \$9.20
each) x 2 ÷ 3,000 hrs 0.08

Haulback line straps:
(3/4" IPS x 20′ @ \$1.72/ft
+ 2 swaged eyes @ \$9.15
each) x 4 ÷ 4,000 hrs 0.05

Rigging:

Haulback blocks (for 3/4" wire rope):
\$559 each x 4 ÷ 4,000 hrs 0.56

Tommy Moore rigging blocks:
\$351 each x 3 ÷ 4,000 hrs 0.26

Miscellaneous rigging supplies:
Knock-out shackles (4)
Safety shackles (6)
Nylon tailtree straps (2)
Line clamps (10)
Railroad spikes (60)
Guyline sleeves (4)
Splicing needle set (2)
Riggers maul
Felling axe
Wedges (4)

\$1,909 ÷ 4,000 hrs 0.48

Double-end guyline hook (5)
Screwy-eye guyline hook (5)
Strawline Hooks (36)
Tree irons (4)
Climbing gear set (2)
Cable cutter
Rigging chain (2)
Ratchet puller

\$3,030 ÷ 8,000 hrs 0.38

EQUIPMENT OPERATING COSTS (continued)	$/hr
7. Wire Rope, Rigging, and Landing Supplies (continued)	
Landing Supplies:	
Chainsaws:	
2 Husqvarna 266's @ $600 ÷ 4,000 hrs	0.30
1 Husqvarna 281 @ $800 ÷ 4,000 hrs	0.20
Saw operating cost	1.18
Miscellaneous landing supplies:	
Gas cans (3)	
Bar wrenches (6)	
Boxes of files (8)	
Boxes of ear plugs (2)	
Logger's tapes (10)	
Protective chaps (4)	
First Aid supplies	
Other	
$860 ÷ 4,000 hrs	0.22
Total Wire Rope, Rigging, and Landing Supplies ..	18.97
Total Equipment Operating Cost	233.61
TOTAL COST PER SCHEDULED HOUR	$328.60

APPENDIX L:
Costs of Yarding and Loading Equipment Move In and Out and Set Up and Tear Down

MOVE IN AND OUT COSTS

(USDA Forest Service, 1990; and Oldham, 1992)

Note: Costs reflect transport distance af 100 total miles.

Yarder (Self Propelled Rubber Mount T-Bird TMY70):

Fuel:

Yarder:

(23.5 gal/hr) (2 hr/move) ($0.84/gal) (2 moves) x 1.07 lube and oil adj. 84.49

Flag/Pilot Vehicle:

$\frac{(100 \text{ mi/move}) (\$1.21\text{/gal}) (2 \text{ moves}) (2 \text{ vehicles})}{20 \text{ mi/gal}}$ x 1.07 lube and oil adj. . 25.90

Labor:

Yarder (Yarder Operator wages and Supervision):

($20.40/hr) (2 hrs/move) (2 moves) 81.60

Flag/Pilot Vehicle (Chokersetter wages and Supervision):

($16.84/hr) (3 hrs/move-vehicle) (2 moves) (2 vehicles) 202.08

Permits:

($30/permit) (2 permits) + $0.40/loaded mile for loads in excess of 80,000 lbs. 100.00

Total Yarder 494.07

Loader: (Contract low-boy transport with pilot vehicles; per hour costs are for loaded and unloaded time)

Transport:

($100/hr) (4 hr/move) (2 moves) 800.00

Permits:

($30/permit) (2 permits) + $0.40/loaded mile for loads in excess of 80,000 lbs. 100.00

Total Loader 900.00

MOVE IN AND OUT COSTS (continued)

<u>Landing cat:</u> (Contract, as above)

Transport:
($60/hr) (3 hr/move) (2 moves) 360.00

Permits:
($30/permit) (2 permits) .... <u>60.00</u>

Total Landing cat 420.00

<u>Tailhold cat:</u> (Contract, as above)

Transport:
($70/hr) (3 hr/move) (2 moves) 420.00

Permits:
($30/permit) (2 permits) .... <u>60.00</u>

Total Tailhold cat 480.00

<u>Fuel truck:</u>

Fuel:

$$\frac{(50\text{ mi/move})\ (\$1.11\text{/gal})\ (2\text{ moves})}{8\text{ mi/gal}} \times 1.07 \text{ lube and oil adj.}$$ 14.85

Labor: (Chaser wages and Supervision)
($19.54/hr) (2 hr/move) (2 moves) .... <u>78.16</u>

Total Fuel truck .... <u>93.01</u>

TOTAL MOVE IN AND OUT COST $2,387.08

SET UP AND TEAR DOWN COSTS
(Sedlak, 1992)

Set Up:

Assume approximately 4 hours to set up with Hooktender, Rigging Slinger, Yarder Operator, and Loader Operator.

Hourly Rate = Total Cost per Scheduled Hour
- Uninvolved Direct Labor
- [(Uninvolved Direct Labor) (0.15 Supervision)]

= \$328.60 - 63.26 - [(63.26) (0.15)]

= \$255.85

(\$255.85/hr) (4 hr) 1,023.40

Tear Down:

Assume approximately 2 hours to tear down with full crew.

Hourly Rate = \$327.88

(\$328.60/hr) (2 hr) 657.20

TOTAL SET UP AND TEAR DOWN COST \$1,680.60

APPENDIX M:
Road/Landing Change Time-Study Form

Date: Unit #:
Start: Cable Road # :

ROAD CHANGE TIME STUDY

Component	Time	# people	Tailhold Type
Rig-Down			
Move Yarder			
Rig-Up			
Pre-Rigging			

Delay(s) and Description:

Comments:

APPENDIX N:
Study Area Unit Specific Calculated Yarding Distances and Areas Yarded by Logging System

Unit-Rx	Average Yarding Distance ft (m)	Average External Yarding Distance ft (m)	Long Corner Distance ft (m)
1-CCF	600 (183) 300 (91) - Skidder	910 (277)	1260 (384)
2-GSPS	490 (149)	960 (293)	1050 (320)
3-GSF.5P	570 (174)	780 (238)	1120 (341)
4-GSF1.5P	380 (116) 110 (34) - Skidder	500 (152)	820 (250)
5-GSFW	630 (192)	950 (290)	1010 (308)
6-GSP.5P	390 (119) 300 (91) - Skidder	790 (241)	1010 (308)
	Weighted Average (Cable Only):		
	530 (162)	840 (256)	1090 (332)

Unit-Rx	Area Cable Yarded - acres (hectares); % of Harvested Area	Area Skidder Yarded - acres (hectares); % of Harvested Area	% Total Area
1-CCF	19.1 (7.7); 78	2.6 (1.1); 11	89
2-GSPS	9.9 (4.0); 100	-	38
3-GSF.5P	8.8 (3.6); 100	-	35
4-GSF1.5P	7.1 (2.9); 84	1.4 (0.57); 16	34
5-GSFW	7.1 (2.9); 100	-	35
6-GSP.5P	7.8 (3.2); 88	1.1 (0.45); 12	32
			Group Selection Weighted Average:
			35

APPENDIX O:
Study Area Unit Specific Miscellaneous Yarding and Loading Shift-Level Timber Scale Attributes

Unit-Rx	Gross to Net Timber Scale Ratio	Average Gross Log Volume bd. ft. (m^3)
1-CCF	0.919583	216 (1.22)
2-GSPS	0.920293	171 (0.969)
3-GSF.5P	0.932736	173 (0.981)
4-GSF1.5P	0.928951	179 (1.01)
5-GSFW	0.928184	173 (0.981)
6-GSP.5P	0.919590	169 (0.958)
	Weighted Average:	
	0.927575	177 (1.00)

Unit-Rx	Average Scaled Length ft (m)	Average Scaled Diameter in (cm)
1-CCF	29.4 (8.96)	12.0 (30.5)
2-GSPS	28.3 (8.63)	11.0 (27.9)
3-GSF.5P	27.9 (8.50)	11.2 (28.4)
4-GSF1.5P	28.4 (8.66)	11.1 (28.2)
5-GSFW	28.9 (8.81)	10.8 (27.4)
6-GSP.5P	29.7 (9.05)	10.4 (26.4)
	Weighted Average:	
	29.2 (8.90)	10.9 (27.7)

APPENDIX P:

Ground View Photographs of Study Treatment Units

Illustration 1: Unit 1 - Clearcut Fan (1-CCF). From eastern bottom edge of unit; looking west towards wildlife tree groups.

Illustration 2: Unit 2 - Group Selection Parallel Strips (2-GSPS). From top of second from west first entry landing; looking down towards lift tree.

Illustration 3: Group Selection Fan 0.5 acre (0.20 hectare) Patches (3-GSF.5P). From top of patch in western portion of unit; looking down towards lift tree.

Illustration 4: Group Selection Fan 1.5 acre (0.61 hectare) Patches (4-GSF1.5P). From top of southwestern landing; looking down towards lift tree.

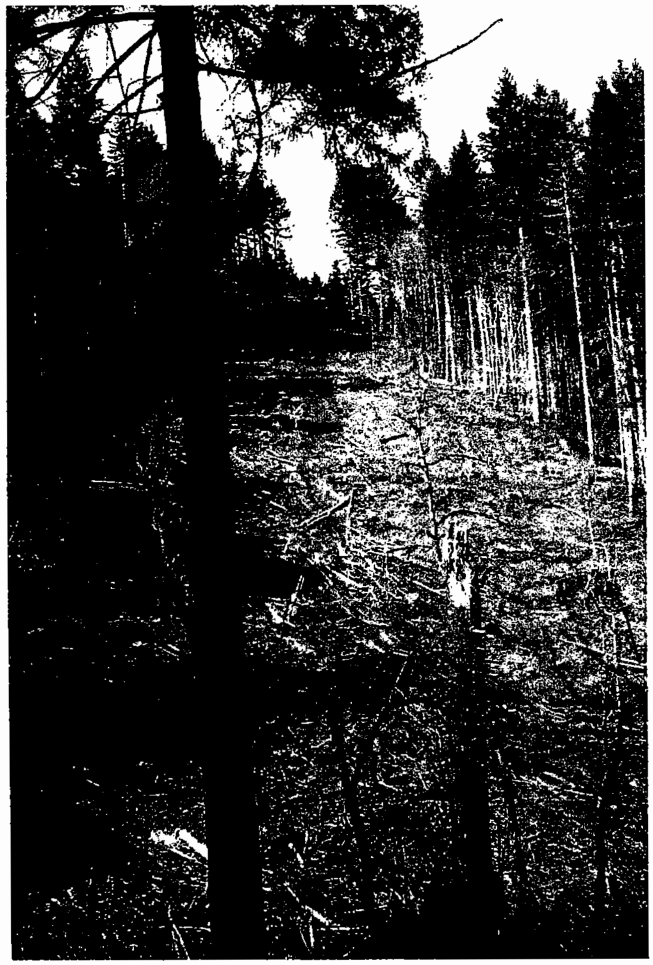


Illustration 5: Unit 5 - Group Selection Fan Wedge (5-GSFW). From bottom of middle wedge; looking up towards landing.

Illustration 6: Unit 6 - Group Selection Parallel 0.5 acre (0.20 hectare) Patches (6-GSP.5P). From bottom of southernmost first entry patch, second skyline road from east; looking up towards landing.

APPENDIX Q: Unit Specific Logging Planning Time Components

Unit 1 - CCF:

Planning Component	hrs/acre (hrs/hectare)	$/Mbf ($/m^3)
Randomized:		
Flag Skyline Roads	0.0000	0.00
Mark Trees	0.3141 (0.7761)	0.20 (0.04)
Ground Profiles	0.3665 (0.9056)	0.24 (0.04)
Map	0.0576 (0.1423)	0.04 (0.01)
Computer	0.0785 (0.1940)	0.05 (0.01)
Other:		
Flag Landings	0.0262 (0.0647)	0.02 (<0.01)
Reconnaissance	0.0346 (0.0855)	0.02 (<0.01)
Photo Interpretation	0.0000	0.00
Office	0.0115 (0.0284)	0.01 (<0.01)
Sum	0.8890 (2.1967)	0.58 (0.10)

Unit 2 - GSPS:

Planning Component	hrs/acre (hrs/hectare)	$/Mbf ($/m^3)
Randomized:		
Flag Skyline Roads	1.6667 (4.1183)	1.08 (0.19)
Mark Trees	0.9596 (2.3712)	0.62 (0.11)
Ground Profiles	0.6061 (1.4977)	0.39 (0.07)
Map	0.4293 (1.0608)	0.28 (0.05)
Computer	0.3283 (0.8112)	0.21 (0.04)
Other:		
Flag Landings	0.1010 (0.2496)	0.07 (0.01)
Reconnaissance	0.0000	0.00
Photo Interpretation	0.0000	0.00
Office	0.0000	0.00
Sum	4.0909 (10.1086)	2.66 (0.47)

Unit 3 - GSF.5P:

Planning Component	hrs/acre (hrs/hectare)	\$/Mbf (\$/m^3)
Randomized:		
Flag Skyline Roads	4.1477 (10.2490)	2.69 (0.47)
Mark Trees	2.5284 (6.2477)	1.64 (0.29)
Ground Profiles	1.2500 (3.0888)	0.81 (0.14)
Map	0.7386 (1.8251)	0.48 (0.08)
Computer	0.4261 (1.0529)	0.28 (0.05)
Other:		
Flag Landings	0.1420 (0.3509)	0.09 (0.02)
Reconnaissance	0.0852 (0.2105)	0.06 (0.01)
Photo Interpretation	0.2841 (0.7020)	0.18 (0.03)
Office	0.0284 (0.0702)	0.02 (<0.01)
Sum	9.6307 (23.7975)	6.25 (1.10)

Unit 4 - GSF1.5P:

Planning Component	hrs/acre (hrs/hectare)	$/Mbf ($/m³)
Randomized:		
Flag Skyline Roads	3.5915 (8.8746)	2.33 (0.41)
Mark Trees	1.9412 (4.7967)	1.26 (0.22)
Ground Profiles	1.4085 (3.4804)	0.91 (0.16)
Map	1.6765 (4.1426)	1.09 (0.19)
Computer	0.2817 (0.6961)	0.18 (0.03)
Other:		
Flag Landings	0.4706 (1.1629)	0.31 (0.05)
Reconnaissance	0.1471 (0.3635)	0.10 (0.02)
Photo Interpretation	0.0882 (0.2179)	0.06 (0.01)
Office	0.0000	0.00
Sum	9.6052 (23.7344)	6.24 (1.10)

Unit 5 - GSFW:

Planning Component	hrs/acre (hrs/hectare)	$/Mbf ($/m^3)
Randomized:		
Flag Skyline Roads	0.4225 (1.0440)	0.27 (0.05)
Mark Trees	1.4789 (3.6544)	0.96 (0.17)
Ground Profiles	1.3380 (3.3062)	0.87 (0.15)
Map	0.5282 (1.3052)	0.34 (0.06)
Computer	0.3169 (0.7831)	0.21 (0.04)
Other:		
Flag Landings	0.2113 (0.5221)	0.14 (0.02)
Reconnaissance	0.1056 (0.2609)	0.07 (0.01)
Photo Interpretation	0.0352 (0.0870)	0.02 (<0.01)
Office	0.0000	0.00
Sum	4.4366 (10.9628)	2.88 (0.51)

Unit 6 - GSP.5P:

Planning Component	hrs/acre (hrs/hectare)	\$/Mbf (\$/m^3)
Randomized:		
Flag Skyline Roads	2.3397 (5.7814)	1.52 (0.27)
Mark Trees	1.8258 (4.5116)	1.19 (0.21)
Ground Profiles	1.6026 (3.9600)	1.04 (0.18)
Map	0.7584 (1.8740)	0.49 (0.09)
Computer	0.4808 (1.1881)	0.31 (0.05)
Other:		
Flag Landings	0.1685 (0.4164)	0.11 (0.02)
Reconnaissance	0.1685 (0.4164)	0.11 (0.02)
Photo Interpretation	0.0000	0.00
Office	0.0562 (0.1389)	0.04 (0.01)
Sum	7.4006 (18.2869)	4.80 (0.85)

APPENDIX R:
Unit Specific Felling Production Regression Model Parameter Summary Statistics

Unit-Rx	Parameter	Average	Standard Deviation	Range	Sample Size
1-CCF	DIAM	23.4 in (59 cm)	8.2 (21)	8-39 (20-99)	122
2-GSPS	DIAM	18.6 in (47 cm)	7.0 (18)	7-41 (18-104)	128
3-GSF.5P	DIAM	15.9 in (40 cm)	5.9 (15)	7-29 (18-74)	150
4-GSF1.5P	DIAM	15.7 in (40 cm)	5.8 (15)	8-34 (20-86)	137
5-GSFW	DIAM	20.8 in (53 cm)	7.8 (20)	7-40 (18-102)	114
6-GSP.5P	DIAM	17.2 in (44 cm)	7.4 (19)	7-39 (18-99)	118
Study		18.4 in (47 cm)	7.5 (19)	7-41 (18-104)	769

Unit-Rx	Parameter	Average	Standard Deviation	Range	Sample Size
1-CCF	WDGE	0.237	-	0 or 1	122
2-GSPS	WDGE	0.383	-	0 or 1	128
3-GSF.5P	WDGE	0.300	-	0 or 1	150
4-GSF1.5P	WDGE	0.226	-	0 or 1	137
5-GSFW	WDGE	0.307	-	0 or 1	114
6-GSP.5P	WDGE	0.263	-	0 or 1	118
Study		0.311	-	0 or 1	769

Unit-Rx	Parameter	Average	Standard Deviation	Range	Sample Size
1-CCF	BFVOL	762 bf ($3.19\ m^3$)	645 (2.70)	40-2980 (0.17-12.47)	122
2-GSPS	BFVOL	479 bf ($2.00\ m^3$)	611 (2.56)	30-5030 (0.13-21.05)	128
3-GSF.5P	BFVOL	293 bf ($1.23\ m^3$)	242 (1.01)	30-1040 (0.13-4.35)	150
4-GSF1.5P	BFVOL	261 bf ($1.09\ m^3$)	346 (1.48)	40-1900 (0.17-7.95)	137
5-GSFW	BFVOL	708 bf ($2.96\ m^3$)	705 (2.95)	30-3940 (0.13-16.49)	114
6-GSP.5P	BFVOL	359 bf ($1.50\ m^3$)	466 (1.95)	30-2980 (0.13-12.47)	118
Study		464 bf ($1.94\ m^3$)	553 (2.31)	30-5030 (0.13-21.05)	769

Unit-Rx	Parameter	Average	Standard Deviation	Range	Sample Size
1-CCF	LOGS	2.63	0.89	1-6	122
2-GSPS	LOGS	2.52	0.88	1-5	128
3-GSF.5P	LOGS	2.28	0.87	1-4	150
4-GSF1.5P	LOGS	1.89	0.97	1-5	137
5-GSFW	LOGS	2.98	1.03	1-5	114
6-GSP.5P	LOGS	2.07	0.92	1-5	118
Study		2.38	0.99	1-6	769

APPENDIX S:
Unit Specific Felling Delays - Percentage of Total Delay-Free Cycle Time + All Recorded Delays

General:

Delay	1-CCF % Study	2-GSPS % Study	3-GSF.5P % Study	4-GSF1.5P % Study	5-GSFW % Study	6-GSP.5P % Study	All Units % Study
Operational:							
-Move Fuel/Saw	0.49	0.27	0.45	0.31	0.46	0.13	2.11
-Consult with other Cutter	0.02	0.06	0.00	0.35	0.23	0.04	0.70
-Consult with Administrator	0.32	0.19	0.70	0.17	0.32	0.00	1.70
-Bar Hang-Up	0.07	0.00	0.00	0.34	0.01	0.00	0.42
-Cut other Cutter out of Hang-Up	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	0.90	0.52	1.15	1.17	1.02	0.17	4.93
Fell Non-Merch:	0.92	0.44	0.77	0.70	0.56	0.44	3.83
Other:	0.02	0.28	0.09	0.19	0.04	0.22	0.84
Repair:	0.19	0.00	0.12	0.01	0.02	0.00	0.34
Maintenance:							
-Install/ Sharpen Chain	0.36	0.46	0.26	0.42	0.00	0.08	1.58
-Adjust Bar Tension	0.08	0.00	0.01	0.06	0.00	0.00	0.15
-Adjust Idle	0.00	0.00	0.00	0.00	0.00	0.07	0.07

General (continued):

Delay	1-CCF % Study	2-GSPS % Study	3-GSF.5P % Study	4-GSF1.5P % Study	5-GSFW % Study	6-GSP.5P % Study	All Units % Study
Maintenance (continued):							
-Clean Air Filter	0.05	0.09	0.00	0.08	0.02	0.00	0.24
Sum	0.49	0.55	0.27	0.56	0.02	0.15	2.04
Fuel:	1.08	0.74	0.65	0.67	0.99	0.50	4.63
Personal:							
-Water/Food Break	0.60	0.44	0.85	0.44	0.61	0.37	3.31
-Urinate/ Defecate	0.16	0.10	0.08	0.02	0.08	0.02	0.46
-Rest Break	1.73	0.62	1.26	0.62	1.71	1.01	6.95
Sum	2.49	1.16	2.19	1.08	2.40	1.40	10.72
Sum General ...	6.07	3.68	5.25	4.36	5.05	2.89	27.30

Treatment Specific:

Delay	1-CCF % Study (% Unit)	2-GSPS % Study (% Unit)	3-GSF.5P % Study (% Unit)	4-GSF1.5P % Study (% Unit)	5-GSFW % Study (% Unit)	6-GSP.5P % Study (% Unit)	All Units % Study
Planning:	0.15 (0.77)	0.00 (0.00)	0.08 (0.49)	0.18 (1.36)	0.09 (0.50)	0.10 (0.83)	0.60

APPENDIX T:
Unit Specific Yarding Production Regression Model Parameter Summary Statistics

Unit-Rx	Parameter	Average	Standard Deviation	Range	Sample Size
1-CCF	YDS	627 ft (191 m)	218 (66)	130-1020 (40-311)	186
2-GSPS	YDS	424 ft (129 m)	245 (75)	70-880 (21-268)	203
3-GSF.5P	YDS	725 ft (221 m)	250 (76)	130-1140 (40-347)	218
4-GSF1.5P	YDS	401 ft (122 m)	170 (52)	90-680 (27-207)	221
5-GSFW	YDS	621 ft (189 m)	222 (68)	80-930 (24-283)	180
6-GSP.5P	YDS	404 ft (123 m)	178 (54)	70-760 (21-232)	179
Study		534 ft (163 m)	253 (77)	70-1140 (21-347)	1187

Unit-Rx	Parameter	Average	Standard Deviation	Range	Sample Size
1-CCF	LDS	30 ft (9.1 m)	24 (7.3)	0-115 (0-35.1)	186
2-GSPS	LDS	38 ft (11.6 m)	29 (8.8)	0-120 (0-36.6)	203
3-GSF.5P	LDS	33 ft (10.1 m)	27 (8.2)	0-120 (0-36.6)	218
4-GSF1.5P	LDS	39 ft (11.9 m)	33 (10.1)	0-160 (0-48.8)	221
5-GSFW	LDS	38 ft (11.6 m)	30 (9.1)	0-135 (0-41.1)	180
6-GSP.5P	LDS	41 ft (12.5 m)	33 (10.1)	0-150 (0-45.7)	179
Study		37 ft (11.3 m)	30 (9.1)	0-160 (0-48.8)	1187

Unit-Rx	Parameter	Average	Standard Deviation	Range	Sample Size
1-CCF	TLG	3.32	1.02	1-7	186
2-GSPS	TLG	4.21	1.29	1-9	203
3-GSF.5P	TLG	3.80	1.10	1-7	218
4-GSF1.5P	TLG	3.19	0.91	1-6	221
5-GSFW	TLG	3.25	0.72	2-6	180
6-GSP.5P	TLG	3.50	1.01	1-8	179
Study		3.55	1.09	1-9	1187

Unit-Rx	Parameter	Average	Standard Deviation	Range	Sample Size
1-CCF	PR	0.462	-	0 or 1	186
2-GSPS	PR	0.798	-	0 or 1	203
3-GSF.5P	PR	0.821	-	0 or 1	218
4-GSF1.5P	PR	0.724	-	0 or 1	221
5-GSFW	PR	0.967	-	0 or 1	180
6-GSP.5P	PR	0.793	-	0 or 1	179
Study		0.761	-	0 or 1	1187

APPENDIX U:
Unit Specific Yarding Delays - Percentage of Total Delay-Free Cycle Time + All Recorded Delays

General:

Delay	1-CCF % Study	2-GSPS % Study	3-GSF.5P % Study	4-GSF1.5P % Study	5-GSFW % Study	6-GSP.5P % Study	All Units % Study
Operational:							
-Landing	0.06	0.08	0.51	0.19	0.05	0.18	1.07
-Planning	0.00	0.00	0.00	0.18	0.00	0.00	0.18
-Rigging Cuts	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-Pulled Tail Stump/Tree	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-Wait Yarder	0.03	0.13	0.15	0.24	0.17	0.10	0.82
-Wait Loader	0.15	0.19	0.01	0.10	0.06	0.28	0.79
-Wait Chaser	0.05	0.09	0.04	0.00	0.10	0.17	0.45
-Line/Rigging Adjustment	0.11	0.41	0.69	0.55	0.07	0.02	1.85
-Put on/Take off Chokers	0.14	0.16	0.09	0.05	0.03	0.06	0.53
-Transfer of Rigging, etc	0.25	0.43	0.82	0.27	0.13	0.07	1.97
-Fuel	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-Pick Up Logs	0.17	0.42	0.71	0.37	0.26	0.38	2.31
-Wait Log Truck	0.31	0.19	0.01	0.14	0.00	0.00	0.65
-Miscellaneous	0.02	0.02	0.02	0.01	0.01	0.01	0.09
Sum	1.29	2.12	3.05	2.10	0.88	1.27	10.71
Repair:							
-Yarder	0.00	0.00	0.03	0.03	0.00	0.00	0.06
-Loader	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-Line	0.00	1.54	0.52	0.68	1.34	0.83	4.91

General (continued):

Delay	1-CCF % Study	2-GSPS % Study	3-GSF.5P % Study	4-GSF1.5P % Study	5-GSFW % Study	6-GSP.5P % Study	All Units % Study
Repair (continued):							
-Block	0.00	0.00	0.00	0.01	0.10	0.00	0.11
-Miscellaneous	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	0.00	1.54	0.55	0.72	1.44	0.83	5.08
Personal:							
-Food,Water	0.01	0.00	0.00	0.00	<0.01	0.00	0.01
-Discussion	0.00	0.01	0.00	0.05	0.07	0.00	0.13
-Miscellaneous	0.01	0.03	0.02	0.01	0.05	0.00	0.12
Sum	0.02	0.04	0.02	0.06	0.12	0.00	0.26
Other:							
-Researcher in Way	0.01	0.00	0.00	0.01	0.00	0.00	0.02
-Miscellaneous	0.00	0.03	0.00	0.00	0.00	0.00	0.03
Sum	0.01	0.03	0.00	0.01	0.00	0.00	0.05
Sum General	1.32	3.73	3.62	2.89	2.44	2.10	16.10

Treatment Specific:

Delay	1-CCF % Study (% Unit)	2-GSPS % Study (% Unit)	3-GSF.5P % Study (% Unit)	4-GSF1.5P % Study (% Unit)	5-GSFW % Study (% Unit)	6-GSP.5P % Study (% Unit)	All Units % Study
-Reposition Carriage/ Reset Chokers	0.11 (0.74)	0.31 (1.81)	0.72 (3.42)	0.46 (2.64)	0.53 (3.43)	0.62 (4.36)	2.75
-Fell and Buck	0.00 (0.00)	0.08 (0.45)	0.25 (1.19)	0.20 (1.15)	0.00 (0.00)	0.00 (0.00)	0.53
-Clear Corridor with Carriage	0.00 (0.00)	0.00 (0.00)	0.34 (1.59)	0.04 (0.22)	0.00 (0.00)	0.00 (0.00)	0.38
Sum Treatment Specific	0.11 (0.74)	0.39 (2.26)	1.31 (6.20)	0.70 (4.01)	0.53 (3.43)	0.62 (4.36)	3.66

APPENDIX V:
Unit Specific Road/Landing Change* Time Component Summary Statistics (hours)

Rig Down:

Unit-Rx	Average	Standard Deviation	Range	Sample Size
1-CCF	0.4208	0.1563	0.2167-0.7167	8
2-GSPS	0.6889	0.1173	0.5333-0.8167	3
3-GSF.5P	0.4028	0.2056	0.2333-0.8167	6
4-GSF1.5P	0.2972	0.1317	0.1167-0.4667	6
5-GSFW	0.5667	0.2667	0.3000-0.8333	2
6-GSP.5P	0.9833	0.0500	0.9333-1.0333	2

Move Yarder:

Unit-Rx	Average	Standard Deviation	Range	Sample Size
1-CCF	0.0250	0.0441	0-0.1167	8
2-GSPS	0.2444	0.1530	0.0833-0.4500	3
3-GSF.5P	0.0917	0.1049	0-0.2833	6
4-GSF1.5P	0.1000	0.1364	0-0.3833	6
5-GSFW	0.0833	0	0.0833	2
6-GSP.5P	0.2083	0.0750	0.1333-0.2833	2

* Times for Units 2 and 6 represent landing changes; the remainder of the times for units represent road changes.

Rig Up:

Unit-Rx	Average	Standard Deviation	Range	Sample Size
1-CCF	1.0833	0.4124	0.5167-1.7500	8
2-GSPS	2.0222	0.3104	1.5833-2.2500	3
3-GSF.5P	1.4556	0.6922	0.2667-2.4833	6
4-GSF1.5P	0.6528	0.4552	0.1833-1.5667	6
5-GSFW	1.0667	0.1333	0.9333-1.2000	2
6-GSP.5P	2.4750	0.6417	1.8333-3.1167	2

Pre-Rigging:

Unit-Rx	Average	Standard Deviation	Range	Sample Size
1-CCF	1.4479	0.7453	0-2.5000	8
2-GSPS	2.0833	1.0274	0.7500-3.2500	3
3-GSF.5P	1.2639**	1.0676	0.3333-3.5000	6
4-GSF1.5P	1.0417	1.5970	0-4.5000	6
5-GSFW	1.5000	0.5000	1.0000-2.0000	2
6-GSP.5P	1.0000	1.0000	0-2.0000	2

** This average does not include an average 2.0833 hours per road change of treatment related pre-rigging.

APPENDIX W:
Road/Landing Change Delays - Percentage of Total Delay Time for Time-Study

Delay	1-CCF	2-GSPS	3-GSF.5P	4-GSF1.5P	5-GSFW	6-GSP.5P	All Units
Operational:							
-Wait Loader	0.0	4.0	2.3	0.0	0.0	0.0	**6.3**
-Line/Rigging Adjustment	0.0	3.8	4.0	1.0	0.0	0.0	**8.8**
-Felling and Bucking	0.0	0.0	0.0	0.0	3.3	0.0	**3.3**
-Wait Log Truck	1.3	0.0	0.0	0.0	0.0	0.0	**1.3**
-Miscellaneous	0.0	4.0	1.8	0.0	0.0	0.0	**5.8**
Repair:							
-Yarder	0.0	38.4	0.0	2.5	0.0	0.0	**40.9**
-Line	6.3	15.2	0.0	1.8	0.0	0.0	**23.3**
Personal:							
-Discussion	0.0	2.5	5.8	0.0	0.0	0.0	**8.3**
-Miscellaneous	0.0	0.0	2.0	0.0	0.0	0.0	**2.0**
Sum Unit	**7.6**	**67.9**	**17.9**	**3.3**	**3.3**	**0.0**	

APPENDIX X:
Yarding Cost Tree Example for Unit 1 (1-CCF)
(After Olsen, 1992)