AN ABSTRACT OF THE PAPER OF

Nathan E. Putnam for the degree of Master of Forestry in

Forest Engineering presented on April 14, 1983.

Title: A Comparison of Productivity for Whole Tree, Tree Length, and Log Length Skyline Thinning in 35 Year Old Douglas-fir Stands of Western Oregon

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Whole tree and tree length thinning are two alternatives which are likely to be more productive and may prove to be more cost effective than conventional log length thinning. The purpose of this study was to evaluate and compare log length, tree length, and whole tree thinning techniques in terms of productivity and harvesting costs. The thinning operation took place in a second-growth Douglas-fir stand [Pseudotsuga menziesii (Mirb.) Franco] (average dbh = 12.8") using a small skyline yarder (28' tower, 120 HP) in a gravity return configuration.

The treatments were defined by the amount of work done by the faller prior to yarding. Log length implies that felling, limbing, bucking and topping occured at the stump. Tree length indicates that trees were felled, limbed and topped only, and finally, whole trees were felled only prior to yarding.

A rubber-tired cable skidder was used to swing material from the landing chute to a processing area. Here the skidder operator

completed any limbing and bucking which was necessary. He then sorted and decked the logs prior to loading. During log length thinning, logs were either cold decked in front of the yarder or swung with the skidder to a loading deck.

Detailed time studies were used to evaluate the felling and yarding operations for each of the three thinning techniques. Multiple linear regression was then used to develop predictive models for felling and yarding work cycles. An analysis of the delays on this study made it possible to separate out delays which were affected by a particular thinning technique, rather than having a single prorated delay time as is usually done. By combining results from the regression and delay analyses, estimates of productivity for each thinning technique were obtained. Finally, harvesting costs in dollars per cunit at the loading deck were generated and used to compare log length, tree length, and whole tree thinning.

Results indicated that where cold decking is feasible and will not overly hamper the operation it will probably still be the cheapest alternative since a skidder is not required. The cost per cunit for this method was $8.24 or 11% cheaper than its closest competitor, the whole tree system. However, where cold decking is not feasible, as is often the case on steep slopes with narrow roads, the whole tree technique will be the most cost effective alternative. It has a per cunit cost which is $10.06 or 12% less expensive than conventional log length thinning with a skidder swing. The advantage to the whole tree system results primarily from transferring limbing and bucking from the stump to the landing where it is not only done more efficiently, but also reduces operator idle time on the skidder swing.

A COMPARISON OF PRODUCTIVITY FOR WHOLE TREE, TREE LENGTH, AND LOG LENGTH SKYLINE THINNING IN 35 YEAR OLD DOUGLAS-FIR STANDS OF WESTERN OREGON

by

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A PAPER

submitted to

Oregon State University

in partial fulfillment of
the requirement for the
degree of

Master of Forestry

Completed April 1983

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Date paper is presented April 14, 1983

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ACKNOWLEDGEMENTS

I would like to thank Eldon Olsen for the continuous help and support he has given me throughout the course of this study and during the writing stages of this paper. To Loren Kellogg, many thanks for working with me in the field and for his contributions to this paper. I would also like to thank George Brown and the Forest Engineering Department for making it possible for me to present the results of this study at the 1983 Oregon Logging Conference and for the support they provided in so doing.

Many thanks to Tree Farm Stewards for their cooperation and help throughout the operational stages of the project.

To my wife, Betsy, my sincere thanks and appreciation for her continuous encouragement and support and for her help with the finishing touches which went into this paper.

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A COMPARISON OF PRODUCTIVITY FOR WHOLE TREE, TREE LENGTH, AND LOG LENGTH SKYLINE THINNING IN 35 YEAR OLD DOUGLAS-FIR STANDS OF WESTERN-OREGON

INTRODUCTION

Cost effective management of the second-growth timber resource is largely dependent on the economics of smallwood harvesting. Commercial thinnings are of particular concern to the forest manager because they are a means of stand improvement and provide the first return on an expensive silvicultural investment. Smallwood thinnings, however, are costly to execute. In areas with steep topography where cable equipment is necessary, thinning is a viable proposition only during times of good market conditions. Harvest planning for these cable systems is therefore critical and operational efficiency must be high in order to minimize costs and realize a profit.

To date the majority of the work in this area has involved conventional log length yarding techniques. However, whole tree and tree length thinning are two alternatives which may significantly improve operational efficiency and help to reduce costs. This study compares the productivity of these different systems while thinning with a small skyline yarder (120 HP, 28 foot tower) in a standing skyline, gravity carriage return configuration. Processing of whole tree and tree length material (i.e., limbing, bucking, and topping) was performed as part of a swing and sort operation done with a rubber-tired cable skidder along the haul road. For definitional purposes, processing shall include any operations necessary to convert a felled tree to log length form prior to loading and hauling.

The concept of central processing (i.e., limbing and bucking at or near the landing) is gaining recognition from the industry of the Pacific Northwest as a result of the transition from old growth to second growth timber harvesting. The smaller timber size associated with second growth harvesting and commercial thinnings makes whole tree and tree length yarding a much more reasonable alternative. The benefits to using these systems are that they offer a potential for higher efficiency, better wood utilization, and the opportunity to make use of residue wood.

Whole tree thinning is a technique in which trees are felled, but not limbed, bucked, or topped prior to yarding. The advantage and basic principle of whole tree thinning is to do as little work as possible at the stump and the remainder in prepared work areas. The choice of the final product is thus made in improved working conditions (Bent 1969). Tree length thinning is a compromise between log length and whole tree thinning. In this case the trees are felled, limbed and topped, but not bucked prior to yarding.

Whole tree and tree length yarding could be especially well suited to commercial thinnings on steep ground. In many thinning situations landings must be located on narrow roads which provide poor decking opportunities. Oftentimes a swing-boom yarder is not available to deck logs on the road, which makes it necessary to have a loader or skidder on the landing in order to swing logs out of the landing chute to a loading deck. In a low production thinning operation these machines are often underutilized. However, with whole tree or tree length yarding a processing phase could be incorporated into the swing operation resulting in better utilization of the machine and operator.

By switching the processing phase to the landing, felling productivity can be improved considerably. Aulerich (1975) reported that 29% of the faller's time was spent in the limbing and bucking phase. On steep or brushy terrain the savings realized here could be even greater.

While better use of the faller offers the most obvious potential for savings, yarding productivity may also benefit. By yarding tree length material the average lateral yarding distance may be effectively reduced. This is due to the fact that the top logs, which are usually furthermost from the corridor, will still be attached to a butt log relatively close to the corridor.

Often a major problem in smallwood thinnings is maintaining the system payload capacity. When hooking a turn the rigging crew generally tends to work within a zone of a certain size and will send a turn in to the landing if they run out of logs. On thinning operations, where logs are small and often scattered, it therefore often becomes difficult to hook enough pieces to build turns to full capacity. Whole tree or tree length yarding should help to overcome this problem by reducing the number of pieces which need to be hooked in order to reach the optimal turnsize. One would therefore expect the average volume per turn to be higher for the full tree systems.

The disadvantges of whole tree and tree length logging occur primarily in the yarding operation. Garlicki and Calvert (1969) have shown that for ground skidding more power is required to skid whole trees in comparison to tree length material primarily because of the added weight of branches. Therefore, one might expect similar results in comparing whole tree to log length cable thinning. The effect on production would be greatest at the "break-out" point (initial movement of logs or trees) during lateral yarding. At this point machine horsepower tends to be most limiting and safe working tensions are most likely to be exceeded (Falk 1980).

A second drawback to full length yarding is the possibility for more hangups and breakage during lateral yarding. Trees with poor lay are likely to be a problem, particularly at the end of lateral yarding when they enter the skyline corridor and pivoting is required. Finally, the relative potential for residual stand damage should be considered.

The primary concern of this study was to examine the cost effectiveness of processing at the landing on a "small" skyline thinning operation using whole tree and tree length techniques. Small skyline yarders include machines ranging in size from the small European systems to the Skagit SJ series. A more rigorous definition of yarder sizes is given in Appendix A.

Delimbing and bucking was accomplished primarily by the operator of a rubber-tired skidder which was used to swing material away from the yarding deck. In this paper, emphasis is placed on comparing felling and yarding production rates for the different thinning methods. A detailed study of the swing operation will be addressed in another master of forestry paper (Burrows 1983).

There are a number of different ways in which tree processing might be accomplished (e.g., loader swing, mechanical delimbing, etc.). In fact, the limbing and bucking phase does not necessarily need to be confined to the woods. Whole tree transport with mill processing is an alternative which would result in maximum wood utilization. Unfortunately, the quantitative analysis which would be required for all possible alternatives is beyond the scope of this study. Instead, the possible application of different whole tree and tree length harvesting methods is included in the discussion section of this report.

OBJECTIVES

I. Describe the operational efficiency of whole tree and tree length harvesting as compared to conventional log length harvesting with a small skyline yarder in a smallwood thinning operation. There were three subobjectives which were used to evaluate each of the three harvesting alternatives:

A. Develop regression equations to predict cycle times for the felling and yarding phases of each harvesting alternative.

B. Determine production rates and costs of the felling and yarding operations for each alternative.

C. Evaluate the operational advantages and difficulties encountered in whole tree and/or tree length thinning.

II. Compare the cost per cunit at the loading deck for each of the following thinning alternatives:

A. Log length without swing: felling, limbing, bucking, and yarding to a cold deck.

B. Log length with swing: felling, limbing, bucking, yarding, swinging, sorting, and decking.

C. Tree length: felling, limbing, topping, swinging, processing, sorting, and decking.

D. Whole tree: felling only, yarding, swinging, processing, sorting, and decking.

III. Make a subjective evaluation of the feasibility of alternative whole tree handling operations.

LITERATURE REVIEW

Whole tree and tree length harvesting systems are certainly not a new concept to the forest products industry. These systems are used extensively throughout the Eastern U.S. and Canada. Unlike this study, however, their application has been limited primarily to pulpwood harvesting, generally with a mechanized ground based system (Bent 1969, Biggar and Hanna 1966). The use of tree length and full tree harvesting on pulpwood operations has increased dramatically over the past 30 years despite the fact that the shortwood systems appear to be more productive. This increase is due largely to economics. The high capital cost associated with the shortwood systems in relation to their output makes them uneconomical in comparison to full tree harvesting (Granskog 1978, Jankowski 1968).

Similarly, hauling of tree length material is quite common on pulpwood operations, particularly where off-highway trucking is involved (Page 1966, Mooney 1966). Lavoie (1980) reported on a loading production study and feasibility report for hauling whole trees (limbs included) using off-highway trucks. He concluded that harvesting of full trees with delimbing at the mill will be a viable alternative only if delimbing is integrated into the manufacturing process at the mill and if a use is found for the wood residues.

The majority of the research regarding whole tree and tree length cable thinning operations has been done in Europe. Lisland (1975) discussed several Norwegian harvesting systems in which trees are yarded full length. Generally, however, the European systems and economic and social conditions are quite different from those found in the Pacific Northwest. The combination of small tree management, expensive labor costs, high wood value, and a demand for high utilization makes full length yarding very attractive in these countries, but does not necessarily imply that the same will be true in the U.S.

Several Canadian studies have utilized various forms of whole tree cable yarding techniques (Heidersdorf 1978, McMoreland 1978). However, most of these studies were equipment evaluations and no comparative analysis between whole tree and conventional log length yarding was done. Furthermore, the majority of these studies have involved clearcut rather than thinning operations.

In 1972 the Forest Engineering Department at Oregon State University initiated a smallwood harvesting research program aimed at improving the state of knowledge for harvesting young growth timber on steep slopes. This paper originates from field studies carried out by OSU during the summer of 1981. Also included in the summer's research was another whole tree study utilizing a Koller yarder and carriage (Lucas 1983). Lucas investigated a harvesting technique termed "hot yarding" in which the faller and chokersetter worked together as a rigging crew. Trees were felled, immediately yarded to the landing (often from a standing position due to frequent hangups), and finally skidder swung, processed, and decked for loading.

This technique is similar to many of the European systems. Lisland (1975), for example, describes a similar technique where limbing and bucking activities are shifted until the work load is balanced among the crew, thereby improving productivity. Results from Lucas' study indicated that cost per cunit at the loading deck for the hot yarding technique is slightly lower than more conventionl log length yarding without a swing element. Thus, where swinging is required anyway, the hot yarding method is likely to be more cost effective.

Not considered in this study, but also of importance is the improved efficiency of loading a skidder sorted and decked pile as opposed to yarder cold decks. McIntire (1981) reported an increase in loading time of 18% for yarder cold decks in comparison to skidder swung decks when using self loading log trucks.

In summary, the literature indicates that significant savings may be realized by using various forms of whole tree and tree length harvesting methods. Therefore, one would also expect a cost savings for full length cable thinning operations. The purpose of this study is to determine whether a savings can be expected and, if so, to quantify that value.

AREA DESCRIPTIONS

Site Description

Smallwood harvesting research at OSU during the summer of 1981 involved three different thinning projects on a study area of approximately 195 acres. The study area was located in the SW 1/4 of Section 15 and the SE 1/4 of Section 16, T.10S., R.5W., Willamette Meridian. This area lies within the Dunn State Forest along the 210 Road, which is 12 miles north of Corvallis off Route 99W and the Old Portland and Umpqua Valley Road. Figure 1 shows the study area location.

The site was characterized as rolling ground with both northwest and southeast aspects. Slopes varied from 5 to 50% with an average of approximately 25%. Elevations for the study area ranged from 600 to 1000 feet. A pre-logging cruise indicated a 50 year site index of 116 (high site III, low site II) (King 1966). Soils on the area are classified in the Price series as Price-Ritner complexes (PTE and PTF).

Stand Description

Stand statistics for this area were determined from a pre-logging variable plot cruise. The statistics given in this paper are representative of the stand conditions which were associated with this particular project.

The stand was composed of a mixture of Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco], grand fir [Abies grandis (Dougl.) Lindl.], bigleaf maple (Acer macrophyllum Pursh), and Pacific madrone (Arbutus

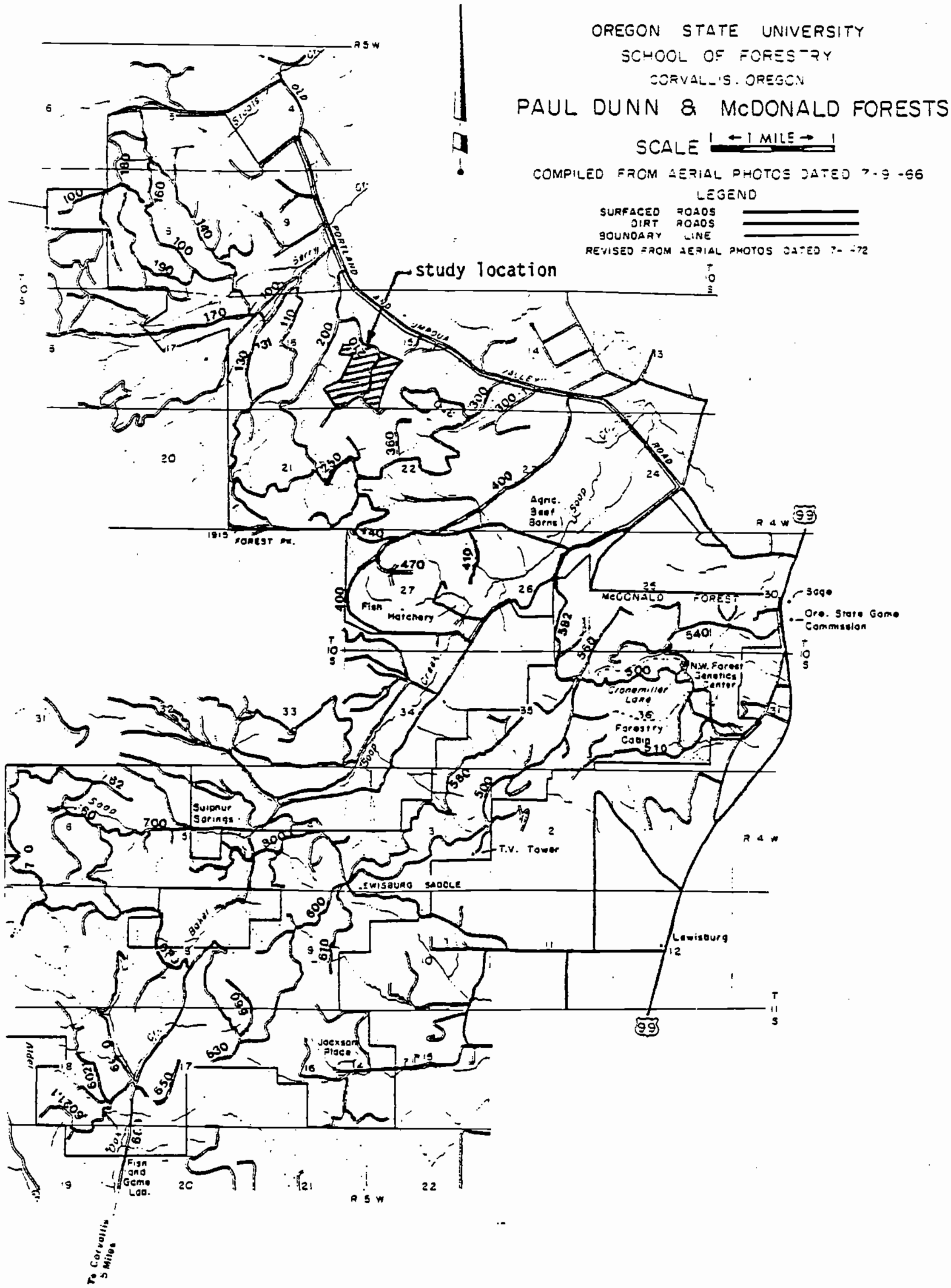


Figure 1. Study area location.

menziesii Pursh). The stand can be described as naturally regenerated with patchy stocking. Most areas were overstocked; however, natural drainages and a few other areas were definitely understocked in commercial softwood species. The mean stand age was 34 years, although grand fir trees, many of which resulted from an understory release, were significantly older. Average diameter for the softwood species was 12.8 inches and average total height was 78 feet. Softwood volume for the stand averaged approximately 3200 cu. ft. per acre. A hardwood component comprised 9% of the total stand volume. A post-logging cruise consisting of 30 tenth-acre plots was run in order to determine the actual thinning intensity. Approximately 32% of the total number of merchantable stems were cut during thinning. A more detailed summary of the stand statistics is included in Appendix B.

Unit Layout

In the spring of 1981, 35 skyline corridors were laid out for use in the three OSU thinning studies. A map of the study area and detailed layout is shown in Figure 2. Data from 14 of these corridors were analyzed for this paper.

Field profiles were run for the individual corridors using clinometers and a string measuring gauge. The profiles were analyzed on a Hewlett Packard 9830 desk top computer using two paylod analysis programs: Skyline Analysis Program (SAP) and Multispan Skyline Analysis Program (MSAP) (Sessions 1978).

These programs were used to determine the rigging specifications necessary to obtain a 2000 pound payload given a 10 foot ground clearance. Tail trees and intermediate supports were field located

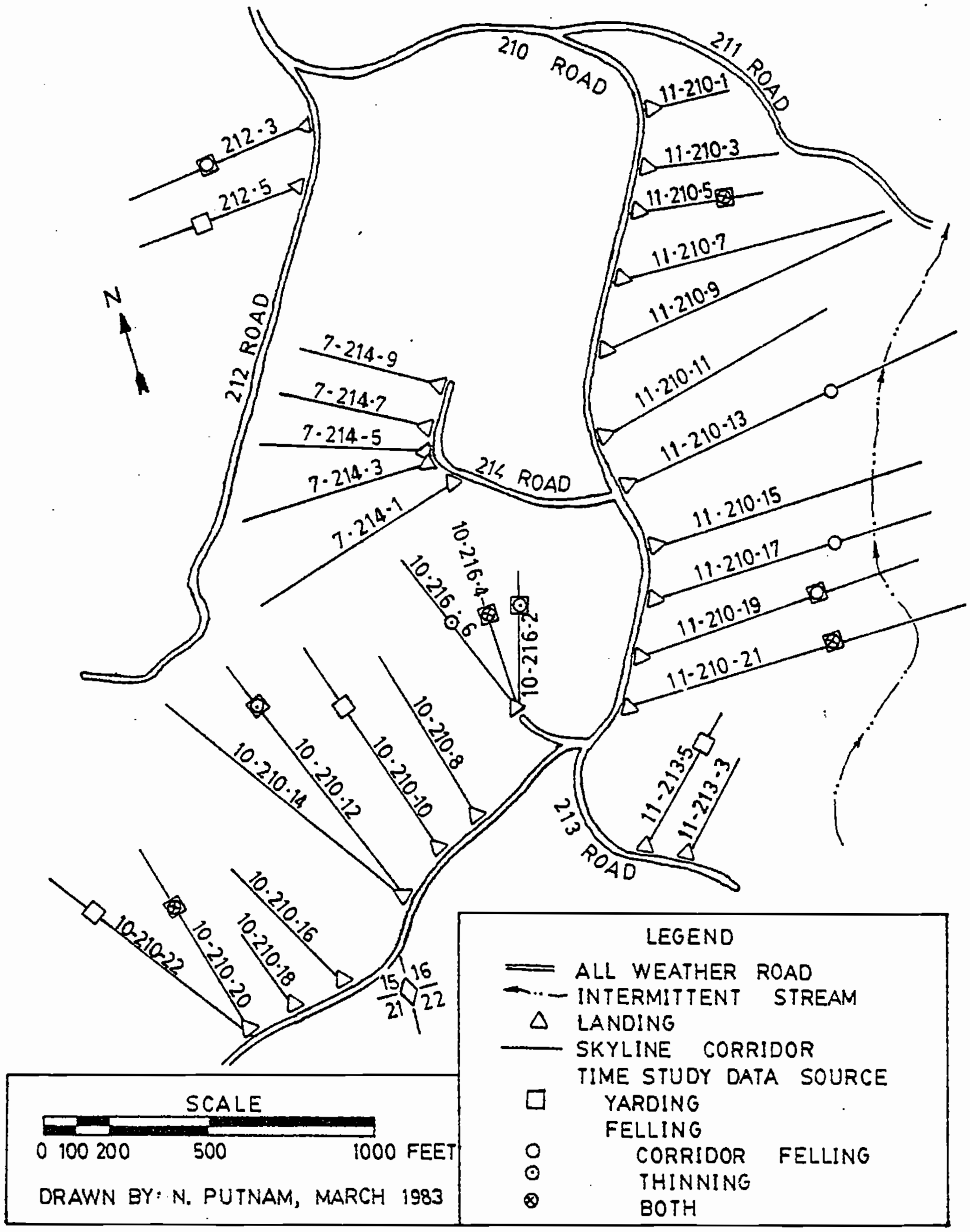


Figure 2. Corridor layout on study area. Note: Numbers are for road and corridor identification.

prior to logging. Finally, the payload analyses and recommended rigging heights were supplied to the logging contractor.

Skyline roads had an average external yarding distance of 600 feet and average lateral spacing of 160 feet. Several corridors were continued across a drainage to improve deflection, although thinning ended at the creek. This resulted in a maximum span of 1130 feet and maximum external yarding distance of approximately 900 feet.

HARVESTING SYSTEM

Felling

The silvicultural objective of this thinning was to free the better dominant and codominant stems from competition, and thus improve growth rates on these remaining trees. Crown spacing was the major criterion for tree selection. No marking was done in the area; instead, trees were selected by the fallers after instruction from the forest manager.

Felling in each setting was completed prior to yarding. Fallers used Stihl 041 chain saws and felled at an angle of 45° ± 15° to the corridor whenever possible. In order to facilitate the yarding operation, fallers were encouraged to locate the most feasible extraction route for each tree and to fell accordingly. Variability in felling production was reduced by using the same two man felling crew throughout the study.

Yarding

Yarding equipment consisted of an older Schield Bantam T-350 loader converted to a 3 drum yarder and mounted with a 28 foot tower. The Bantam was used in conjunction with a Wyssen 2.5 ton mechanical carriage with a time activated skyline clamp. The system was rigged as a live skyline in a shotgun configuration (see Figure 3). The Wyssen's skyline clamp, however, allowed the system to operate generally as a standing skyline except when the chokersetters could not reach the chokers.

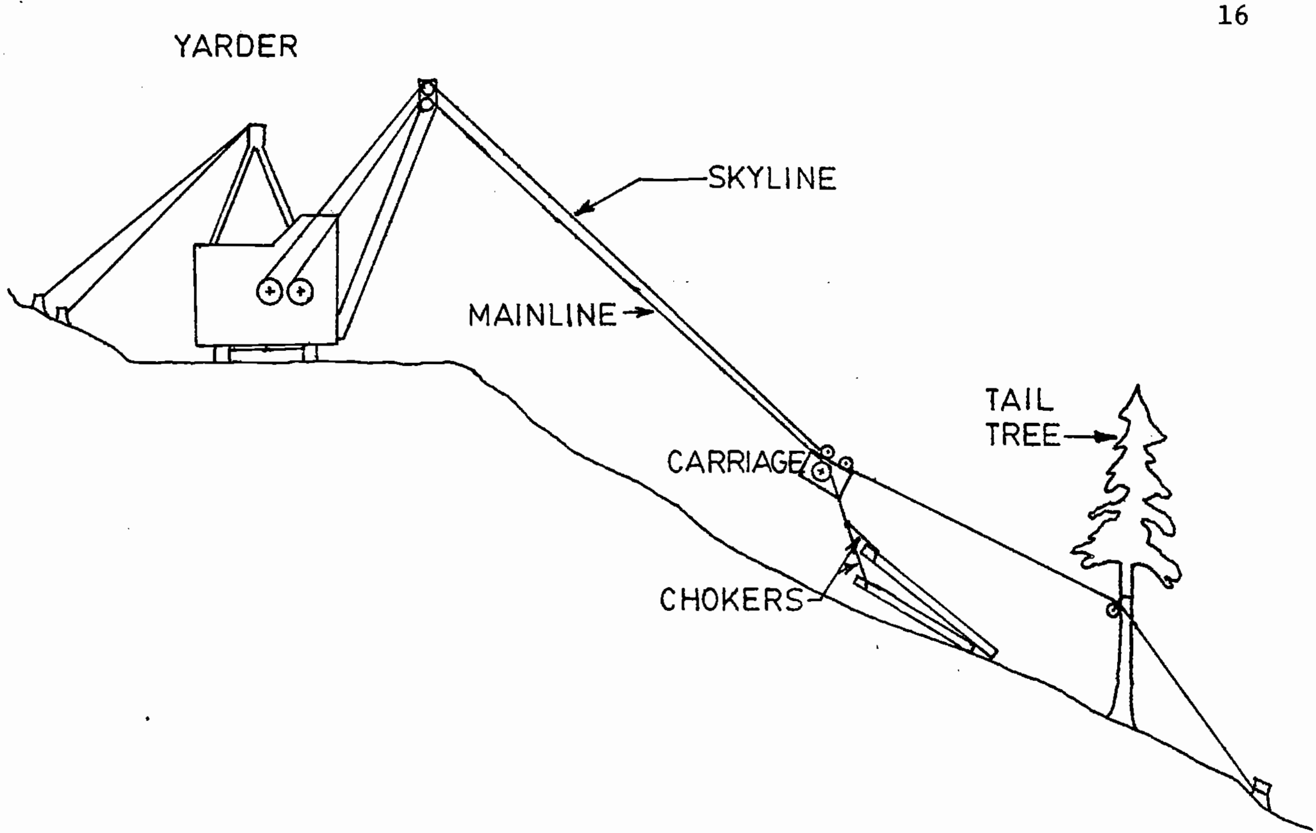


Figure 3. Live skyline system - gravity return (shotgun) configuration.

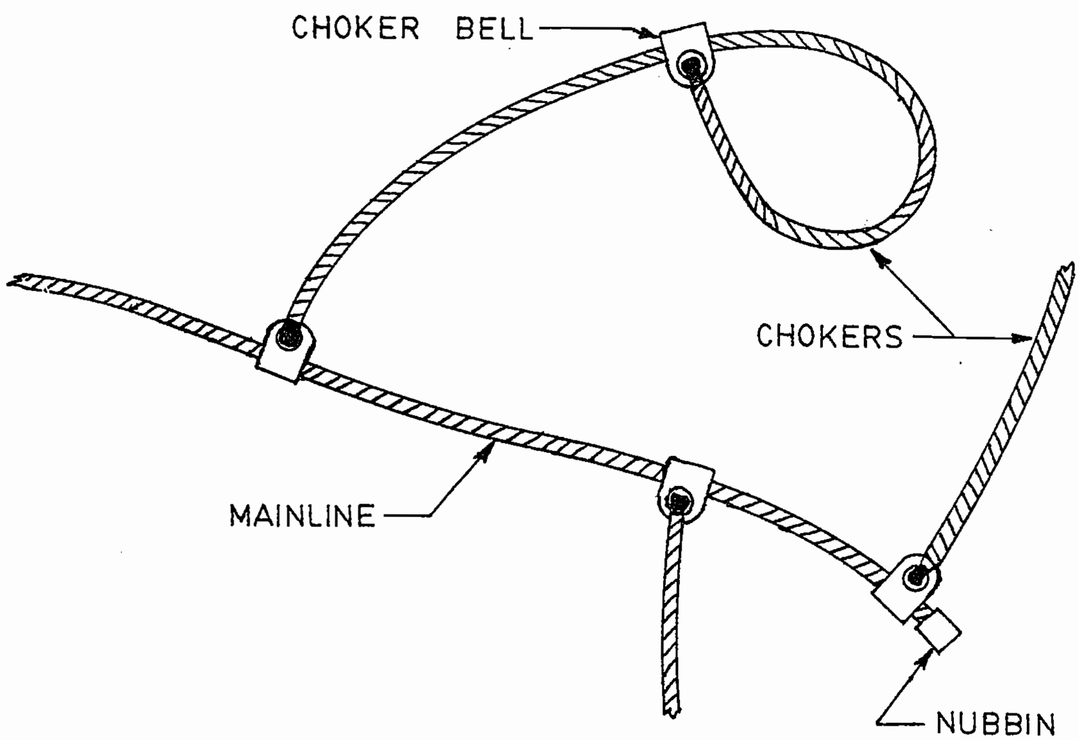


Figure 4. Slider type chokers.

Lateral yarding was accomplished by hand slackpulling of the mainline through the carriage. The Wyssen normally operates with a drop hook to which all the chokers are attached. A new modification to the carriage, however, allowed the use of slider type chokers, similar to those used in tractor logging (see Figure 4). Yarder and carriage specifications are listed in Table 1.

The Bantam held 1000 ft of 3/4 inch skyline and for this particular operation ran a 7/16 inch mainline (normally this line was used for the haulback). The contractor felt that this line size provided adequate strength for the timber conditions and payload constraints. The advantages to using an undersized mainline were easier slackpulling and a freespooling drum which reduced outhaul time. In doing so, however, this generally became the limiting line (relative to the skyline) and on several turns the mainline broke while trying to dislodge a large or impeded log.

Tail trees were rigged except where good deflection allowed otherwise. One multispan setting was necessary on the area involved with this study. Tail trees and intermediate supports were prerigged in order to reduce road changing time.

A four man crew was standard for the yarding operation. This included yarder operator, chaser, rigging slinger, and chokersetter. A woods foreman supervised all of the operations and, in addition, did most of the prerigging. During some parts of the study an additional chaser was added to the crew, primarily to study the effects on the swing operation. It was felt that this extra man had no significant effect on yarding productivity.

Table 1. Machine specifications.

Schield Bantam T350 mobile swing yarder

Power source - 453 Detroit diesel engine, 120 HP (approximately)
28 foot tower.

Line capacities

Skyline 1000 ft. x 3/4 in.
Mainline 900 ft. x 5/8 in.
Haulback 1600 ft. x 7/16 in.

Wyssen W 2.ST (2.5 ton carriage)

Hydraulically activated, spring tension skyline clamp.
Clamping is controlled by programmed carriage cycle (time adjustable).
Capability to pass intermediate supports.

John Deere 440C skidder

Articulated frame power steering.
Power source - John Deere 4 cylinder diesel, 70 HP (net).
Winch capacity - 217 ft. x 1/2 in. cable.
Operating weight - 14,175 lbs.

Ramey loader

No information was available on this loader. The Ramey is in a size class similar to the Barko 160 truck mount loader which has the following specifications:

Lift capacity	- 20,000 lbs. at 10 ft.
	6,300 lbs. at full reach.
Boom reach	- 24.5 ft (horizontal)
Power source	- GM 353 diesel engine, 72 HP.
Weight	- 14,280 lbs. (less attachment).

Swinging

Two types of swing machines were studied. A John Deere 440C, 70 HP rubber-tired skidder was used on the majority of the corridors. This skidder used up to six, 12-foot chokers to swing logs away from the landing and to a processing area, usually located on or adjacent to the truck road. The skidder operator did most of the limbing and bucking, although he was assisted at times by the chaser. Once processed, logs were decked at the roadside prior to loading.

The second machine studied was a truck mounted Ramey loader. Yarded material was swung to a processing area adjacent to the landing where the chaser did all of the limbing and bucking. Logs were then swung to a loading deck with the loader. Specifications for both swinging machines are listed in Table 1.

Loading and Hauling

Peterbuilt self loading log trucks were used for the loading and hauling phase of the operation. Logs were loaded out of decks which were generally oriented parallel to the road where a skidder swing had been used, or perpendicular to the road in the case of cold decking. Loads were subject to Oregon State highway restrictions and had a final weight of approximately 42,500 pounds.

STUDY DESIGN AND PROCEDURES

Treatments

This study examined three degrees of processing at the stump. They are defined as follows:

1. Log length (LL) - The trees were felled, limbed, and bucked at the stump. Logs were then yarded to a cold deck or swung with a skidder to a loading deck.
2. Tree length (TL) - This method has previously been defined as felling, limbing, and topping at the stump. However, in actual practice the cutters tended to only cut enough limbs to allow them to "walk" the tree and top it at 4 inches. Trees were then yarded, swung to a processing area where limbing and bucking was completed, and finally decked for loading.
3. Whole tree (WT) - The operational sequence for this treatment was similar to that of tree length except that the trees were neither limbed nor topped by the faller.

An attempt was made to reduce variability between treatments which resulted from local stand and ground conditions. Whole tree and tree length treatments were designated according to a checkerboard pattern as illustrated in Figure 5. This pattern was not used for log length yarding. The thinning technique (i.e., whole tree or tree length) which was used during corridor felling matched the treatment scheduled for the top right section of that skyline road. In order to get an equivalent sample size and to remove bias, whole tree and tree

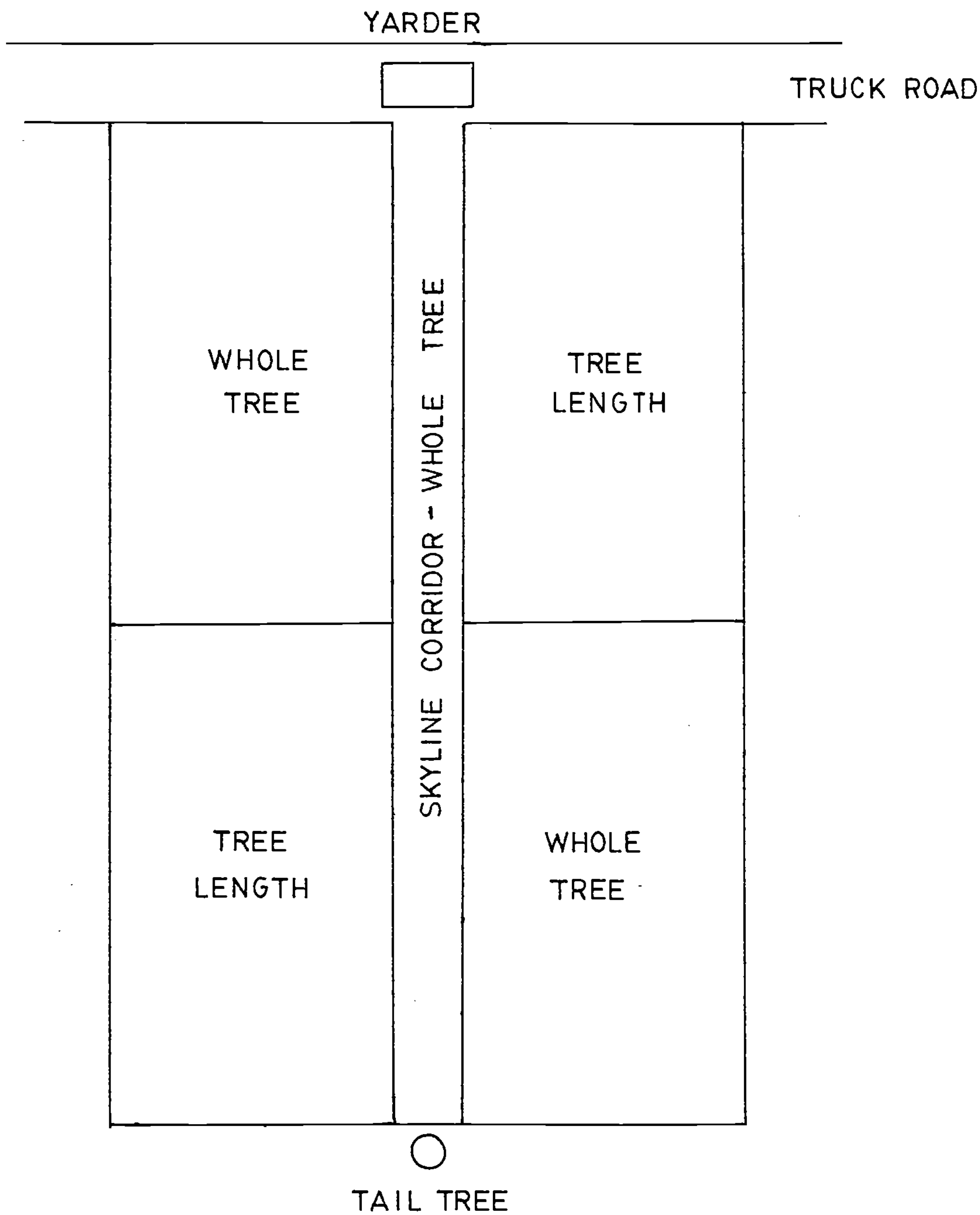


Figure 5. Checkerboard layout pattern.

length assignments were reversed on alternate skyline roads. During the actual operation, yarding was completed first on the corridor, upper right, and lower left sections of the skyline road. This allowed better separation of the two techniques for data collection purposes. The checkerboard pattern worked well for the yarding time study, but not so well on the skidder swing study since skidder turns tended to have mixed products (both tree length and whole tree).

Corridor width and corridor angle to the truck road were two other treatments which were investigated during the course of the study. Ten foot and twenty foot wide corridors were used. The goal was to determine what effect, if any, this difference in width had on yarding productivity. A second reason for varying the width was to determine if it had any significant effect on residual stand damage (covered in a separate M.F. paper by Caccavano 1982). Because corridor angle influences primarily swinging productivity it was not specifically addressed in this paper. This topic is discussed in a separate M.F. paper by Burrows (1983).

Data Collection

Detailed time studies on each of the operational phases provided the basis for regression analysis used in this study. Time studies were performed on the felling, yarding, and swinging operations. A limited time study sample was also taken on whole tree loading.

Two types of time were recognized in the detailed time studies, productive time and delays (downtime). They were defined for this study as follows:

Productive time - Time which is spent that contributes directly to output. Productive time is further subdivided into basic elements (dependent variables) which together constitute one complete cycle (excluding operating delays). These elements are defined in detail for each operational phase in subsequent sections of this report.

Delays and downtime - These are interruptions in the work cycles which include:

1. Operating delays - Delays which are generally of short duration and related to the continuation of immediate operations. They generally include such events as hangups, resets, and lost chokers. The combination of operating delays and productive time together constitute operating time.
2. Equipment delays - Delays which result from equipment service, malfunctions, and minor equipment adjustments. These delays are also of relatively short duration.
3. Equipment repair - Delays which include equipment breakdowns and major adjustments. These delays normally are of longer duration and/or divert a large part of the crew from their normal activities.
4. Other nonproductive time - This includes rest breaks, long working delays, etc.

Data forms for the detailed time studies are shown in Appendix C. The "snap back" method of recording, in which times are recorded continuously by resetting the watch to zero with the start of each time element, was used. When a cycle was interrupted by a delay the time was recorded as the sum of the components for that activity. Times were recorded to the nearest one hundredth of a minute. All delays were coded according to their type, and the activity during which they occurred. A summary of the delay types is given in Appendix D.

Felling Study

The felling cycle corresponds to the time required to fell and process one tree. The basic time elements for this study are defined as follows:

Move and select - The time required to select a new tree to be cut and move to it. This includes slashing to prepare an escape route and moving felling tools and equipment. This element begins when the faller starts to leave the work area of the previous tree and ends with the initiation of the undercut.

Cut and wedge - The time required to actually fell the tree. This element ends when the tree hits the ground. Time spent in getting hangups to the ground is not included in the element (hangups are a delay).

Limb and buck - The time required to process the tree prior to yarding. In the case of whole tree felling the element was usually zero. This element ends with the start of move and select.

Data was also recorded for several independent variables. The following is a description of the quantitative independent variables measured during the felling operations:

Move distance (DIST) - The distance in feet which the faller travels from the time he leaves the work area until he arrives at the next tree to be cut. This variable was measured by pacing.

Number of limbs (NLIMBS) - The number of limbs removed during the limbing and bucking process which require a definite sawing action (does not include those broken off with the bar). A tally counter was used to record this variable.

Number of cuts (NCUTS) - The number of bucking cuts which occurred during the limbing and bucking process.

Diameter (DIA) - Stump diameter measured to the nearest inch.

Volume (VOL) - Gross cubic foot volume of the tree. Two regression equations (one for logs, one for tree length and whole tree) were used to determine volume (see Appendix E). They were developed from measurements taken on a sample of trees in the immediate area.

LEARN - The number of working days since the cutter had started falling for this study.

Indicator varibles were used to code nonquantitative descriptor variables. The felling variables are defined as follows.

Corridor/Thin (CORTHIN) = An indicator variable which distinguished corridor clearing from thinning where:

0 = corridor clearing

1 = thinning

CUTTER - A zero-one indicator variable which identified the faller (two fallers were used throughout the study).

HANGUP - A variable to identify trees which hung up during felling where:

0 = normal (no hangup)

1 = hangup

Yarding Study

A two person time study crew was used during the yarding study. Both worked in the hooking area. One person recorded times and independent variables while his partner measured piece sizes and angles, and observed distances. The individual time elements which together constitute one turn are described as follows:

Outhaul - The time required to return the carriage from the landing to the hooking area. The element started when the carriage unclamped from the skyline and ended when the carriage clamped again at the hooking area.

Lateral-out - The time required to pull the chokers to the logs which are to be hooked. The element started at the end of outhaul and ended when the chokersetter reached the furthest log to be hooked.

Hook - The time required to attach the chokers to the logs. Hook started at the end of lateral-out and ended with the "ahead on mainline" signal.

Lateral-in - The time required to pull the logs from their beds to the skyline corridor. This element started at the end of hook and ended when the carriage unclamped from the skyline, or, in the case of a hangup or reset, when a "stop" signal was blown.

Inhaul - The time required to move a turn of logs up the corridor to the landing. Inhaul started upon the completion of lateral-in and ended when the carriage clamped to the skyline.

Unhook - The time required to remove the chokers from a turn. Unhook started at the end of inhaul and ended at the start of outhaul. This time did not include repositioning logs in order to adjust the deck.

Reset - A delay element which occurred frequently during lateral-in. This element was included on the time forms with the other time elements, but was not included in delay free turn time. Resets included any hangups or potential hangups. They started when the "stop" whistle was blown and ended once the turn had moved past the obstacle.

The quantitative independent variables which were measured for yarding are as follows:

Slope distance (SLPDIST) - Distance along the skyline corridor from the landing to the clamped carriage position. This distance was premarked on trees adjacent to the corridor and recorded to the nearest 5 feet.

Line distance - Distance from the carriage to the furthest log hooked. This distance was determined by pre-marking the mainline at 25 foot intervals and interpolating to 5 feet. During the analysis line distance was converted to a perpendicular lateral distance (LATDIST) by multiplying the line distance times the sine of the lead angle.

Number of pieces (NPIECES) - Number of logs yarded in the turn. This does not include those lost during lateral-inhaul and inhaul.

Lead angle (LEADA) - The angle between the corridor and the direction of the mainline. The mainline azimuth was measured in the field to the nearest 10°, then later subtracted from the corridor aximuth to obtain lead angle.

Log angle (LOGA) - The angle between the projected mainline direction and the log axis. This was also measured as an azimuth and later adjusted. In the case of multiple log turns the most extreme angle was determined. Lead angle and log angle are illustrated in Figure 6.

Volume (TURNVOL) - Gross cubic foot volume of the turn. This was determined by measuring butt diameter and log length, then applying the appropriate regression equation as described in the felling section.

Chordslope (SLOPE) - Chordslope of the skyline in percent as determined from the payload analysis. In the case of multispans the lowest value was used.

Corridor width (WIDTH) - Width of the corridor in feet. Two different corridor widths, 10 feet and 20 feet, were investigated during this study.

Piecesize (PSIZE) - Average piecesize for the turn, calculated by dividing TURNVOL by NLOGS.

Several nonquantitative variables were also recorded. The yarding indicator variables are defined as follows:

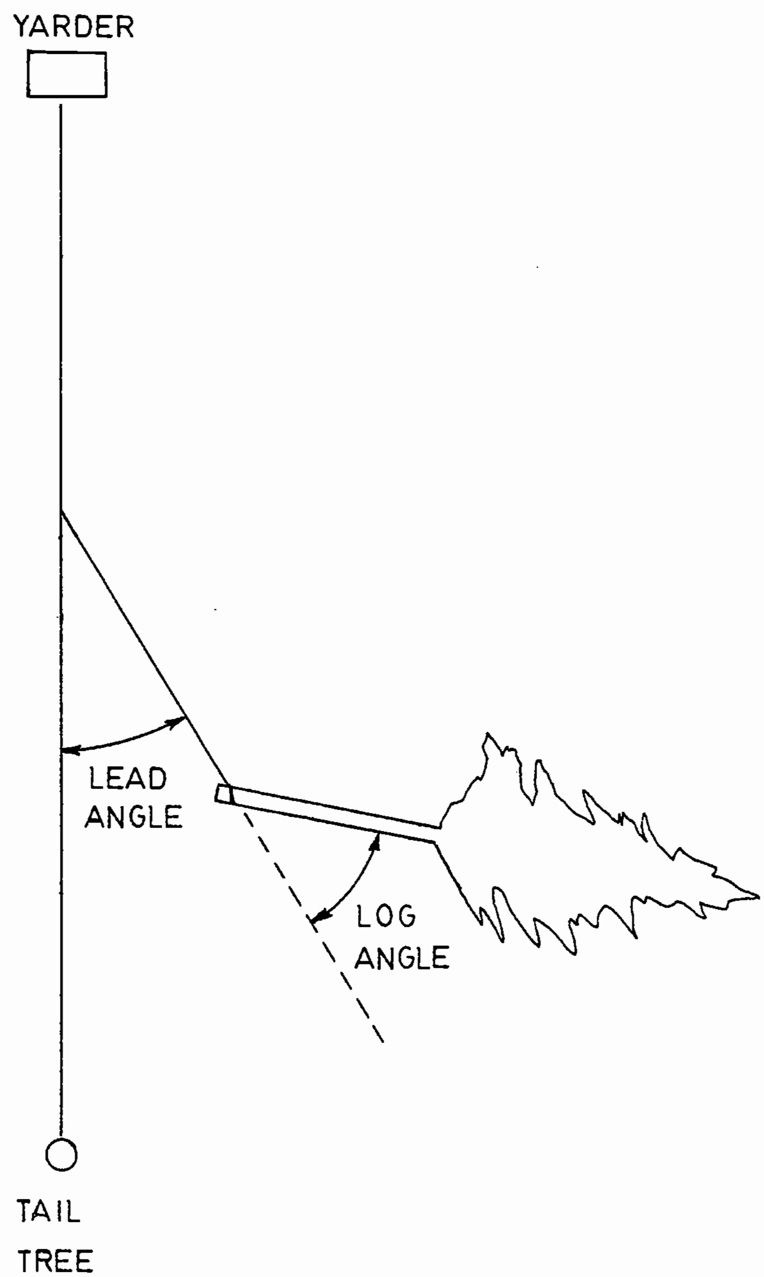


Figure 6. Lead and log angle.

Hangup - A zero-one variable used to distinguish turns on which a hangup occurred.

0 = normal

1 = hangup

Swing - A zero-one indicator variable which denoted the type of swing machine used.

0 = skidder

1 = loader

The remaining indicator variables were in essense a rating system for various operational and enviornmental conditions. The variables took on values according to:

1 = best conditions

2 = average conditions

3 = poor conditions

The variables which were classified in this manner included:

Landing (LAND) - Available landing area as it pertains to the degree to which it limits the operations.

Operator (OPER) - A combined measure of motivation, skill, and performance.

Surface conditions (SURFCO) - The degree to which existing surface conditions (soil) hampered activity.

Surface type (SURFTYP) - The degree to which brush, slash, etc. hampered activity.

Swinging Study

The swinging study examined two different machines (cable skidder and hydraulic loader) to determine productivity for swinging, processing, and decking of log length, tree length and whole tree material. The procedures, analysis, and results for this study are covered in a separate master's paper by Burrows (1983).

Loading Study

This study did not investigate productivity for the "normal" loading operations. However, a limited time study was performed for whole tree loading. The objectives were to determine feasibility, general production rates, and problems associated with whole tree loading.

Whole trees yarded to the landing were swung without processing to loading decks oriented parallel to the haul road. Two whole tree loads were built using Peterbuilt self loading log trucks. The limited data base did not allow detailed elemental and regression analysis as in the other phases of the harvesting operation. Feasibility and problems associated with whole tree loading are included in the discussion section of this report.

DATA ANALYSIS

The major purpose of the data analysis section of this paper is to identify and quantify the differences between the different thinning techniques. Analysis was done on Oregon State University's CYBER 70/73 computer using the Statistical Interactive Programming System (SIPS) of Rowe et al. (1982).

Regression Analysis

Multiple linear regression techniques served as the basis for a majority of the analysis procedures used in this report. Regression analysis has a twofold purpose, prediction and comparison. Prediction implies the development of a model from which one can obtain a value for the dependent variable, given a set of values for the independent variables. A comparison can then be made between different sets of independent variables, which in our case correspond to the different treatments. The general linear regression model, with normal error terms, is defined as follows:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots \beta_{p-1} X_{i,p-1} + \varepsilon_i$$

where:

Y_i is the value of the response variable in the ith trial.

$\beta_0, \beta_1, \ldots \beta_{p-1}$ are parameters.

$X_{i1}, \ldots X_{i,p-1}$ are known constants, the values of the independent variables in the ith trial.

ε_i are random error terms, normally distributed with mean $\mu = 0$ and variance σ^2.

$i = 1, \ldots n$

For this analysis the dependent variable will always correspond to delay free cycle time. This represents working time per tree for felling and turn time for yarding. The hypothesis was that total cycle time was a function of the independent variables measured for that operation.

Data was initially compiled on SIPS, then regressed in the REGRESS subsystem of SIPS. Cycles (i.e., trees or turns) which contained missing time elements were automatically deleted from the regression analysis by the computer, so that the cycle times would not be biased.

Rather than building separate models for the different treatments, two indicator variables, TL (tree length) and WT (whole tree), were used to distinguish between the different thinning techniques. Values of zero or one were assigned to these variables and defined the treatments as follows:

WT	TL	
0	0	Log length thinning
0	1	Tree length tinning
1	0	Whole tree thinning

The selection of independent variables to be included in the final regression model is an important part of the analysis procedure. Independent variables were allowed to enter the model separately using the SIPS command STEPWISE. Evaluation and selection of the final variables was based on three criteria: minimum C_p criterion (defined in Appendix A), maximum R^2, and minimum mean squared error. The latter two criteria are constrained in that they must show reasonable improvement with the addition of each new variable (otherwise these criteria would always dictate using all the variables). The fact that a variable is excluded does not necessarily imply that it is non-significant. Several variables, particularly those in the yarding model, were significant, but excluded because they contributed very little to improving the R^2 value. After the final model had been developed a marginal F-test was performed on the variables excluded from the model. This test showed which variables would be significant (.05 level) if included individually in the final model. A description of the test procedure is given here (Neter and Wasserman 1974: 264):

Hypothesis

NH: $\beta_i = 0$ the variable X_i is significant

AH: $\beta_i \neq 0$ the variable X_i is not significant

Test Statistic

$$F^* = \frac{SSR(X_1, \ldots X_{p-1}) - SSR(S_1, \ldots X_{p-2})}{MSE(X_1, \ldots X_{p-1})}$$

where: SSR = residual sum of squares

MSE = mean square error

Decision Rule

if $F^* \leq F(1-\alpha; p-1, n-p)$, conclude NH

if $F^* > F(1-\alpha; p-1, n-p)$, conclude AH

where: α = level of significance

n = sample size

p = number of coefficients in the new model

A summary of the results of tests on the excluded variables is given in Appendix F.

A random 20% of the data observations were withheld from the regression analysis in order to perform model validations. A paired t-test which compared observed versus predicted delay free cycle time was used to validate the models. The test procedure is described as follows (Neter and Wasserman 1974: 14):

Hypothesis

NH: $\bar{e} = 0$ no difference in population means

AH: $\bar{e} \neq 0$ population means are different

Test Statistic

$$t^* = \frac{\bar{e}}{S(\bar{e})}$$

where: e_i = difference in observed and predicted values of a paired observation

n = sample size

$$\bar{e} = \frac{\Sigma e_i}{n}$$

$$S^2(\overline{e}) = \frac{\Sigma(e_i - \overline{e})^2}{n-1} \div n$$

Decision Rule

if $|t^*| \leq t(1-\alpha/2, n-1)$, conclude NH

if $|t^*| > t(1-\alpha/2, n-1)$, conclude AH

Results for these tests are included in Appendix G. Both the felling and yarding models were validated using this procedure. It is important to note that this validation does not mean that the models can be used for any smallwood thinning operation. The predicted cycle times are valid only within their own data set, i.e., the validation proves that no gross blunders have been made in developing the models. It is important that the user realize this fact and use discretion when applying the results to his own operation.

Felling

The regression model for felling is given in Figure 7. Note that the indicator variables WT and TL are not included. Preliminary analysis had shown a positive coefficient for the variable TL rather than a negative one as would be expected (a negative term would appropriately reduce cycle time for tree length felling). The reason for the positive coefficient is most likely due to high correlations between TL, NLIMBS, and NCUTS. Rather than dropping only one of the indicator variables and causing more confusion it was decided to drop both. In this case the variables NLIMBS and NCUTS, which are

Felling

$$\text{Delay Free Felling Time (minutes)} = 1.322 + (.01447)\ \text{DIST} + (.05542)\ \text{NLIMBS} + (.9589)\ \text{NCUTS} + (.05800)\ \text{VOL} + (.7375)\ \text{CORTHIN} - (.05328)\ \text{LEARN}$$

$R^2 = .720$

Yarding

$$\text{Delay Free Turn Time (minutes)} = 1.333 + (.005364)\ \text{SLPDIST} + (.2955)\ \text{NPIECES} + (.01310)\ \text{TURNVOL} + (.01706)\ \text{LATDIST} - (.4164)\ \text{TL/WT}$$

$R^2 = .661$

Figure 7. Regression models. Note: All variables are significant at the .001 level except LEARN which is significant at the .01 level.

different for each treatment, distinguish between differences in felling time for each thinning technique.

Appendix G shows the results of testing variables excluded from the model for significance. In this case only WT and TL proved to be significant.

Yarding

The regression model for yarding is also presented in Figure 7. Again the variables WT and TL are not present in the model; instead a new variable, TL/WT is included. Early analysis showed that TL and WT had almost identical coefficients. This indicated that there was no significant difference in yarding productivity between tree length and whole tree yarding. Therefore, the two categories were combined and the indicator variable TL/WT used. A value of zero indicates conventional log length yarding while a value of one means whole tree or tree length yarding.

The variable lead angle is not included in the model. This variable entered in the STEPWISE procedure relatively early, but with a negative coefficient. This would imply that as lead angle increases, turn time decreases. Past research has shown lead angle to be an important variable, but always with a positive coefficient (Kellogg 1976, Lucas 1983). This would seem to be the logical result; as the angle to the log from the corridor increases, the log must turn a sharper corner and has a more difficult transition between lateral yarding and inhaul.

Further analysis showed lead angle to be highly correlated with lateral distance ($r = 0.65$). In fact, if LATDIST is excluded from the model then the coefficient for LEADA becomes positive. Since lateral distance is a better predictor of turn time than lead angle, LEADA was dropped from the model.

Several variables excluded from the model proved to be significant (.05 level) in predicting turn time (Appendix F). These included SLOPE, SWING, LAND, OPEFF, SURFCO, and SURFTYP. However, the fact that all these variables were significant does not necessarily imply that they could all be included in the model together. The test only shows that they may be added to the model individually.

Independent Variable Analysis

Statistical summaries of the independent variables were used to explain treatment differences. This analysis included calculations of the mean, standard deviation, and minimum and maximum values for "measured" variables of the different thinning techniques. Discrete variables were summarized with frequency distributions.

The production comparisons included in this report were determined by substituting mean values for the independent variables into the regression models. Depending on the variable in question, its mean value may or may not differ for different thinning techniques. For example, mean number of limbs cut is quite different for whole tree thinning as compared to log length thinning. In order to determine which variables were treatment related a standard t-test comparing two population means was performed. The following is a description of the general test procedure (Neter and Wasserman 1974: 12):

Hypothesis

NH: $\mu_1 = \mu_2$ the population means are the same

AH: $\mu_1 \neq \mu_2$ the population means are different

Test Statistic

$$t^* = \frac{\overline{Y} - \overline{Z}}{S_{yz} \quad (1/n_1 + 1/n_2)}$$

where: $\overline{Y}$ = sample mean from population 1

$\overline{Z}$ = sample mean from population 2

n_1 = sample size from population 1

n_2 = sample size from population 2

S^2_{yz} = estimator of the common variance

$$S^2_{yz} = \frac{\Sigma(Y_i - \overline{Y})^2 + \Sigma(Z_i - \overline{Z})^2}{n_1 + n_2 - 2}$$

Decision Rule

if $|t^*| \leq t(1 - \alpha/2,\ n_1 + n_2 - 2)$, conclude NH

if $|t^*| > t(1 - \alpha/2,\ n_1 + n_2 - 2)$, conclude AH

A summary of the test results comparing means of the independent variables is given in Appendix H. Specific results of the independent variable anlaysis for each operational phase follow.

Felling

Measured independent variables which were used in the felling regression model are summarized in Table 2. Statistical summaries for the remaining independent felling variables are listed in Appendix H.

Table 2. Felling independent variables.

Variable	Treatment	Sample size	Mean	Minimum	Maximum	Sample standard deviation
MDIST	LL	162	55.66	0	250	44.667
(feet)	TL	241	38.79	0	420	42.004
	WT	219	24.57	0	180	25.646
	All/COR	252	28.53	0	125	25.424
	All/THIN	370	44.75	0	420	45.875
	Overall	622	38.18	0	420	39.689
VOL	LL	146	25.14	2.34	91.27	18.414
(cu. ft.)	TL	238	19.35	4.02	126.80	15.474
	WT	221	21.63	4.02	106.27	16.189
	All/COR	252	23.43	2.34	106.27	17.142
	All/THIN	370	20.26	4.02	126.80	15.602
	Overall	605	21.58	2.34	126.80	16.570
NLIMBS	LL	146	25.88	0	99	23.999
	TL	156	9.80	0	63	14.358
	WT	217	0.09	0	19	1.290
	Overall	519	10.26	0	99	18.324
NCUTS	LL	157	1.395	0	7	0.9251
	TL	160	0.913	0	2	0.5651
	WT	216	0.005	0	1	0.0680
	Overall	533	0.687	0	7	0.8370
LEARN	LL	165	3.48	2	5	0.762
(days)	TL	246	14.27	8	27	5.585
	WT	225	13.92	8	21	4.870
	Overall	636	11.35	2	27	6.501

Felling statistics were broken out not only for the different thinning techniques, but also for corridor felling versus regular thinning. This was necessary because the felling regression model contains an indicator variable which distinguishes between these two operations.

Probably the most surprising difference in mean values occurred with the variable move distance. Average move distance between trees for log length thinning was 17 feet longer than for tree length thinning and 31 feet further than the mean move distance for whole tree thinning. This value would logically be shorter for the whole tree technique since the faller is not required to move out the tree to top it. The difference between log length and tree length move distance, however, was not expected and was probably due to local stand conditions. In the production analysis an overall average value for log length and tree length move distance was used. Note also that there was a significant difference between corridor felling and thinning. This is to be expected since there is less distance between cut trees in a clearcut situation (the corridor).

A second area of concern occurred with mean tree volumes. Trees in the log length thinning proved to be significantly larger than those in the other two treatments. This result was again due to local stand conditions. An overall mean volume was used in the production comparison. The fact that trees were larger than average on log length felling areas does not necessarily imply that the same is true for yarding. Part of the felling data was obtained from several skyline roads outside the yarding study.

The learn variable had a range of 25 days. For the production analysis a value corresponding to the maximum number of days on the job (27) was used.

Yarding

Independent variables which were used in the yarding regression model are described in Table 3. The remaining variables which were measured during the study are included in Appendix H.

Prior to the study it had been hypothesized that mean lateral yarding distance might be shorter for the tree length and whole tree yarding techniques. When felling away from the corridor extra line would not be needed in order to reach the top logs. By felling towards the corridor it was thought that the average lateral distance could be reduced even more. In practice this latter procedure worked acceptably well for tree length yarding, but not so well for whole tree yarding since the tops tended to cause hangups and break where the chokers were attached.

From a quantitative standpoint, however, it would be rather difficult to prove significant differences in mean lateral distance for the different thinning techniques. This would require production data from several corridors of similar dimensions in order to obtain a sample of mean lateral distances. Since this kind of data was not available on this study an overall average was used for lateral yarding distance. Therefore, predicted cycle times for whole tree and tree length yarding may be somewhat conservative.

Table 3. Yarding independent variables.

Variable	Treatment	Sample size	Mean	Minimum	Maximum	Standard deviation
SLPDIST	LL	169	302.04	0	880	198.89
(feet)	TL/WT	876	283.46	0	850	180.10
	Overall	1045	286.47	0	880	183.29
LATDIST	LL	169	34.41	0	156	30.993
(feet)	TL/WT	869	32.19	0	169	28.093
	Overall	1038	32.55	0	169	28.581
NPIECES	LL	169	2.10	1	4	0.6329
	TL/WT	882	1.80	0	5	0.7661
	Overall	1051	1.85	0	5	0.7539
TURNVOL	LL	169	28.80	8.04	71.78	12.304
(cu. ft.)	TL/WT	880	29.24	0	89.91	14.061
	Overall	1049	29.17	0	89.91	13.788

The number of pieces yarded per turn was significantly different, as expected. This figure averaged 2.1 logs per turn for log length yarding and 1.8 for tree length and whole tree yarding.

Surprisingly, mean turnvolume on this study was not significantly different for the thinning methods. However, there are several reasons for believing that this may not always be the case. Log length yarding data were derived from only two skyline roads. Since payload capacity is directly influenced by ground profile it would be unfair to base any conclusions on such a limited sample of skyline roads.

Several other factors have an influence on the variable turnvolume. When available payloads are large and piecesize small, turnvolume might be increased with full length yarding simply because fewer pieces need to be hooked. On the other hand, when available payload is low whole tree yarding might result in smaller net turnvolumes because of the added weight associated with tops, increased drag resistance from limbs, and the additional force needed to break trees free of their beds.

Dependent Variable Analysis

The dependent variables in this study are simply the basic time elements. In the regression analysis they are combined into a delay free cycle time. Statistical summaries of the cycle elements are given in Table 4 for felling and Table 5 for yarding. The elemental summaries illustrate at what time during the work cycle differences occur for log length, tree length, and whole tree thinning. Thus, they help to explain productivity differences between the

Table 4. Felling dependent variables.

Element	Treatment	Sample size	Mean	Minimum	Maximum	Standard deviation
Move and select	LL	144	1.716	0	6.77	1.474
	TL	233	1.441	0	6.89	1.209
	WT	205	0.994	0	5.70	0.967
	Overall	582	1.352	0	6.89	1.236
Cut and wedge	LL	144	1.531	0.14	9.99	1.535
	TL	241	1.233	0.24	7.52	1.124
	WT	218	1.229	0.11	9.99	1.106
	Overall	603	1.303	0.11	9.99	1.233
Limb and buck	LL	143	3.306	0	9.99	2.500
	TL	191	1.822	0	9.99	1.898
	WT	225	0.110	0	4.33	0.538
	Overall	559	1.513	0	9.99	2.141
Delay free cycle time	LL	116	6.730	0.58	16.09	3.507
	TL	179	4.661	0.32	16.32	2.946
	WT	202	2.339	0.11	11.12	1.738
	Overall	497	4.200	0.11	16.32	3.190

Note: All times are in decimal minutes.

Table 5. Yarding dependent variables.

Element	Treatment	Sample size	Mean	Minimum	Maximum	Standard deviation
Outhaul (minutes)	LL	160	0.843	0	2.40	0.4433
	TL/WT	827	0.726	0	2.40	0.3470
	Overall	987	0.744	0	2.40	0.3625
Lat-out	LL	166	0.518	0	1.54	0.2808
	TL/WT	848	0.498	0	2.56	0.3516
	Overall	1014	0.502	0	2.56	0.3410
Hook	LL	166	0.659	0.11	2.70	0.4523
	TL/WT	852	0.534	0.08	6.09	0.4281
	Overall	1018	0.554	0.05	6.09	0.4344
Lat-in	LL	158	0.486	0	1.21	0.2523
	TL/WT	852	0.485	0	3.20	0.3366
	Overall	1010	0.485	0	3.20	0.3247
Reset	LL	168	0.198	0	4.92	0.6192
	TL/WT	883	0.318	0	8.82	0.9143
	Overall	1051	0.298	0	8.82	0.8747
Inhaul	LL	163	1.101	0	3.20	0.5525
	TL/WT	840	0.911	0	4.00	0.4790
	Overall	1003	0.942	0	4.00	0.4964
Unhook	LL	145	0.904	0.12	3.78	0.6402
	TL/WT	780	0.796	0.19	3.50	0.4025
	Overall	925	0.813	0.17	3.78	0.4495
Delay free time	LL	127	4.534	1.46	9.05	1.428
	TL/WT	684	3.865	1.35	10.60	1.374
	Overall	811	3.970	1.35	10.60	1.402

treatments. However, these comparisons are valid only when the stand characteristics and working conditions are identical for log length, tree length, and whole tree thinning.

Felling

Differences which occurred in the move and select element are probably due largely to the different move distances which were noted in the independent variable analysis. The cut and wedge element is also larger for log length felling. This fact can be attributed to the larger average tree size for that treatment. As one would expect, the greatest differences occur in the limb and buck element. Table 4 indicates that some limbing and bucking was done during the whole tree treatment. This was necessary for a few trees which were too large to yard as whole trees.

Yarding

The most notable difference between log length and whole tree/tree length yarding occurred in the hook and unhook elements. This outcome can be attributed to the number of pieces hooked per turn. Average reset time (a delay element) was slightly higher for whole tree/tree length yarding. This difference, however, was not found to be significant due to the high variability in the element. For purposes of production comparisons an overall average was used.

The only other elements which proved to be significantly different were the outhaul and inhaul elements. A good explanation for this could not be found except for a slightly higher average slope distance associated with log length yarding.

Delay Analysis

Delays are events which in theory occur randomly throughout the operation. These time elements generally are infrequent in comparison to productive time elements. Furthermore, there are many different types of delays which effectively reduces the sample size even more. This fact makes it extremely difficult, if not impossible, to obtain a precise estimate of their occurrence with any degree of certainty. In order to obtain the best possible estimate all delays which occurred during the study, including those in the validation set, were used in the analysis.

In the past, time studies at OSU have determined production by combining predicted delay free cycle time with a standard prorated delay time. This prorated delay was based on the percent of the total recorded time that was spent in delays. This study takes a different approach in that prorated delay time is on a per cycle basis. Average delay time per cycle is thus determined by dividing the total delay time by the total number of cycles. In this manner a standard delay time is assigned to each turn regardless of the length of delay free turn time. This method assumes that time spent in delays is proportional to the number of cycles rather than scheduled time.

This analysis also adopts a technique, introduced by Lucas (1983), of distinguishing between treatment and nontreatment delays. The majority of delays are random events which occur regardless of which thinning technique is being used (nontreatment delays). Treatment delays, on the other hand, are influenced by the treatment itself. For example, limbing and bucking delays occur during log length felling procedures, but generally not during whole tree felling. This raises the question of what defines a treatment delay. Potential treatment delays were first selected on a judgement basis. A statistical analysis was then performed to determine if there were actually any significant differences (.10 level) between thinning techniques for the selected delay types.

The fact that delay time is prorated on a per cycle basis somewhat complicated the test procedure. Instead of one, two separate tests were required to determine which types of delays were correlated with the treatments. First, a standard t-test was performed to determine if there was a significant differece in mean delay time (between treatments) for each type of potential treatment delay. This test procedure was the same as that used in the independent variable analysis. A second test was used to determine if there was a difference in percent occurrence (on a per cycle basis) for that delay type. If a significant difference was not found in both cases the delay was assumed to be unrelated to the treatment. Otherwise, the appropriate mean values (depending on the individual test results) were assigned to delay time and percent occurrence. Finally, mean delay time for each treatment was multiplied times the corresponding percent occurrence to obtain a delay time per cycle for that particular delay type.

The test procedure used to compare percent occurrence is summarized as follows (Dixon and Massey 1969: 249):

Hypothesis

NH: $p_1 = p_2$ percent occurrence is the same

AH: $p_1 \neq p_2$ percent occurrence is different

Test Statistic

$$Z^* = \frac{(\overline{x}_1/n_1) - (\overline{x}_2/n_2)}{\hat{p}(1 - \hat{p})(1/n_1 + 1/n_2)}$$

where: x = number of occurrences (delays)

n = denominator in percent (cycles)

p = x/n = decimal percent

$$\hat{p} = \frac{x_1 + x_2}{n_1 + n_2}$$

Decision Rule

if $|Z^*| \leq Z(1 - \alpha/2)$, conclude NH

if $|Z^*| > Z(1 - \alpha/2)$, conclude AH

The significance of this test may be of questionable value. Preferably this test should only be used to test large populations (i.e., $x_i > 5$). Several delay samples did not meet this criteria. In view of the situation, however, the author believes that the use of this test is justifiable. In any case it will not have a profound effect on the final results. A summary of the test results and sample calculations are included in Appendix C. The results for the felling and yarding operations are summarized here.

Felling

The delay analysis for the felling operation required still another category for delays. Since corridor felling and thinning were being analyzed separately it was necessary to break out delays influenced by the variable COR/THIN in addition to treatment delays.

Three delays were determined to be influenced by the COR/THIN variable only. These included inspecting the area, notching anchors, and slashing unmerchantable material. Delays involving hangups were influenced both by corridor versus thinning and the thinning technique. One other delay, extra bucking required for yarding, was affected by the treatment only. This delay occurred occasionally with the whole tree and tree length thinning techniques when trees were too large to yard in one piece.

Yarding

Since whole tree yarding and tree length yarding were combined in the regression analysis the same procedure will be used for the yarding delay analysis. This assumption may not be quite true since extra saw-work is probably necessary in whole tree yarding. The final analysis, however, will show treatment delays to be relatively insignificant in the production comparisons. Only one delay, log hangup on the lines, was found to be treatment related.

Efficiency

An overall efficiency value was determined for both the felling and yarding operations. Total operating time for both felling and yarding was determined by combining delay free turn time and operating delays. A requirement of operating delays was that they be less than 10 minutes in duration. Efficiency was then calculated with the following formula:

$$\text{Efficiency} = \left(\frac{\text{Total Operating Time}}{\text{Total Scheduled Time}}\right) \times 100\%$$

Mechanical availability was calculated using the formula:

$$\text{MA} = \left(\frac{\text{Scheduled Time - Mechanical Delays}}{\text{Scheduled Time}}\right) \times 100\%$$

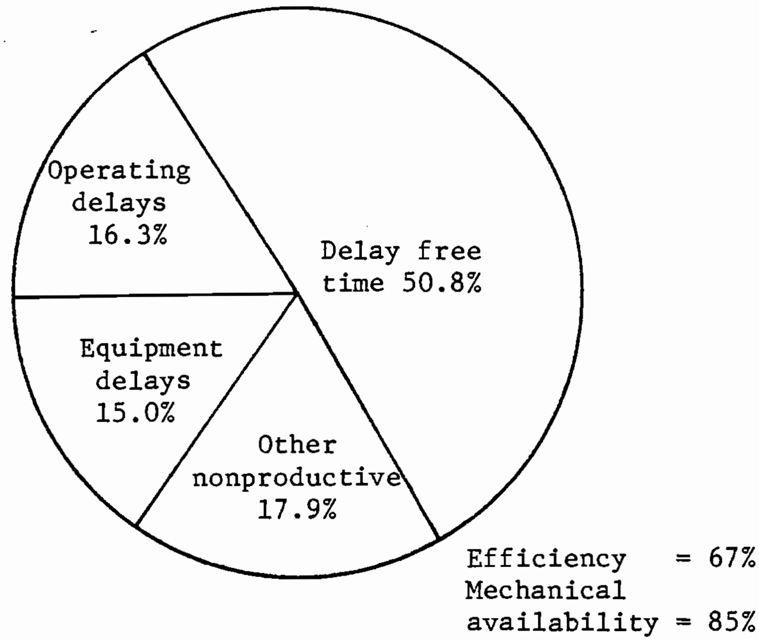
Values for efficiency and availability for felling and yarding are given in Figure 8 along with a breakdown of scheduled working time.

Production Comparisons

The regression models which have been developed enable us to explain a portion of the variability (that portion indicated by the R^2 value) which occurs in the data. By using these models the explained variability which is undesirable can be eliminated and a comparison of the thinning techniques obtained. The basis for this comparison is important. Production (volume per hour) is a better means of comparison than cycle time because it not only accounts for differences in the productive time elements, but also for differences in delays and turnsize (for this study there was no difference in mean turnsize, but this may not always be the case).

The procedure used to arrive at this comparison involved two steps. First the regression model was used to predict a delay free

Felling



Yarding

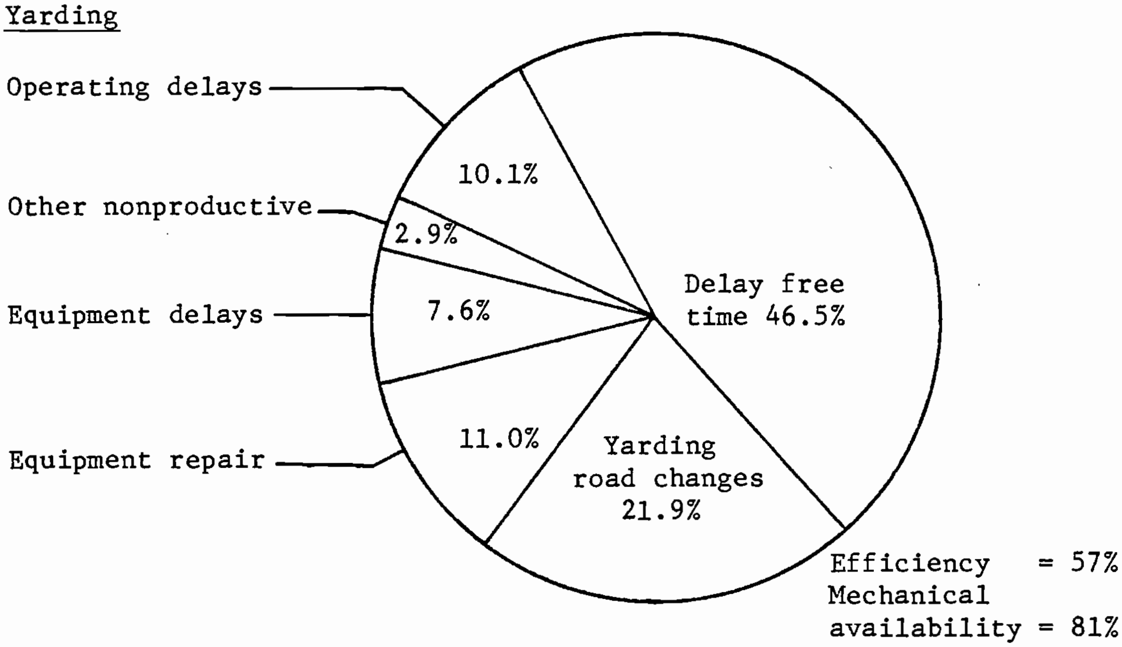


Figure 8. Breakdown of scheduled time.

cycle time for a given set of working conditions corresponding to a treatment (i.e., log length, tree length, or whole tree). The treatment conditions are defined by those mean values for variables used in the regression model which were determined in the independent variable analysis. If, for the different treatments, there was a significant and explainable difference in the mean value of a given variable, then the separate mean values were used. Otherwise, an overall mean value for that variable was assigned to all treatments.

The second step involved transforming cycle time to an hourly production rate. Productive cycle time was combined with its corresponding delay element. The total cycle time was then divided into an average tree or turn volume (the same value as that used in the regression model) to obtain a production estimate.

A summary of the productive and delay elements, together with hourly production estimates for each thinning technique, are shown in Tables 6 and 7. A more detailed discussion of the production derivations for the felling and yarding operations follows.

Felling

The felling production analysis is further complicated by the fact that the regression model recognizes a difference between corridor felling and regular thinning. Mean cycle time for corridor felling is generally shorter for several reasons. The time spent in tree selection is shorter, move distances are smaller, and fewer hangups occur. Production rates are further affected by average tree size. In thinning the dominants and better codominants are favored as

Table 6. Predicted felling cycle times and production estimates.

	Felling time (minutes per tree)		
	Log length	Tree length	Whole tree
Corridor Felling			
Delay free time ($\hat{Y}$)	4.65 ± .77*	3.38 ± .67	1.53 ± .55
Adjusted delay time	4.22	4.29	4.29
Total time per tree	8.87	7.67	5.82
Thinning			
Delay free time ($\hat{Y}$)	5.25 ± .88	3.98 ± .78	2.33 ± .71
Adjusted delay time	4.73	3.48	3.36
Total time per tree	9.98	7.46	5.69
Weighted felling time (minutes/tree)	9.81	7.49	5.71
Hourly production (cubic feet/hour)	127	166	218
Daily production (cubic feet/day)	1010	1330	1740

*95% confidence limits

Table 7. Predicted yarding cycle times and production estimates.

	Yarding time (minutes per turn)	
	Log length	Tree length/whole tree
Delay free turn time ($\hat{Y}$)	4.43 ± .16*	3.93 ± .07
Delay time	2.60	2.61
Road changes (prorated)	1.94	1.94
Total turn time	8.97	8.48
Hourly production (cubic feet/hour)	195	206
Daily production (cubic feet/day)	1560	1650

*95% confidence limits.

final crop trees. The average corridor tree is therefore considerably larger than the average tree felled in thinning.

The approach which was taken to account for these differences was to obtain a weighted average production rate based on the number of trees cut in each operation (corridor felling and thinning). The procedure used is described briefly here. Detailed calculations are shown in Appendix I.

First, correction factors which reflected the percent of trees cut in the corridor and outside the corridor were determined. These factors were calculated from the average dimensions for a skyline road, number of trees per acre, and the thinning intensity. Next, cycle times were determined for the six possible treatment combinations (i.e., whole tree thinning, tree length corridor felling, etc.). The correction factors were then used to obtain a weighted felling time per tree for each treatment and a weighted volume per tree. Finally, production rates for each treatment were obtained by dividing volume per tree by time per tree. As Table 6 indicates, production rates are 32% higher for tree length felling and 72% higher for whole tree felling in comparison to conventional log length felling.

Yarding

Yarding production rates were relatively easy to determine in comparison to felling. Sample calculations are shown in Appendix I. Road changing times were summed for the entire study and prorated on a per turn basis. The average road changing time between corridors was 2.1 hours. Prerigging was a standard practice for this study and was usually done by the hooktender. Time which was spent in waiting for tail trees and intermediate supports to be rigged during road changes was therefore generally minimal.

Similarly to the regression analysis, whole tree and tree length yarding was combined and compared to conventional log length yarding. Production differences are somewhat smaller than those found in felling. Table 7 shows a 6% production increase for TL/WT yarding in comparison to conventional log length yarding.

As a result of layout and operational problems only a small amount of data was obtained for log length yarding with swinging. For this reason it was necessary to use yarding data obtained from skyline roads which were cold decked. Slightly higher production rates might be expected for log length yarding with swinging. However, the dependent variable analysis indicated that this difference was not large. The mean time for the unhook element was only slightly shorter for yarding WT/TL with swinging than for log length yarding and cold decking. For this analysis we will assume an equivalent productivity for log length yarding with and without swinging.

Cost Analysis

The bottom line in most any comparison of harvesting methods is an economic analysis. Just which method is optimum in terms of dollar cost per unit volume produced? This analysis will evaluate system cost from the stump to the loading deck (i.e., felling, yarding, swinging, and processing). Limbing and bucking, for this analysis, occur prior to loading for all thinning techniques (i.e., tree length and whole tree hauling are not considered).

Several assumptions are made for this analysis. Loading and hauling cost elements are assumed to be a constant for the different thinning techniques and therefore have no effect in determining the order of cost effectiveness. Also, costs which are shown here do not necessarily reflect those incurred by the contractor involved with the study. The Bantam yarder is an old machine which has long since been depreciated. In addition, an estimate of the cost of this machine is difficult to obtain since it was a "home-built" type of yarding machine. This analysis attempted to estimate a harvesting cost for an operator still concerned with depreciation. A used Skagit SJ2, similar in age and size to the Bantam, was used for the analysis. The resulting costs may be somewhat higher than those incurred by the contractor in this situation. However, they are indicative of what an operator recently starting in smallwood thinnigs might expect to encounter, given similar production rates.

Calculations for equipment rates are given in Appendix J. The source for the majority of the cost data used here was the Cost Guide for Emperical Appraisals, USFS, 1981.

Swinging was assumed to have a production rate equivalent to yarding. This may not always be true, but was a reasonable assumption for the conditions on this study. In some cases it may be possible to better utilize a skidder by working it part time on an operation adjacent to the yarding area, particularly during road changes. Swinging costs could then be substantially reduced by partially charging the machine and operator off to this second operation.

Prerigging costs were not included in the cost calculations. Since this is a fixed cost it will not affect the relative outcome of the analysis. If desired, total costs may be estimated by increasing the yarding costs given by 20%, essentially the cost of a hooktender.

Detailed calculations for the cost analysis are included in Appendix I. The results of this analysis are illustrated in Figure 9. Four possible thinning strategies are shown:

1. Log length cold deck: felling, limbing, bucking, and topping by the faller/yarding to a cold deck.
2. Log length swing: felling, limbing, bucking, and topping by the faller/yarding/swinging, final limbing, sorting and decking by the skidder operator.
3. Tree length: felling, limbing, and topping by the faller/yarding/swinging, final limbing, bucking, sorting and decking by the skidder operator.
4. Whole tree: felling/yarding/swinging, limbing, bucking, topping, sorting and decking by the skidder operator.

Log length yarding with no swinging is included for situations where cold decking is feasible and to emphasize the cost of the swing element. For this situation it offers the optimum cost per unit volume, being $8.24 per cunit or 11% cheaper than its closest competitor, the whole tree system. Felling and yarding productivity is improved with the whole tree system, but the requirement for an

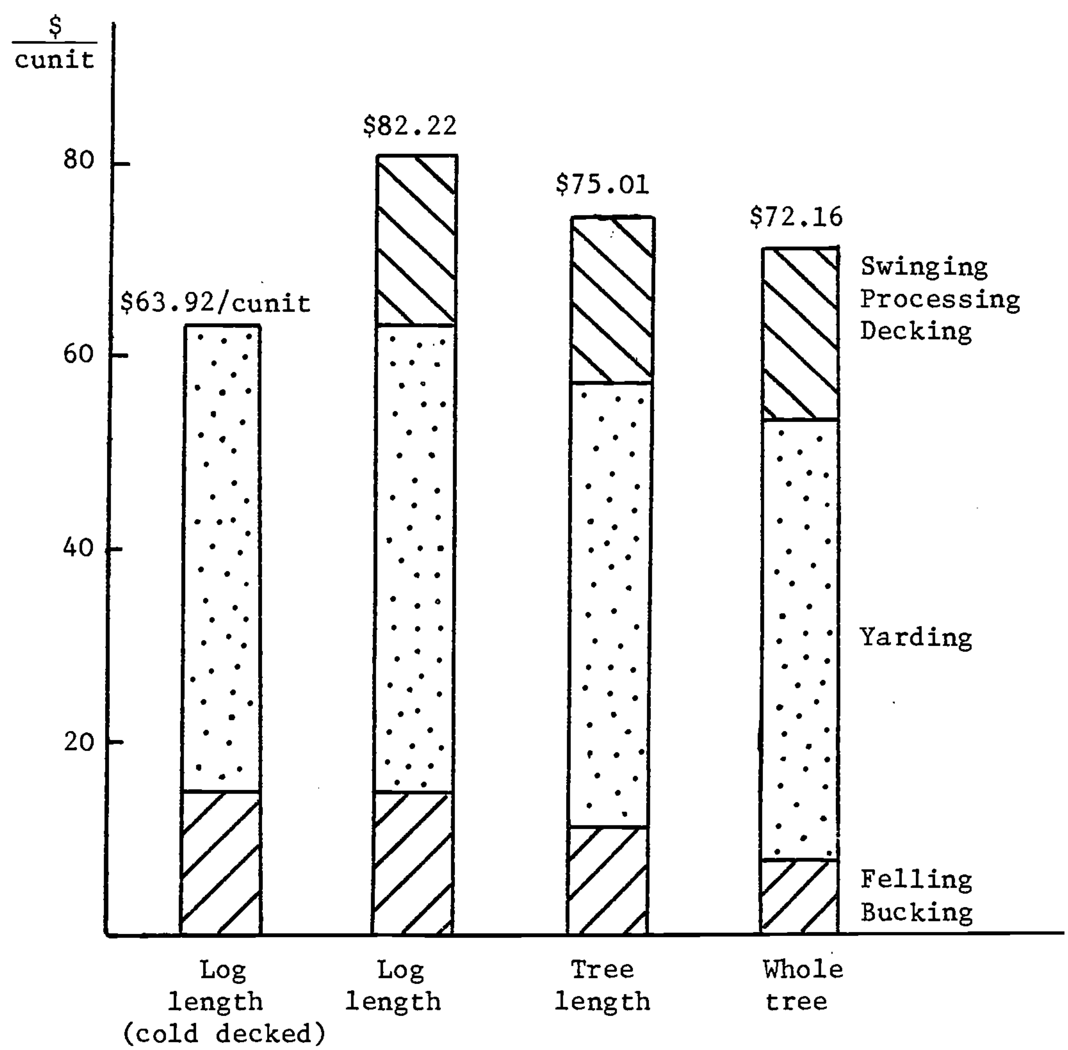


Figure 9. Harvesting costs for four thinning schemes.

expensive swing machine and operator makes this system the more costly alternative.

The opportunity for cold decking, however, is not always available, particularly on steep terrain. Oregon state law prohibits cold decking on slopes over 20% (Oregon Administrative Rules 1981: 83, 84). In the case where a swing element is required the whole tree system becomes the most cost effective alternative. The whole tree system offers a unit cost which is $2.85 per cunit or 4% cheaper than the tree length system and $10.06 per cunit or 12% cheaper than log length yarding with a skidder swing. The cost differences here reflect the inefficiency of the tree length and log length swing operations. This is particularly true for the log length alternative where the skidder operator is not being fully utilized and a large idle time cost results.

DISCUSSION

The results of this study indicate that the greatest contribution to cost savings for the whole tree and tree length systems lies with improved productuvity in the felling operations. Although the limbing and bucking process is not eliminated, its efficiency is greatly improved by transfering it to the landing area. Not only is the task of limbing and bucking more productive in a prepared work area, but a large number of limbs are broken off from Douglas-fir trees during the yarding operation. On this study an average of 30.2 limbs per tree were removed during log length limbing at the stump in comparison to an average of only 5.2 limbs removed by the skidder operator following whole tree yarding (Burrows 1983). Grand fir trees, on the other hand, tended to retain more of their branches. Finally, if a skidder is used to swing logs in a conventional log length thinning operation, the operator is likely to spend a large percentage of his time waiting for the yarder. By incorporating a processing phase into the work cycle of a skidder swing much of this costly idle time could be eliminated.

Yarding is generally the most expensive and critical component of a cable thinning operation. The efficiency of the yarding operation is therefore an important factor in determining total harvesting costs. These study results have indicated that whole tree and tree length yarding procedures are more productive than conventional log length yarding. However, the differences for this operation, in terms of relative gains in productivity and cost effectiveness, were rather minor.

In the author's opinion the benefits noted for whole tree and tree length yarding on this study are important, but are not a fair representation of the systems' potential. The reasoning for this is due primarily to operational circumstances and conditions on the study area.

Prior to the data analysis it was expected that turnvolume for the whole tree and tree length techniques would be significantly higher since fewer pieces would need to be hooked. However, as noted in the independent variable analysis this was not the case; mean turn volumes were very nearly the same. There are several possible reasons for this outcome. One reason is that the mean volume (PSIZE) for whole trees was not considerably larger than average log length piece-size (15.36 cubic feet and 17.85 cubic feet, respectively). This fact is supported by the NCUTS variable which indicates an average of only 1.4 logs per tree.

Another factor which probably contributed to the lack of difference in mean turnvolume is related to payload capacity. Convex ground profiles resulted in rather marginal payload capacity on a number of corridors. As a result it was probably not difficult to build log length turns to payload capacity. The problem was further complicated by using an undersized mainline. This line was particularly limiting during lateral inhaul (resulting in failure on several occasions) and effectively reduced available payload even more.

Yarding production rates recorded on this study were considerably lower than one might expect for a thinning operation of this nature due to a number of problems. Flat chordslopes hampered the outhaul cycle on many corridors and poor deflection, particularly over old growth stumps and snags, resulted in numerous hangups during inhaul. Production was hampered most seriously, however, by equipment breakdowns and delays. Breakdowns were common not only with the yarder but also with the skidder which was used for swinging. This created problems on the landing and often resulted in a jackstrawed deck.

Utilization has a significant effect when comparing production for the different yarding techniques. The production analysis indicated that most of the differences between the thinning techniques occurred during time spent in productive work. If delay time could be reduced the proportion of time spent in productive work would increase and the full tree systems would become much more attractive. For example, an analysis was done which assumed that efficiency for both felling and yarding was improved to 85% (details of this analysis are contained in Appendix K). For this efficiency the relative difference between the whole tree system and conventional log length with swinging would jump from 12% for the original efficiency to 16% for 85% efficiency (in favor of the whole tree system). Furthermore, the difference between log length without swinging and the whole tree system drops from $8.24 per cunit (11%) to only $3.33 per cunit (6%). It is possible that this latter difference may even go to zero if one considers improved utilization for the whole tree system.

Operational Feasibility

From an operational standpoint there were both advantages and disadvantages to the whole tree and tree length harvesting systems. Felling production on the study benefitted not only from eliminating limbing and bucking requirements, but also from a reduction in time spent in delays, more specifically, hangups. This does not imply that there were fewer hangups, but only that many of the difficult hangups were left standing. The reasoning was that since processing was being done at the landing it was not necessary to get the trees to the ground to limb and buck them. Hangups can be yarded just as easily if not easier than trees on the ground, provided they lean away from the corridor. The only problem with this technique is the safety hazard it presents to the felling and yarding crew.

From general field observations the full length yarding operation appeared to work fairly well, provided that trees were felled to lead in a herringbone fashion and with some consideration for the yarding operation. Breakage was probably slightly higher than with the conventional system, as expected, but it was still a very minor problem. It was estimated that residual stand damage was not significantly greater for the full length techniques, although this hypothesis has yet to be proven.

The advantage of potentially being able to build turns up to payload capacity more easily has already been mentioned. Somewhat related to this, but from the opposite viewpoint is the fact that whole trees have a significant weight in tops and branches which effectively reduces potential turnvolume. Furthermore, the increased weight and drag resistance caused by the branches should require more horsepower to yard the turn.

The issue of drag resistance brings to bear on an important consideration for determining potential turnsize. In many if not most cases, the critical point in terms of line tensions occurs not during the inhaul phase, but at the break-out point in lateral yarding. In a study which investigated lateral yarding forces in log length cable thinning, Falk (1980) found a great deal of variability in initial break-out forces. For example, cable tension required to pull a 1500 pound turn free of its bed ranged up to five times the turn weight. Furthermore, Falk concluded that the initial resistive force (not including turn weight) was independent of turn weight, turn length, ground slope, and log angle.

Whole trees may have higher break-out forces due to branch resistance; however, this will be dependent on limbing and bucking procedures used with the tree length or log length alternatives. For example, on this operation the cutters usually "walked" the tree during the limbing process. As a result few of the lower branches were cut, and these are the ones most effective in holding the tree in place during yarding.

These considerations and others immensely complicate the task of determining what turn size the system is capable of removing. The forces which are involved are difficult to evaluate and nearly impossible to predict. Furthermore, a great deal will depend on the operator and how much he is willing to strain the system.

Other Concerns for Whole Tree Yarding

Residue is another subject important to whole tree yarding. If one considers the cost of yarding to be covered by the value of the sawtimber, then the tops are essentially yarded free of charge. Where there is a market for the residue wood and its mill value will justify the loading and hauling costs, this material becomes an added bonus to the whole tree system. Its value, however, will probably not be great due to the relatively low volume of residue wood associated with smallwood thinnings. If, on the other hand, utilization of residue is not economically feasible, the residue material becomes a disposal problem. For this operation, since no market was available, slash was pushed off the road by the skidder.

Whole tree logging is attractive from the standpoint that slash is removed from the woods thereby leaving a much cleaner residual stand. This is especially helpful for the rigging crew since they do not have to work in as much slash while setting chokers. Slash removal may also be important in reducing the fire hazard in the woods. However, if the residue is not utilized it may present an even greater problem in terms of fire danger since it is concentrated and adjacent to the road. On this study slash volumes at the landing were not high, largely due to delimbing which occurred during yarding; however, this slash undoubtedly contributed to the fire potential. This hazard might be reduced by burning the piles later in the year, but this would be difficult to carry out due to their proximity to the residual stand.

In opposition to the concept of utilizing residue material for fuel or chip material is the argument that residue is an important source of nutrients and organic matter. Thus, whole tree harvesting may be a detriment to future site productivity. The issue has received considerable attention due to the fact that branches and foliage are well known for holding a large percentage of the tree's total nutrient capital. Fortunately, this problem is not quite as serious for Douglas-fir thinnings, again due to the large percent of the branches which are broken off and left in the woods during yarding.

The literature is by no means in agreement as to the effect of whole tree harvesting on site quality. Much will depend on the species, site characteristics, harvesting conditions, and the rate of nutrient input to the site through precipitation and weathering of soil. However, there is a general consensus that where the site quality is already poor and nutrients limited, whole tree harvesting is likely to have an adverse effect on site productivity and future rotations (Weetman and Webber 1972, Wells and Jorgensen 1979, and others).

Applications for the Whole Tree and Tree Length Systems

The comparative analyses shown in this report have indicated that the whole tree system is not a cure-all for smallwood thinning operations, but certainly it does have potential for use by the industry. Whether or not to use the whole tree or tree length yarding techniques as opposed to the more conventional methods depends on the individual situation. The stand and topography conditions which are likely to be most ideal for whole tree or tree length thinning include the following:

- Older stands with a larger difference between log length and tree length piecesize.
- Stands with scattered trees making it difficult to build full capacity turns with log length pieces.
- Terrain which provides good deflection and allows yarding 2-4 whole trees per turn.

The operational conditions under which these newer methods will work best are those where it is necessary or advantageous to have a swing machine (i.e., skidder or loader) operating in conjunction with the yarder. Cold decking in the landing chute is not always feasible. This is often the case for thinning operations performed on steep ground where roads are narrow and landing space limited. Logs must somehow be swung out of the skyline corridor to a flatter decking area to prevent them from sliding down the hill.

If a swing-boom type yarder is available then logs may be decked in the road beside the yarder. However, this may also present problems if a large number of logs need to be yarded from one skyline road since room is limited and unhooking becomes difficult (Gabrielli 1980). Furthermore, most of the newer swing-boom yarders are quite expensive and their use may not be economically justifiable in low volume thinning operations. A second swing machine such as a skidder would then be the only alternative. Using the cost values presented in Figure 9, one could reason that you could afford to spend an additional $8.24 per cunit on a swing-boom yarder, if it was a reasonable alternative, before going to a whole tree system with skidder swing.

There are other factors which are likely to make whole tree thinning on steep ground more attractive. Most notably, felling costs are likely to increase substantially in steep terrain. It is also reasonable to assume that time spent in limbing and bucking will be proportionately greater because of the difficult working conditions (Lisland 1975). The cost difference between log length and whole tree felling operations could thus be significantly greater than those presented in this paper.

Steep terrain is not the only situation where whole tree or tree length systems might be advantageous. High volume settings will require that the landing chute be occasionally cleaned out in order to facilitate yarding. If self loading log trucks are to be used this would be a feasible option, although not necessarily an attractive one. Normally, loading can be done early or late in the day when the yarder is not operating. However, if this is not possible or if the deck builds up too rapidly, considerable downtime would result since the yarder would need to be moved. If, instead, a swing machine is used on the landing, operational efficiency would be improved and working conditions would be safer for the chaser since he would not need to climb a precarious deck to unhook chokers. For this case the whole tree alternative would again be the most cost effective option.

The use of a swing machine benefits not only yarding, but also the loading element. Although the effect which the swing element has on loading was not quantified in this study, it should at least be considered in selecting a harvesting system. This is especially important where there is a product mix (size and species) with logs having different destinations. In a study using self loading log trucks McIntire (1981) found a reduced loading time for skidder sorted decks as opposed to yarder decks. Using his regression equation the difference in loading time per truck is 16.7 minutes (a 21% reduction). For McIntire's cost estimates this difference equates to a savings of $1.37 per cunit in loading costs for the skidder swung decks.

An alternative to running a skidder for swinging and processing is to use a loader on the landing. This method is usually standard procedure for operations other than thinnings and may be the only alternative if self loading log trucks are not available. The cost effectiveness of a loader will be primarily dependent on yarding production. For low volume thinning operations a loader will likely be an expensive and underutilized piece of machinery. Furthermore, if processing is to be done on the landing it is possible that a second chaser would be needed since neither the loader operator nor the yarder operator typically leave their cabs to do chaser duties.

Another disadvantage to the loader is that it requires a larger working area, which is especially critical in thinning operations. Observations from the loader swing part of this study indicated that the limited working area created an especially hazardous situation for the chaser. The loader, however, does have an advantage over a skidder since it does not break up the road surface and cause rutting. Road damage was not experienced on this study because thinning was done during the summer months on a well rocked road. However, operations which need to be carried out on nonrocked or recently constructed roads during wet weather will have more problems.

Alternate Scenarios

This study has been concerned primarily with examining the cost effectiveness of tree length and whole tree yarding when a skidder is used for swinging and processing. However, this harvesting scheme is certainly not the only means of applying the full tree concept. Whole tree or tree length trucking combined with mill processing are two alternatives which may be cheaper in terms of total system costs and benefits. For example, a Swedish study (Granquist 1977) which compared a tree length logging system to their conventional shortwood system found that logging and hauling costs generally were greater for the tree length system. The added cost, however, was more than offset by the increased income due to better utilization. The study showed a net gain of $.25 (1976 price levels) per final felled cubic foot. Sixty six percent of this gain was attributed to improved bucking and greater exploitation of wood at the mill. Another 16% resulted from greater yields of chip material and pulpwood.

For smallwood thinning operations in the Pacific Northwest tree length or whole tree hauling could reduce harvesting costs, particularly if yarding to a cold deck is feasible. In order to investigate the feasibility of whole tree trucking, two trucks were loaded with unprocessed whole trees during this study. The fact that such a large percentage of the limbs are broken off during yarding allows truck loads of whole tree material to be built without any major difficulties.

Trees were loaded from skidder decks which were oriented parallel to the road, so space limitations were not a problem. If, however, trees are yarded to a cold deck, then the space required for loading will need to be considered.

The only problem encountered during the loading operation was in tying down the load. The branches which failed to break off during yarding caused the load to be quite compressible. Since the binders were not designed to take up such an excessive amount of slack it was more difficult to secure these loads.

The average loading time per truck from the time the actual loading commenced until the load was secured was 39.4 minutes.

Average delay free time for actual loading of the truck was 29.8 minutes. For purposes of a general comparison, McIntire's (1981) regression equation for loading log length material from skidder swung decks predicts a delay free loading time of approximately 41 minutes under similar working conditions. Thus, whole tree loading for this comparison is over ten minutes faster than conventional log length loading.

Final weight of the loads was approximately 42,500 pounds in accordance with Oregon State restrictions. However, due to the overhanging tops the majority of the weight was concentrated on the rear bunk. In order to haul material of this nature it will be necessary to adjust the truck reach (which controls the distance between the bunks) so the weight of the load is distributed more uniformly and the rear overhang is not excessive.

Trucking of tree length material is presently a reasonable alternative, but whole tree trucking will be more difficult to implement. The major drawbacks to whole tree hauling include difficulties encountered in transport and the requirement of mill processing. Fortunately, many forest holdings are accessed by extensive private road systems so that load restrictions are less of a problem than for on-highway trucking. The fact that tree length hauling in the Pacific Northwest is a feasible alternative has already been demonstrated on many of Crown Zellerbach's operations (Pease 1972). Finally, the problem of mill processing is really a question of economics. The industry must determine if the improved utilization and reduced harvesting costs will justify the investment needed to upgrade the mill and allow whole tree processing.

CONCLUSIONS

Whole tree and tree length cable thinning techniques have been shown to be viable and in many cases cost effective alternatives to the more conventional log length yarding methods. For this study an analysis of harvesting cost at the loading deck indicated a 12% reduction ($10.06 per cunit) for whole tree yarding with a skidder swing in comparison to log length yarding and swinging. However, when cold decking is feasible and will not hamper the operation excessively, conventional log length yarding will still probably be the cheapest alternative. In this case the log length alternative is $8.24 per cunit less costly than the whole tree method. The added efficiency gained from the full length yarding techniques apparently does not justify the additional cost of an expensive swing machine. However, it has been shown that with improved utilization (i.e., percent delay free time) and by considering lower loading costs out of skidder sorted decks this difference could be reduced to $1.96 per cunit.

The use of whole tree and tree length thinning systems will be most attractive when a swing machine would be needed on the landing anyway. Processing could then be incorporated into the swing element which would help to improve operational efficiency. Three cases where a swing machine is likely to be required are listed below:

1. Steep ground and narrow roads prevent cold decking.
2. High volume settings which would otherwise require the yarding deck to be loaded out frequently in order to continue yarding.

3. A high product mix makes it advantageous to have a landing sort.

The results of this study indicate that the best harvesting system to use will be dependent on the particular situation. Available equipment, type of terrain, and size and volume of timber to be removed are all important factors which need to be evaluated. Whole tree and tree length yarding are important options which should be considered in selecting a harvesting system.

Several possibilities exist for future research in regard to whole tree harvesting. This study has illustrated productivity differences for only one particular thinning operation. In the author's opinion the benefits shown here which result from whole tree yarding are the minimum which one might expect for a thinning operation of this nature. Further production studies under different harvesting conditions may show even greater savings for these full length methods. For example whole tree thinnings in older stands may prove to be more cost effective as a result of a larger difference in piecesize between logs and whole trees.

Whole tree and tree length yarding techniques should certainly not be confined to thinning operations only. These methods are also applicable to clearcutting second growth stands on relatively short rotations (50 to 70 years). In fact, these yarding methods may be even more attractive under clearcut conditions since the higher productivity would allow for more efficient swinging and processing.

Finally, this study has briefly examined the feasibility of whole tree loading and hauling. A more detailed investigation of this subject in terms of productivity and problems encountered in trucking will need to be undertaken. Whole tree hauling in conjunction with mill processing is certain to be an important topic for the Pacific Northwest in the coming years.

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APPENDIX A

I. Glossary

Break-out point - Initial movement of logs during lateral yarding. The point in time when logs are pulled free of their beds.

Clearance - The distance between the ground and the skyline at the carriage location.

Corridor (or skyline corridor) - The clearcut strip where the skyline is located.

C_p criterion - A criterion used for selecting the "best" set of independent variables to be used in a regression equation. This criterion is concerned with minimizing the total squared error term of the n fitted observations for any given regression model (Neter and Wasserman 1974). The estimator which is used is defined as:

$$C_p = \frac{SSE_p}{\hat{\sigma}^2} - (n - 2p)$$

External yarding distance - The slope distance from the headspar to the cutting unit boundary.

Intermediate support - A tree or set of trees which is (are) used to provide additional support to the skyline. Double tree intermediate supports, in which the trees are located on both sides of the skyline corridor, were used in this study. A line passing between the trees is rigged with a special support jack which holds the skyline.

Landing chute - The area in front of the yarder where logs are landed and unhooked.

LL (log length) - Felled, limbed, bucked, and topped by the faller.

MBF - Thousand board feet (Scribner).

Payload capacity - The maximum turn size (weight or volume) which the yarding system can handle within the safe working tensions of the yarding lines (usually defined as 1/3 their breaking strength).

PH - Productive hour.

Setting - The area logged to one landing (one yarder position).

SH - Scheduled hour.

Skyline road - The area logged to one skyline position.

Span - Horizontal distance from the headspar to tail tree.

Swing-boom yarder - A yarder mounted on a turret base, thus enabling it to swivel and deck logs to the side rather than directly in front of the yarder.

Tail tree - A tree rigged at the end of the skyline corridor to provide additional deflection for the skyline.

TL (tree length) - Felled, limbed, and topped, but not bucked by the faller.

WT (whole tree) - Felled only, with no additional processing by the faller.

Yarder size - Yarder size is defined for this study by the maximum mainline pull. Yarders are categorized as follows (from Aubuchon 1982):

Maximum mainline pull

Small: less than 25,000 pounds

Medium: 25,000-71,000 pounds

Large: greater than 71,000 pounds

II. U.S. - Metric Conversion Factors

1 acre = 0.4047 hectare

1 foot = 0.3048 meter

1 mile = 5280 feet = 1.609 kilometers

1 pound = 4.45 Newtons = .454 kilogram f

1 HP = .746 kilowatts

1 cubic foot = .02832 cubic meters

1 cunit = 100 cubic feet

Cubic foot - board foot conversion varies with log size.

A conversion factor of .31 cubic foot per board foot (Scribner) was used for this study.

APPENDIX B

STAND STATISTICS

	Volume/acre				
Species	Cu. ft.[1]	Bd. ft.[2]	Trees/acre	Mean DBH	Mean height
Bigleaf maple	180	--	14	13.7	--
Red alder	100	--	20	7.9	--
Pacific madrone	20	--	1	9.0	--
Total hardwood	300		35		
Douglas-fir	3080	10,400	220	12.7	78.0
Grand fir	130	500	5	16.2	83.4
Total softwood	3210	10,900	225		
Total stand	3510		260		

[1]Hardwood volumes are gross cubic foot volumes (including stump and top) from Brackett (1977) using British Columbia equations. Softwood cubic foot volumes were determined by converting Scribner board foot volume to cubic foot volume using Table 32 of Dilworth (1980).

[2]Softwood board foot volumes were determined from Washington D.N.R. tarif tables (Chambers et al. 1980, Cole et al. 1972), Scribner board foot volumes for 32 foot logs to a 6 inch top.

APPENDIX C

DATA FORMS

YARDER DETAILED

Date

Observer

Corridor

Comment

Loader	Skidder	Whole Tree	Log	Reset	P15°30"	10	20	Unbucked load	Cut/yard

Number	Outhaul 1	Lat out 2	Hook 3	Lat in 4	Reset	Inhaul 6	Unhook 7	Cut 8	Delay Code	Delay I.D.	Delay Time	Slope Dist.	Lat. Dist.	# Logs	Lead Angle	Log Angle	Diameter	Length	Diameter	Length	Diameter	Length	Diameter	Length	Landing	Deck	Operator	Surf Co.	Surf Ty.

FELLING DETAILED

Date

Observer

Corridor Feller

Comment

Whole tree

Tree length

Log length

Ground slope

FORTRAN STATEMENT

Distance	Move & Select 1	Cut & Wedge 2	Diameter 1	Limb & Buck 3	# Limbs	# B. Cuts	Height	Delay Code	Delay I.D.	Delay Time	Length 1	Diameter 2	Length 2	Diameter 3	Length 3	Tag #	Tag #	Tag #	Tag #		Stand Co.	Operat.	Surf. Co.	Surf. Ty.

APPENDIX D

DELAY ANALYSIS

I. Summary of Delay Types

Description of delay	Type[1]	Class[2]	Frequency	Mean[3]	Standard deviation
Felling delays					
Equipment maintenance	E	N	48	14.633	13.373
Equipment delay	E	N	10	8.981	11.729
Fuel and service	O/D	N	42	5.222	3.720
Planning delay	O/D	N	1	2.080	0.000
Misc. prep., moving to new location	O/D	N	7	13.743	23.707
Working delay	O/D	N	7	3.350	1.922
Wedged saw	O/D	N	7	4.740	5.800
Inspecting area	O/D	C	31	4.864	3.617
Slashing	O/D	C	15	4.828	3.095
Anchor notching	O/D	C	4	13.988	8.236
Hangup	O/D	C/T	57	4.677	5.200
Extra bucking (on WT treatment)	O/D	T	10	3.328	2.094
Walk in/out	D	N	39	9.146	5.538
Aiding another cutter	D	N	1	10.890	0.000
Rest	D	N	24	5.532	4.031
Education	D	N	4	6.158	3.080
Yarding delays					
Carriage maintenance	E	N	2	4.250	1.075
Communications delay	E	N	7	1.100	0.552
Carriage malfunction	E	N	24	2.187	3.056
Equipment delay	E/R	N	13	16.415	26.463
Yarder adjustments	E/R	N	57	3.670	4.500
Rigging gear, yarding lines	E/R	N	11	8.239	6.500
Major equipment repair	R	N	9	60.333	37.762
Carriage repair	R	N	18	6.976	16.830
Attach saw	O	N	2	2.025	1.167
Attach choker	O	N	1	0.920	0.000
Planning delay	O	N	5	2.050	1.456
Reposition carriage	O	N	28	1.689	1.705
Log hangup on lines	O	T	1	8.100	0.000
Hangup	O/D	N	43	2.985	3.126
Landing delay	O/D	N	56	3.033	3.345
Working delay	O/D	N	33	4.925	9.304
Reposition yarder	D	N	4	9.880	4.000

[1]The codes for delay type are defined as follows:
- O - operating delay (under 10 minutes)
- E - equipment delays, service, and malfunctions
- R - equipment repair and long adjustments
- D - other nonproductive.

[2]The codes for delay class are defined as follows:
- N - nontreatment delay
- C - corridor/thinning delay
- T - treatment delay

[3]All times are in decimal minutes

II. Comparison of Potential Corridor-Thinning Felling Delays

A. Statistical Summary

Delay	Type[1]	Sample size	Mean time[2]	Standard deviation[2]	Occurrence (% of trees)
Inspecting area	C	6	1.640	0.707	2.34
	T	26	5.500	3.605	6.86
Anchor notching	C	19	5.177	3.784	7.39
	T	0	---	---	---
Hangups	C	16	3.650	3.272	6.23
	T	41	5.078	5.841	10.55
Slashing	C	63	2.946	5.142	24.514
	T	28	4.930	8.225	7.388

[1]C = corridor, T = thinning.

[2]Times are in decimal minutes (each occurrence).

B. Sample Calculation for Comparison of Mean Times

Inspecting area

t(.95, 30) = 1.697

$$t^* = \frac{(5.50 - 1.64)\sqrt{\dfrac{(26)(6)(30)}{32}}}{\sqrt{(26-1)(3.605)^2 + (6-1)(.707)^2}} = 2.58 > 1.697$$

Conclude there is a difference in mean delay time (.10 level).

C. Sample Calculation for Comparison of % Occurrence

Inspecting area

$Z(.95) = 1.645$

$$\hat{p} = \frac{6 + 26}{258 + 378} = .05031$$

$$Z^* = \frac{.0686 - .0234}{\sqrt{(.0503)(1 - .0503)(\frac{1}{258} + \frac{1}{378})}} = 2.56 > 1.65$$

Conclude there is a significant difference in percent occurrence (.10 level).

D. Summary of Results for Corridor-Thinning Delays

	t	t*	Conclusion for mean time	Z	Z*	Conclusion for % occurrence
Inspecting area	1.68	2.58	Different	1.65	2.56	Different
Anchor notching	--	--	Different	--	--	Different
Hangups	1.68	.920	No difference	1.65	1.99	Different
Slashing	1.65	1.40	No difference	1.65	6.05	Different

Note: Level of significance = .10.

E. Sample Calculation for Adjusted Delay Times

1. Mean time and percent occurrence are both different. Inspecting area delay.

   a. Corridor
      Mean time = 1.650 min./delay
      Occurrence = 2.34%
      Adjusted delay time per tree = (1.640)(.0234) = .038 min./tree

b. Thinning

Mean time = 5.500 min.
Occurrence = 6.86%
Adjusted delay time per tree = (5.500)(.0686) = .377 min./tree

2. Mean time is the same, percent occurrence is different. Slashing delay

$$\text{Mean time (each delay)} = \frac{\text{Sum of COR + THIN delay times}}{\text{No. of delays}}$$

$$= \frac{(2.946)(63) + (4.930)(28)}{91} = 3.556 \text{ min./delay}$$

a. Corridor: occurrence = 24.51%

Adjusted delay time per tree = (3.556)(.2451) = .872 min./tree

b. Thinning: occurrence = 7.39%

Adjusted delay time per tree = (3.556)(.0739) = .263 min./tree

III. Comparison of Potential Felling Treatment Delays

A. Statistical Summary

Delay	Treatment	Sample size	Mean time[1]	Standard deviation	Occurrence (% of trees)
Working delay	LL	0	--	--	--
	TL	4	3.468	2.389	1.61
	WT	3	3.193	1.181	1.33
Extra bucking	LL	0	--	--	--
	TL	4	2.558	1.556	1.61
	WT	6	3.842	2.376	2.65
Hangups (trees not on ground)	LL	35	5.454	5.906	21.61
	TL	16	2.728	2.876	6.45
	WT	5	3.908	4.797	2.21

[1]Times are in decimal minutes.

B. Summary of Results for Felling Treatment Delays

	Treatments compared	t	t*	Conclusion	Z	Z*	Conclusion
Working delay	TL/WT	2.02	.17	No difference	1.65	.26	No difference
Extra bucking	TL/WT	1.86	.94	No difference	1.65	.79	No difference

Note: Level of significance = .10.

Hangups are affected by both corridor vs. thinning and the treatment type. An analysis procedure similar to the one above, but combining both effects was used. It showed no difference in mean time or occurrence for any treatment during corridor felling. However, during thinning both mean delay time and occurrence were found to be influenced by the treatment type.

IV. Summary of Adjusted Felling Delays

A. Nontreatment Delays

Sum of time in delays = 1680.58 min.
Number of trees = 636
Delay time per tree = 2.64 min./tree

B. Treatment delays	Sum of adjusted delay time (min.)	No. of trees	Delay time per tree (min.)
Log length	0	162	0
Tree length	17.61	248	.07
Whole tree	16.05	226	.07
C. CORTHIN Delays			
Corridor	332.26	257	1.29
Thinning	242.58	379	.64
D. Hangups			
Corridor	74.83	257	.29
Thinning, LL	183.06	126	1.45
TL	24.48	191	.13
WT	0.67	62	.01

Total delay time per tree is found by adding the appropriate time from each of the four categories.

V. Comparison of Potential Yarding Treatment Delays

A. Statistical Summary

Delay	Treatment	Sample size	Mean time[1]	Standard deviation[1]	Occurrence (% of turns)
Working delay	LL	5	2.422	2.263	3.76
	TL/WT	28	3.626	3.967	3.72
Hangups (yarding obstacles)	LL	7	1.563	1.245	5.26
	TL/WT	36	3.262	3.313	4.78
Log hangup on lines	LL	0	--	--	--
	TL/WT	1	8.100	0	0.13

[1]Times are in decimal minutes.

B. Summary of Results for Yarding Treatment Delays

Delay	t	t*	Conclusion	Z	Z*	Conclusion
Working delay	1.70	.65	No difference	1.65	.02	No difference
Hangups	1.68	1.33	No difference	1.65	.14	No difference

Note: Level of significance = .10.

VI. Summary of Yarding Delays

A. Nontreatment Delays

Sum of time in delays = 2040.88 min.
Number of turns = 886
Delay time per turn = 2.30 min./turn

B. Treatment Delays

Treatment	Sum of delay time (min.)	No. of turns	Delay time per turn (min.)
LL	0	133	--
TL/WT	8.10	753	.01

C. Road Changes

Total time in road changing = 1637 min.
Total number of skyline road changes = 13
Average road changing time = 126 min.
Average turns per road = 65
Road changing time per turn = 1.94 min/turn

APPENDIX E

REGRESSION EQUATIONS FOR LOG AND TREE VOLUME

I. Log Length

$$V_L = 0.00761\ (L)^{0.7589}\ (D)^{2.024}$$

II. Tree Length

$$V_T = 0.0657\ (D)^{2.2954}$$

where: V_L = Log volume in cubic feet

V_T = Whole tree volume in cubic feet to a 4 inch top

D = Butt diameter (tree or log) inside bark in inches

L = Log length in feet.

Note: Regression equations were developed from a sample of logs and trees taken during the study.

APPENDIX F

MARGINAL F-TEST ON EXCLUDED VARIABLES

Sample Calculation for Variable Slope

$SSR(X_1, X_2, X_3, X_4, X_5, X_6) = 870.934$

$SSR(X_1, X_2, X_3, X_4, X_5) = 870.718$

$MSE(X_1, X_2, X_3, X_4, X_5, X_6) = .668974$

$n = 675, p = 7, q = 6$

$$F^* = \frac{873.879 - 870.718}{.664567} = 4.756$$

$F(.95, 6, 668) = 2.10 < 4.756$

Conclude AH, the variable SLOPE is significant (.05 level).

Summary of Test Results

Variable	F*	F	Conclusion	New R^2
Felling				(Original R^2 = .7181)
Diameter	0.21	2.05	Not significant	.7182
Cutter	1.94	2.05	Not significant	.7196
Hangup	0	2.05	Not significant	.7181
Tree length	8.45	2.05	Significant[1]	.7247
Whole tree	8.52	2.05	Significant	.7248
Yarding				(Original R^2 = .6607)
Log angle	0.32	2.10	Not significant	.6609
Slope	4.76	2.10	Significant	.6631
Swing	12.53	2.10	Significant	.6670
Hangup	0.71	2.10	Not significant	.6611
Landing	2.29	2.10	Significant	.6619
Operator	11.96	2.10	Significant	.6667
Surface condition	6.29	2.10	Significant	.6639
Surface type	5.16	2.10	Significant	.6633
Corridor width	1.93	2.10	Not significant	.6617

[1]Although tree length is significant it has an unexpected positive coefficient and four this reason was excluded from the model. To avoid confusion whole tree was also excluded.

APPENDIX G

MODEL VALIDATIONS

I. Felling Validation

Model

DFT = 1.3224
+ (.014466) DIST
+ (.055422) NLIMBS
+ (.95893) NCUTS
+ (.057995) VOLUME
+ (.73749) CORTHIN
- (.053281) LEARN

Validation Set

Sample size: $n = 78$
Mean difference in times: $\bar{e} = .1966$
Standard deviation: $S(\bar{e}) = .1662$

$t^* = 1.183$ $t(.975, 77) = 1.994 > 1.183$

Conclude there is no difference in mean times (.05 level). The model is validated for use with this data set.

II. Yarding Validation

Model

DFT = 1.3332
+ (.0053635) SLPDIST
+ (.29554) NLOGS
+ (.013104) TURNVOL
+ (.017055) LATDIST
- (.41642) WT/TL

Validation Set

Sample size: $n = 128$
Mean difference in times: $\bar{e} = .03926$
Standard deviation: $S(\bar{e}) = .07499$

$t^* = .523$ $t(.975, 127) = 1.979 > .523$

Conclude there is no significant difference in mean times (.05 level). The model is validated for use with this data set.

APPENDIX H

INDEPENDENT VARIABLES

I. Measured Independent Variables (excluded from models)

Variable	Treatment	Sample size	Mean	Minimum	Maximum	Sample standard deviation
Felling						
DIA	LL	163	11.18	6	21	4.397
(inches)	TL	241	11.08	7	27	3.668
	WT	224	11.62	7	25	3.888
	Overall	628	11.30	6	27	3.947
Yarding						
LEADA	LL	169	38.93	0	90	28.620
(degrees)	TL/WT	873	41.74	0	90	29.738
	Overall	1042	41.29	0	90	29.564
LOGA	LL	169	40.00	0	90	32.053
(degrees)	TL/WT	873	32.23	0	90	28.730
	Overall	1042	33.49	0	90	29.418
SLOPE	LL	169	23.55	18	27	3.826
(degrees)	TL/WT	883	18.58	9	28	5.844
	Overall	1052	19.38	9	28	5.859
PSIZE	LL	168	15.36	2.91	71.78	10.274
(cu. ft.)	TL/WT	853	17.85	0	79.24	12.089
	Overall	1021	17.44	0	79.24	11.841

II. Frequency Distributions for Felling Discrete Variables

Variable	Treatment	Value	Frequency	% Frequency
TCUT	LL	1	165	25.94
	TL	2	246	38.68
	WT	3	225	35.38
CUTTER	LL	0	77	46.67
		1	88	53.33
	TL	0	70	28.45
		1	176	71.55

Variable	Treatment	Value	Frequency	% Frequency
CUTTER	WT	0	173	76.89
		1	52	23.11
CORTHIN	LL	0 (corridor)	40	24.24
		1 (thin)	125	75.76
	TL	0	54	21.95
		1	192	78.05
	WT	0	164	72.89
		1	61	27.11
HANGUP	LL	0 (no)	119	72.12
		1 (yes)	46	27.88
	TL	0	207	84.15
		1	39	15.85
	WT	0	197	87.56
		1	28	12.44

III. Frequency Distributions for Discrete Yarding Variables

Variable	Treatment	Value	Frequency	% Frequency
TCUT	LL	1	169	16.07
	TL	2	414	39.35
	WT	3	469	44.58
SWING	LL	0 (cold decked)	169	100.00
	TL/WT	0 (skidder)	705	79.84
	TL/WT	1 (loader)	178	20.16
HANGUP	LL	0 (no)	165	97.63
		1 (yes)	4	2.37
	TL/WT	0	787	89.13
		1	96	10.87
WIDTH	LL	10	169	100.00
(feet)		20	0	0
	TL/WT	10	652	73.84
		20	231	26.16
LAND	LL	1	0	0
		2	169	100.00
		3	0	0
	TL/WT	1	150	16.99
		2	616	69.76
		3	117	13.25

Variable	Treatment	Value	Frequency	% Frequency
DECK	LL	1	0	0
		2	79	46.75
		3	90	53.25
	TL/WT	1	0	0
		2	606	68.63
		3	277	31.37
OPER	LL	1	0	0
		2	169	100.00
		3	0	0
	TL/WT	1	87	9.85
		2	763	86.41
		3	33	3.74
SURFCO	LL	1	169	100.00
		2	0	0
		3	0	0
	TL/WT	1	689	78.03
		2	194	21.97
		3	0	0
SURFTYP	LL	1	0	0
		2	169	100.00
		3	0	0
	TL/WT	1	0	0
		2	700	79.28
		3	183	20.78

IV. T-Test Comparisons of Independent Variables

Variable	Felling variables Treatments compared	t	t*	Conclusion
DIST	LL, TL	1.96	3.77	Different
DIST	TL, WT	1.96	4.33	Different
DIST	C, T	1.96	5.106	Different
VOL	LL, WT	1.97	1.97	Borderline
VOL	LL, TL	1.97	3.38	Different[1]
VOL	TL, WT	1.97	1.55	No difference
VOL	C, T	1.65	2.36	Different[2]
NCUTS	LL, TL	1.65	4.98	Different
NCUTS	TL, WT	1.65	16.47	Different
NLIMBS	LL, TL	1.65	32.03	Different
NLIMBS	TL, WT	1.65	35.60	Different

[1]For the production analysis no difference was assumed.
[2]t = 1.65 indicates a one tailed t-test.

Yarding variables (comparison of LL to TL/WT)			
Variable	t	t*	Conclusion
TURNVOL	1.96	.38	No difference
SLPDIST	1.96	1.21	No difference
NLOGS	1.96	4.79	Different
PIECESIZE	1.96	3.08	Different
LATDIST	1.96	1.01	No difference
Reset (time)	1.96	1.63	No difference

APPENDIX I

PRODUCTION AND COST DETERMINATIONS

I. Detailed Calculations of Felling Production

Assumption for Cutting Unit

Merchantable trees/acre for stand[1]	168 t/ac.
Average volume per merchantable tree[2]	23.43 cu. ft.
Trees per acre removed in thinning[1]	62.3 t/ac.
Average volume per tree removed in thinning[3]	20.26 cu. ft.
Width of skyline corridors	10 ft.
Width of skyline roads	160 ft.
Span of skyline roads (to cutting boundary)	600 ft.
Area in average corridor	
(10')(600')/43560 ft.^{2}/ac. =	.1377 ac.
Area in thinned region	
[(160')(600')/43560] - .1377 ac. =	2.0661 ac.
Trees removed from each skyline road	
Corridor = (168 trees/ac.)(.138 ac.) =	23.1 trees
Thinning = (62 trees/ac.)(2.066 ac.) =	128.7 trees
Total	151.8 trees

Removal Factors

Corridor (CRF) = .152 (15.2%)
Thinning (TRF) = .848 (84.8%)

Weighted Volume/Tree (WFT)

= (CRF)($\overline{\text{Vol}}$./corridor tree) + (TRF)($\overline{\text{Vol}}$./thinned tree)
= (.152)(23.43) + (.848)(20.26) = 20.74 cu. ft./tree

[1] Data from post logging cruise.

[2] Average of corridor trees from felling time study.

[3] Average of thinning trees from felling time study.

Predicted Felling Cycle Times

Assumptions	Log length	Tree length	Whole tree
DIST (corridor)	43.1 ft.	43.1 ft.	20.1 ft.
DIST (thinning)	46.3 ft.	46.3 ft.	36.6 ft.
NLIMBS	26	10	0
NCUTS	1.4	1	0
VOL (corridor)	23.43 cu. ft.	23.43 cu. ft.	23.43 cu. ft.
VOL (thinning)	20.26 cu. ft.	20.26 cu. ft.	20.26 cu. ft.
LEARN	27 days	27 days	27 days

Corridor Felling Time in Minutes Per Tree (CORTHIN = 0)

Delay free time	4.65 ± .77*	3.38 ± .67	1.53 ± .55
Treatment delays	0	.07	.07
CORTHIN delays	1.29	1.29	1.29
Hangups	.29	.29	.29
Nontreatment delays	2.64	2.64	2.64
Total time/tree	8.87	7.67	5.82

Thinning Felling Time (CORTHIN = 1)

Delay free time	5.25 ± .88	3.98 ± .78	2.33 ± .71
Treatment delays	0	.07	.07
CORTHIN delays	.64	.64	.64
Hangups	1.45	.13	.01
Nontreatment delays	2.64	2.64	2.64
Total time/tree	9.98	7.46	5.69

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*.05 significance level

Weighted Felling Time

WFT = (CRF)(time/corridor tree) + (TRF)(time/thinned tree)

Log length = 9.81 min./tree
Tree length = 7.49
Whole tree = 5.71

Felling Production Rates

Production per hour = (WVT) ÷ (WFT)(1/60 min./hr.)

Treatment	Hourly production	Daily production
Log length	127 cu. ft./man hr.	1010 cu. ft./man day
Tree length	166 cu. ft./man hr.	1330 cu. ft./man day
Whole tree	218 cu. ft./man hr.	1740 cu. ft./man day

II. Detailed Calculations of Yarding Production

Assumptions	Log length	Tree length/Whole tree
SLPDIST (ft.)	286	286
NPIECES	2.1	1.8
TURNVOL (cu. ft.)	29.17	29.17
LATDIST (ft.)	33	33
TL/WT	0	1

Predicted Turn Times (Minutes)

Delay free turn time	4.43 ± .16	3.93 ± .07
Mean reset time	0.30	0.30
Treatment delays	.00	.01
Nontreatment delays	2.30	2.30
Yarding road changes	1.94	1.94
Total turn time	8.97	8.48

Production Rates

Hourly production = (Vol./turn) ÷ [(time/turn)(1/60)]

Treatment	Hourly production	Daily production
Log length	195 cu ft./hr.	1560 cu. ft./day
Tree length/whole tree	206 cu. ft./hr.	1650 cu. ft./day

III. Cost Calculations

Sample Calculation

Cost/unit volume = (hourly cost)/(hourly production)

For log length felling:

$$\text{Cost/cunit} = (\$19.78/\text{SH})/(127\ \text{ft.}^3/\text{SH})\left(\frac{1\ \text{cunit}}{100\ \text{cu. ft.}}\right) = \$15.57/\text{cunit}$$

Cost/MBF = ($15.57/cunit)/(.31 MBF/cunit)[1] = $50.24/MBF

[1] Conversion factor for an average log size of 8" (scaling diameter) x 32'.

Summary of Operational Costs

Treatment		Felling	Yarding	Swinging[2]	Total
LL	($/cunit)	15.57	48.35	18.30	82.22
	($/MBF)	50.24	155.98	59.02	
TL	($/cunit)	11.92	45.77	17.32	75.01
	($/MBF)	38.44	147.65	55.87	
WT	($/cunit)	9.07	45.77	17.32	72.16
	($/MBF)	29.25	147.65	55.87	
LL (no swing)	($/cunit)	15.57	48.35	--	63.92
	($/MBF)	38.44	155.98	--	

[2] Swinging production is assumed to match yarding production.

APPENDIX J

EQUIPMENT RATES

I. Felling Cost Information

Equipment Description

Stihl 041AV, 26" bar	$500
Axe and shovel	40
Wedges; 15 @ $7.00	105
Loggers tape; 2 @ $28.00	56
Safety equipment and miscellaneous	75

Purchase cost (P)	$776
Salvage value (S) @ 15%	$116
Estimated life (N)	2 yrs.
Scheduled hours (SYH)	1600 hrs./yr.

Fixed Costs

Depreciation (D) = (P-S)/N	$330/yr.	
Average annual investment (AAI) = ((P-S)(N+1)/2N) + S	$611	
Interest, insurance, taxes, administration	31%	
X (AAI)	$189/yr.	
Total fixed costs/SH = (D + IITA)/SYH		$.32/SH

Variable Costs

Labor (includes fringe and burden factor)		$18.88/SH
Maintenance and repair = .5 X (D/SH)		$ .10/SH
Saw operation		
Fuel = .25 gal./hr. X $1.25/gal.	$.31/PH	
Oil and lube = .5 hourly fuel cost	$.16/PH	
Chain: Purchase = $40, life = 200 hrs.	$.20/PH	
Total saw operating cost/SH x utilization		$ .48/SH
Total cost/scheduled hour		$19.78/SH

PH = Productive hour
SH = Scheduled hour

II. Yarding Cost Information

Equipment	Purchase price (P)	Salvage value (S)	Annual depreciation	Average annual investment (AAI)	Maint. & Repair %	Maint. & Repair $/yr.	Estimated life (N)
Skagit SJ2 yarder (used)	$50,000[1]	$5,000	$11,250	$33,125	50%	$5625	4 yrs.
Wyssen W2.ST (2 1/2 ton) carriage	11,000[2]	1,100	2,475	7,288	60	1485	4
Crew bus, G3500 Rally van	10,700[3]	1,070	1,204	6,487	50	602	8
Rigging hardware	7,950	0	1,988	4,969	0	0	4
Communications, Talkie Tooter MKII	4,523[3]	452	1,018	2,996	60	611	4
			$17,935	$54,865		$8323	

[1] Curthe Meyer, Logging Specialist, Ross Equipment, Inc., Eugene, OR.

[2] Forest Service, Cost Guide for Empirical Appraisals, Revision 10, November 1981.

[3] Equipment brochures and costs from 1982 PNW Logging Conference, Eugene, OR.

Yarding Cost Information (continued)

Fixed Costs

Sum of annual depreciation (D)	$17,935/yr.
Sum of average annual investment (AAI)	$54,865/yr.
Interest, insurance, taxes, administration	31%
X AAI	$17,008/yr.

Total fixed costs/SH = (D + IITA)/1600 SH/yr. $21.84/SH

Variable Costs

A. Labor (includes fringe and burden factor plus travel pay)

1 yarder operator	$16.43/SH
1 chaser	14.51
1 rigging slinger	15.45
1 choker setter	14.26

Total labor $60.65/SH

B. Maintenance and repair = ($8323/yr.)/(1600 SH/yr.) $ 5.20/SH

C. Fuel costs

1. Yarder: (3.5 gal./hr.)($1.20/gal.) = $ 4.20/PH
   Oil and lube @ 10% of fuel = .39/PH

2. Crew bus (50 mi./day)($1.25/gal.)/
   (12 MPG)(8 SH/day) = $ .65/SH
   Oil and lube @ 33% of fuel = .21/SH

D. Operating lines (1500 hr. life)

1. Skyline: (3/4" X 1000' IPS) @ $1.68/ft. = $1,680

2. Mainline: (9/16" X 1000' IPS) @ $1.17/ft. = $1,170
   $2,850
   ÷ 1500 PH life = $1.90/PH

E. Chokers

(1/2" X 12' IPS)(3 @ $20.63)/800 hr. life = $.10/PH

Total variable costs calculated on PH basis = $16.59/PH
x 57% utilization 3.74/SH

Total variable costs $74.25/SH

Total hourly cost for yarding $94.29/SH

III. Swinging Cost Information

Equipment description: John Deere 440-C (70 HP)

Purchase price (P)	$50,000
Salvage value (S) @ 20%	10,000
Estimated life (N)	5 yrs.
Scheduled hours per year (SYH)	1,600 hrs.

Fixed Costs

Depreciation (D) = (P-S)/N =	$ 8,000/yr.	
Average annual investment (AAI) = ((P-S)(N + 1)/2N) + S =	$34,000	
Interest, insurance, taxes, administration =	31%	
X AAI =	$10,540/yr.	
Total fixed costs per SH = (D + IITA)/SYH =		$11.59/SH

Variable Costs

Labor (includes fringe and burden factor)	$16.47/SH
Maintenance and repair = .5 X (D/SYH)	2.50/SH
Fuel = (1.5 gal./hr.) X ($1.20/gal.)	1.80/SH
Oil and lube @ 10%	.18/SH
Tires (4 @ $1200, 1 yr. life)	2.40/SH
Saw	.74/SH
Total variable costs	$24.09/SH
Total hourly cost for swinging	$35.68/SH

APPENDIX K

EFFECT OF IMPROVED EFFICIENCY

Assume yarding and felling efficiency = 85%

Adjusted cycle time = original cycle time

$$- \left(\frac{\text{Total scheduled time}}{\text{No. of cycles}}\right) [(1 - \text{old eff.}) - (1 - \text{new eff.})]$$

Adjusted felling times = 8.30 minutes for LL
= 5.98 minutes for TL
= 4.20 minutes for WT

Adjusted yarding times = 6.61 minutes for LL
= 6.12 minutes for TL/WT

Improved Production and Costs at 85% Efficiency

Treatment	Production (cu. ft./hr.)		Costs ($/cunit)			
	Felling	Yarding and swinging	Felling	Yarding	Swinging	Total
LL	150	265	13.19	35.61	13.47	62.27
TL	208	286	9.51	32.97	12.48	54.96
WT	296	286	6.68	32.97	12.48	52.13
LL (without swinging)			13.19	35.61	--	48.80