Hot-Yarding as an Alternative Approach to Cable Thinning in Young Forest Stands: A Comparative Study.

by

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INTRODUCTION

Thinning is a silvicultural tool often used in the management of immature forest stands. The objectives of most thinnings are to improve residual stand conditions; increase the growth rate on selected remaining stems; shorten the rotational time for timber crops and increase the amount of useable wood fiber obtained from each rotation (Baker, 1950). As an intermediate type cut, thinnings generally yield low volumes per acre as compared to final harvest or regeneration cuts. In addition this volume is contained in numerous, small diameter stems that have a relative low market value. Because of this, the margin for profit in a thinning operation is usually narrow.

Thinning in areas requiring the use of cable yarding techniques such as in steep mountainous terrain, reduces this margin for profit even more. The high investment and operating costs associated with cable yarding equipment, lower production rates when compared with ground based logging and increasing labor costs combine to make cable thinning a risky venture as a commercial operation. This is especially true when market conditions for wood products are low, as is currently the case (1982). Yet thinning young stands using cable methods can make a profit (Gabrielli, 1980) but the magnitude of this profit, if any, is very sensitive to minimizing costs and efficiency in operating procedures.

Cable logging technology in the United States and especially in the Pacific Northwest, has evolved around the development of machines and techniques capable of handling large quantities of old growth timber. As a result there has been little expertise fostered in the area of equipment or procedures applicable to the efficient harvesting of smallwood. Yet,as the amount of old growth timber continues to decline (Tedder, 1979), being replaced by young stands under more intensive management regimes, the need for these types of systems will greatly increase. To date the primary contributors to this specialized field have been the Europeans whose managed forests are many rotations ahead of our own. Through necessity, they have developed equipment and procedures to economically handle the smaller sized timber generated through intensive management practices (Lisland, 1975).

Foreseeing the eventual need and importance of similar technology in the Pacific Northwest, the Forest Engineering Department of Oregon State University initiated a program of smallwood harvesting research in 1972 (Aulerich, 1975). Many of the resultant studies from this program have dealt specifically with equipment and operational techniques associated with cable thinning (Kellogg, 1980). The results from these studies have identified several areas where total costs in a thinning operation may be reduced. Gabrielli (1980) found that felling, bucking and yarding costs accounted for about 84 percent of total thinning costs using a Skagit SJ-2 yarder. Of this approximately 34 percent was associated with the felling and bucking. This would indicate that the yarding operation and the felling activities are the two areas with the greatest potential for reducing thinning costs. An earlier study examined the felling and bucking operation in detail activities into a single operation in both clear cuts and intermediate harvests. Also they have found that yarding whole trees to the landing can provide better efficiency in the limbing and bucking activities (Lisland, 1975).

This study endeavored to incorporate several of the ideas and findings from previous research and currently used methods into a workable alternative to conventional cable thinning in the Northwest. The original proposal and backing for this project came from the Smallwood Harvest Research Program. The approach that was examined combined the thinning and yarding activities into one operation. Thinned stems were yarded to the landing as whole trees where a skidder would swing them from the landing to a processing site. The skidder operator limbed and bucked the trees then sorted the processed logs onto appropriate loading decks. The operation employed four persons and required the use of a rubber tired skidder. This paper outlines the results of field studies and subsequent analyses comparing this technique to a conventional thinning operation in a young growth stand of Douglas-fir.

(Aulerich, 1975). It showed that the limbing and bucking activities consumed the largest percentage (23%-34%) of total felling time per tree. It was also noted that time spent trying to get hangups to the ground represented a significant amount of total thinning time.

Kellogg (1983) examined the effect that various crew sizes had on production and costs in a thinning operation using a Koller K-300 yarder. Labor costs can often account for a large percentage (sometimes greater than 50%) of total harvesting costs in a small wood operation (Olsen, 1981). It is therefore important that people, equipment and operating methods be balanced to make the most efficient use of the labor employed. This particular study found that a 2 person yarding crew proved to be the most cost effective.

The above mentioned study also investigated the effect that using a rubber tired skidder to swing logs away from the landing would have on the yarding and loading operations. Results showed that loading time was reduced by about 14 percent when logs were loaded from the sorted decks built by the swing skidder. It was also apparent that this activity helped to improve yarding production by decreasing landing delays and unhook times. However, this increase in production failed to offset the added costs of the swing skidder when its full cost was charged to the yarding operation (McIntire, 1981).

Traditional cable thinning in the Northwest has employed a two phase operation. The trees are first cut and the skyline corridor cleared, then the yarder is brought in and downed logs are moved to the landing deck. Perhaps this is a carry over from clearcut operations which have been the backbone of the industry for so many years. Several of the European logging methods have combined these two

SCOPE

GENERAL

This project was one of several studies conducted during the summer of 1981 that were part of the Smallwood Harvesting Research Program administered through the Department of Forest Engineering, Oregon State University. The study looked at the feasibility of falling and yarding whole trees as a combined activity in a cable thinning operation. This approach was compared with conventional thinning where the two activities occur as seperate and distinct operations. Field trials utilizing both methods served as the basis for evaluation. These trials were conducted in a young growth stand of Douglas-fir located on the Paul Dunn forest some 12 miles northwest of Corvallis, Oregon.

The crew used in the felling and yarding activities consisted of forest engineering students working for the school forest. They had been logging with a Koller K-300 yarder throughout the summer. This was the same machine that was used for yarding in this project. The "hot-yarding" technique involves the use of a swing operation to remove trees from the landing. A John Deere 440 rubber tired skidder with an experienced operator was employed for this. The regular crew performed all other felling and yarding operations. All settings in this study required the use of one intermediate support for the skyline. A Koller, one ton capacity, self clamping carriage was utilized in the yarding operations.

OBJECTIVES

The general aim of this project was to evaluate a procedural alternative to conventional cable thinning, wherein felling and yarding activities are merged into a single operation. For convenience this procedure was labeled "hot-yarding". Through detailed time studies conducted on field operations, data was collected that would allow the realization of the following objectives:

1) Develop production equations for "hot-yarding" and conventional thinning based on regression models. This includes felling operations as well as yarding operations.
2) Evaluate the functional and economic efficiency of the "hot-yarding" approach by comparative analysis with conventional thinning.
3) Determine if increasing the skyline corridor width from 10 to 20 feet has a significant effect on "hot-yarding" productivity.
4) Determine the major differences between the two methods that influence production or costs and identify those factors that appear to be associated with these differences.

see if the increased corridor width made a significant difference in the "hot-yarding" technique. The swing operation was not studied in detail as part of this project. For evaluation this activity was assumed to require the same amount of time as the yarding operation and therefore had equivalent production in operation hours per cunit output.

Road changes, planning, loading, hauling and road construction were not considered in the scope of this study.

STUDY DESIGN

Detailed time studies conducted on actual operations of each thinning method provided the basic data for comparison. These comparisons were based on the activities involved in felling, corridor clearing, yarding, processing (limbing and bucking) and decking. The sum of these activities reflect the stump to loading deck portion of the entire harvest operation and was used as the basis for comparison in this study. A total of 6 settings were thinned and yarded in conjunction with this project. One was used as a trial corridor for the crew to become familiar with the "hot-yarding" operation.

In the conventional thinning time studies were conducted on the corridor clearing, felling and yarding operations. From these, regression models were developed that could estimate times per cycle for each activity. Delays were expressed as a percentage of total productive time. These models were then combined in such a way as to yield an expression estimating the time required to process a unit of volume through an operation given a specific set of conditions. By combining these times and appropriate delays various expressions of total production can be derived. Total man hours per cunit output and crew (operation) hours per cunit output were used for comparisons in this study.

Similar production equations were developed for the "hot-yarding" method on both 10 and 20 foot skyline corridor widths. These equations were based on the study results from 2 corridors assigned each method. The 10 foot corridors were to be used for comparison with the conventional thinning approach. The 20 foot studies were to

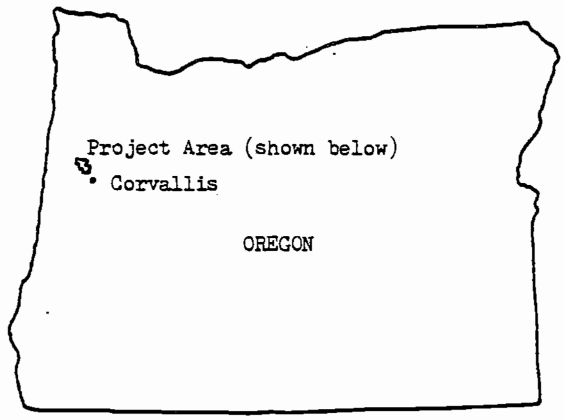
DESCRIPTIONS

SITE DESCRIPTION

The field study was conducted on a portion of the Paul Dunn Forest located in the South West quarter of section 15, T.10S., R.5W., Willamette Meridian, Benton County, Oregon (Figure 1). This forest is owned and managed by Oregon State University. The study area included six settings that covered a total of about 12 acres (Figure 2). The settings were trapezoidal in shape and ranged from 477 to 818 feet slope distance (landing to tailtree). The average setting width was about 200 feet on the lower end and around 90 feet at the landing. The average area per setting was about 2.3 acres (Figure 3). Access to study site was from the 210 road and the newly constructed 214 spur.

Slopes within the study area ranged from 5 to 40 percent with an average of about 28 percent. A definate break in topography occured in the middle portion of each setting. This required the use of intermediate supports in order to access the areas below the break with the skyline. Aspect varied from West to North-West.

The stand was a mixture of Douglas fir (Pseudotsuga menziesii), Grand fir (Abies grandis), Bigleaf maple (Acer macrophyllum), Pacific madrone (Arbutus menziesii) and Bitter cherry (Prunuss emarginatta). Hardwoods averaged about 5 inches DBH and accounted for approximately 14 percent of the total 430 stems averaged per acre. The stand, which was 30-40 years old, resulted from natural regeneration and was in an overstocked condition. Commercial stems (conifers > 6 inches DBH) averaged 340 stems per acre with a mean DBH of about 10 inches. Figure-4 displays the diameter distribution of the coniferous component



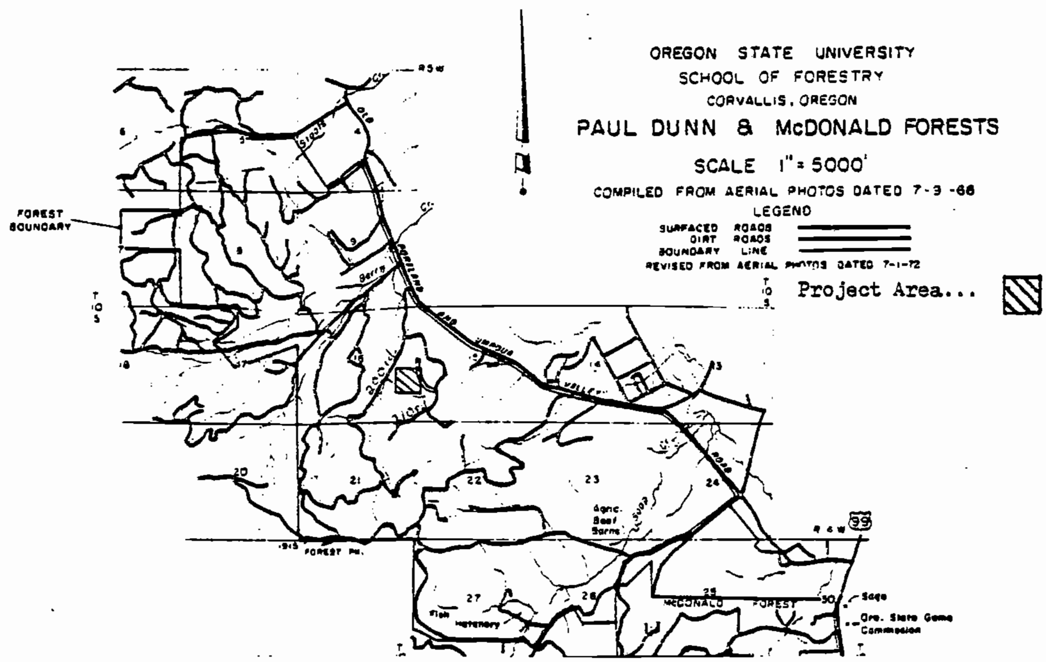


Figure 1. General Location Map.

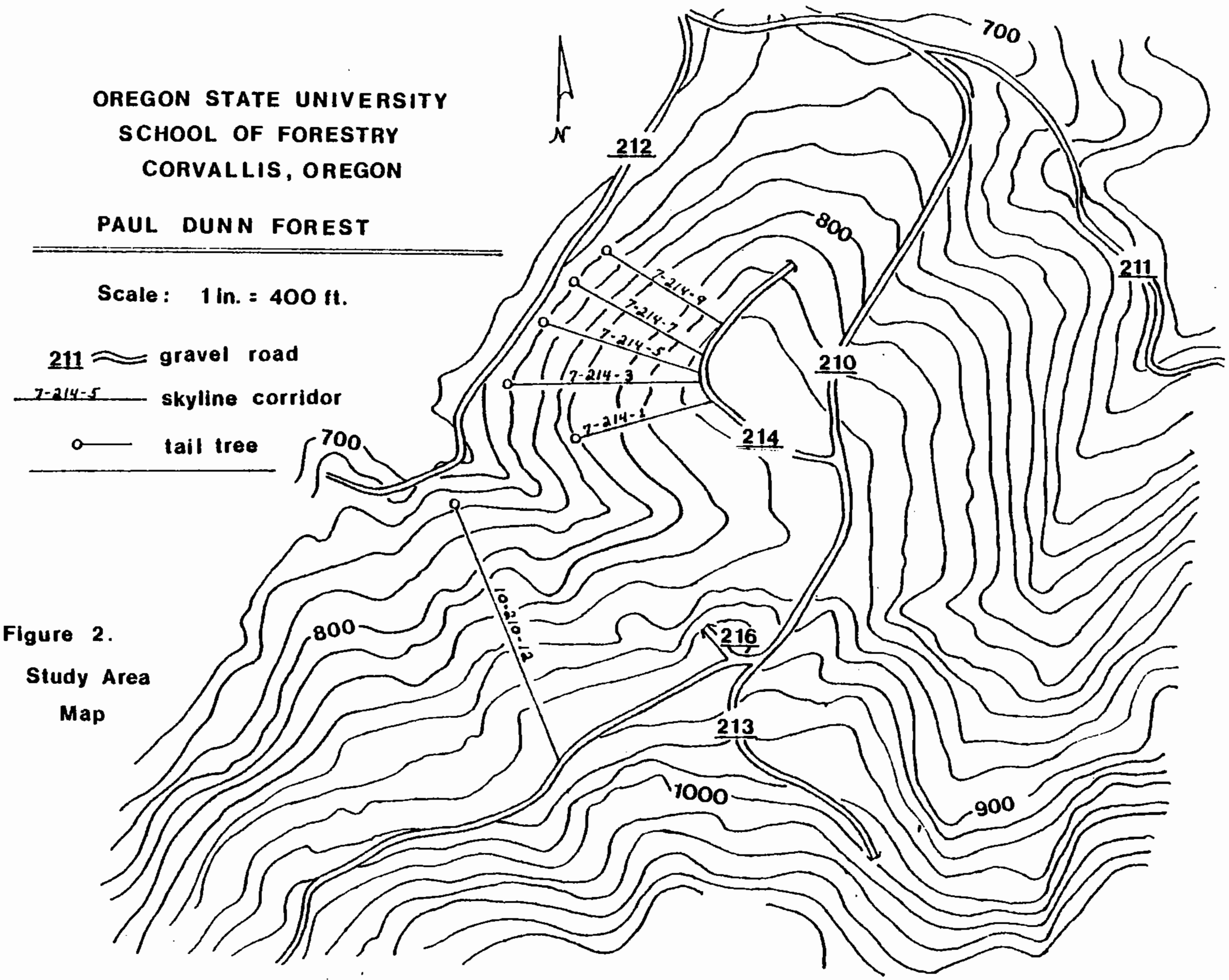
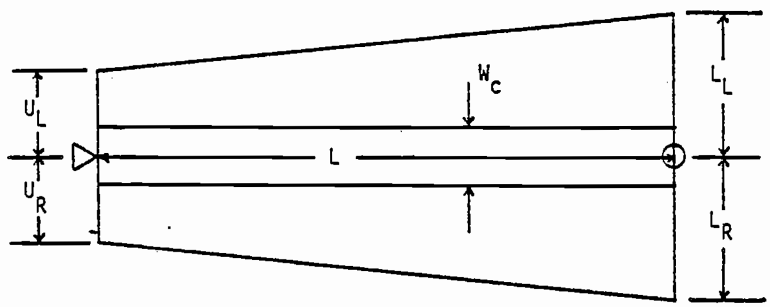


Figure 2.
Study Area
Map



Setting Dimensions - (ft.)

▷ - Landing

○ - Tail tree

W_c — Corridor width

$$\text{Area (acres)} = \frac{0.5(L)\left[(U_L + U_R) + (L_L + L_R)\right]\text{ft}^2}{43{,}560\ \text{ft}^2/\text{acre}}$$

Setting	L	Upper		Lower		W_c	Area (acres)		%
		U_L	U_R	L_L	L_R		Total	Corridor	Corridor
210-12	818	20	125	65	125	10	3.145	0.188	6.0%
214-01	485	55	45	105	110	10	1.754	0.111	6.3%
214-03	635	45	20	110	125	10	2.187	0.146	6.7%
214-05	523	20	25	125	100	10	1.621	0.120	7.4%
214-07	509	25	75	100	75	20	1.607	0.234	14.5%
214-09	477	75	25	75	80	20	1.396	0.219	15.7%

Figure 3. Setting Dimensions and Areas.

of the stand prior to thinning. Based on a 10 percent cruise of the study area, commercial volume was estimated to average about 7,300 cubic feet per acre. Table-1(a) gives a summary of pre-thinning stand conditions for each setting.

Numerous obstructions, in the form of large partially decomposed logs and stumps, were encountered throughout the area [Table-1(a)] These were the result of falling standing snags left from the previous harvest (Rowley, 1981). This occured when the current stand was in the sapling stage.

The silvicultural objective in treating this stand was to improve the growth rate of selected dominant and co-dominant stems. This was to be done by reducing competition for light, water and nutrients through thinning from below. The crew was instructed in thinning procedures by the forest manager. Species priority, dominance and residual crown spacing were the major criteria that shaped the guidelines used in thinning (Rowley, 1981).

For the yarding operation a clearcut corridor is needed that runs the length of the setting. This corridor is generally about 10 feet wide. However, two settings with 20 foot wide corridors were included in this study.

A field survey following harvest operations showed approximately 47% of the commercial stems were removed by thinning. This accounted for about 30% of the available commercial volume per acre (corridors not included). Table 1(b) contains a summary of thinning data on a per setting basis. Over the entire study area approximately 165 trees, per acre were removed by thinning with an average DBH of about 8 inches.

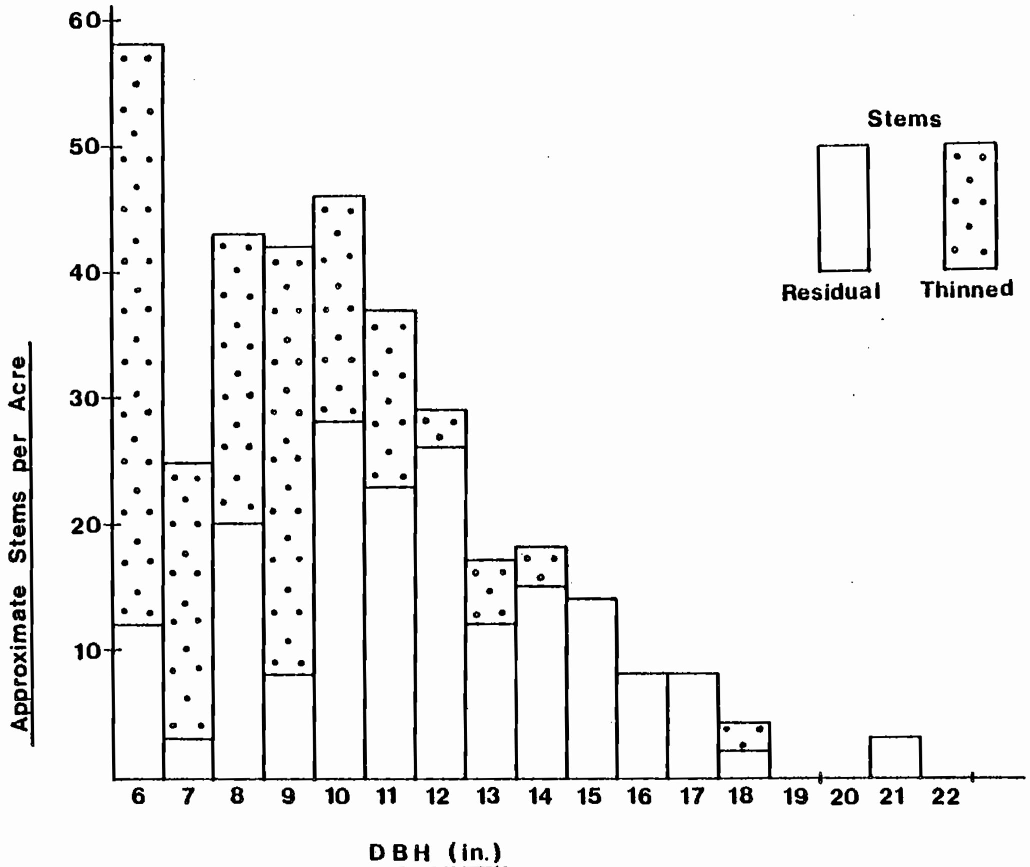


Figure 4. DBH Distribution - Conifers > 5.5 in. DBH.

Table 1(a). Summary of Stand Conditions Prior to Thinning.
Estimates based on sample data from 25 random (0.05 acre) plots.

Setting	COMMERCIAL STEMS			NON-COMMERICAL STEMS			OBSTRUCTIONS		Average Slope (%)
	Stems per acre	Ave. DBH	Ave. Volume per acre (Cu. Ft.)	Saplings per acre	Other Species: Stems per acre	Other Species: Ave. DBH	Number per acre	% area covered	
10-210-12	387	10.28	8,811	40	40	6	140	10%	24%
7-214-1*	500	8.32	6,955	40	140	4	120	5%	21%
7-214-3	270	9.96	5,707	20	60	3	160	10%	33%
7-214-5	250	11.74	7,266	50	100	6	310	25%	32%
7-214-7	340	10.55	7,406	10	30	6	90	5%	33%
7-214-9	393	9.52	7,211	30	40	5	210	15%	24%

* This setting used as a practice corridor for the "hot-yarding" operation.

Table 1(b). Thinning Data Summary.

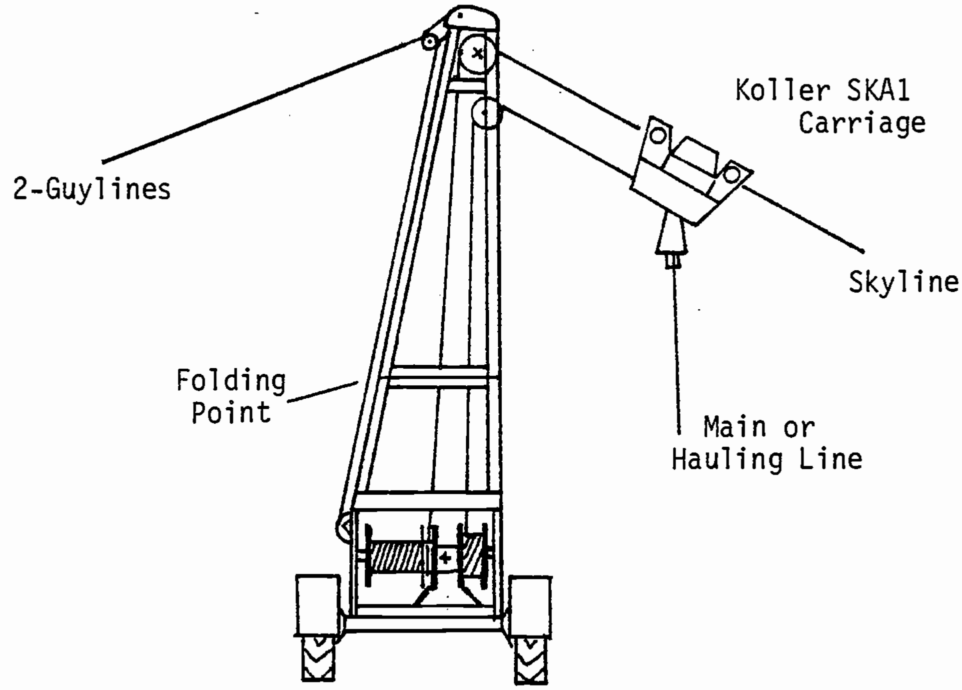
Setting	Commercial Stems Thinned			% of Original Stand Removed	
	Ave. number per acre	Ave. DBH	Ave. Volume per acre (Cu. Ft.)	number of stems	Volume
10-210-12	153	8.12	1,875	39.9%	20.7%
7-214-1 *	260	6.69	1,999	52.0%	28.7%
7-214-3	120	8.04	1,600	44.2%	28.4%
7-214-5	130	9.56	2,370	51.9%	32.6%
7-214-7	190	9.45	2,979	52.6%	39.5%
7-214-9	200	8.35	2,689	51.0%	37.3%
Weighted Averages for Total Area	165	8.30	2,159	47.2%	29.5%

* Used as practice corridor for "hot-yarding" operation.

HARVESTING EQUIPMENT

All thinning, felling and bucking in this study utilized Stilh-041 anti-vibe power saws with standard bars. The yarding was done using a Koller K-300 trailer mounted yarder and tower with a self contained 65 horse power gasoline engine. A Koller SKAI, self clamping 1 ton carriage was used in conjunction with a 16 mm (approx. 5/8 inch) standing skyline. The main or hauling line consisted of 9.5 mm (approx. 3/8 inch) wire rope. Figure-5 lists the pertinent specifications for the yarder and carriage. The swing operation at the landing employed a JD-440 rubber tired skidder with up to six 12 foot chokers.

Skyline corridors were laid out and profiles measured during the planning stage of the project. Payload analysis, using the Multispan Skyline Analysis Program (Sessions, 1978) on a Hewlett Packard-9830 desk top computer, indicated maximum net suspended payload capacities of 1.5 to 2.9 kips. The maximum partially suspended payload would be between 4-5 kips. Average turns with both procedures were estimated at around 1050 pounds. These estimates were based on an assumed density index of 54 pounds per cubic foot with a 10 percent factor increase to account for crown weight with whole trees.



Koller K-300 Yarder

Specifications:

Drum Capacity	Skyline	1150 ft. 350 m	5/8 in. 16 mm
	Hauling line	1150 ft. 350 m	3/8 in. 9.5 mm
	Guyline	2 x 100 ft. 2 x 30 m	9/16 in. 15 mm
Line Speed (with load)		630 ft/min. 3.2 m/s	
Tower Height	23 ft. 7 m		
Power Source	65 HP Gasoline Engine, mounted on front of trailer.		
Carriage	Self-clamping multispan with manual slack pull.		
Load Capacity	1 ton		

Figure 5. Yarder and Carriage Specifications.

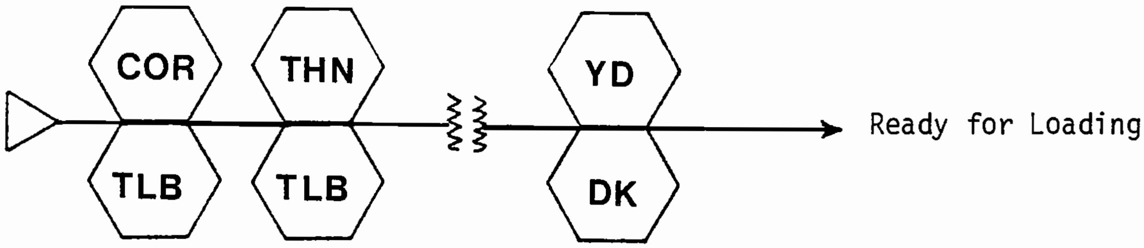
STUDY PROCEDURES

TREATMENTS

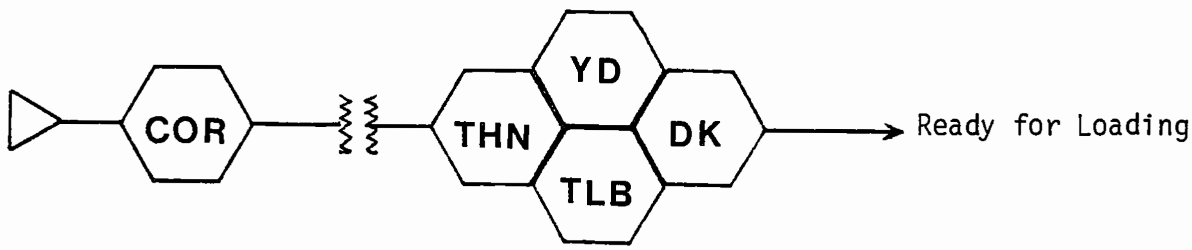
This study examined two approaches to cable thinning in young stands of Douglas-fir. One, the conventional two phase method where the felling and bucking activities are done in advance of yarding. The other, the "hot-yarding" procedure that combines the two activities into one operation. In "hot-yarding" trees are felled (thinned) and yarded to the landing whole tree. A rubber tired skidder then swings them from the landing deck to a processing area where they are limbed and bucked. From there the skidder sorts the processed logs and decks them ready for loading. In both methods the skyline corridor is felled sometime before the start of the yarding operation. The objective of this study was to look at and compare these different treatments. Therefore other aspects of the harvesting process, including planning, road changes, loading and hauling are not included in this analysis. Figure-6 outlines the flow of events for both approaches from felling through logs being placed in final loading decks.

In the "hot-yarding" portion of the study, two corridor widths were examined. These were 10 foot and 20 foot widths. This was done to see if wider corridors would prove beneficial in yarding whole trees. Originally it was planned to collect data on two replications of each treatment. Because of time limitations only one corridor of conventional thinning was completed during the study period. Specific treatment assignments and required crew size for each setting are given in Table 2.

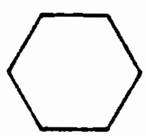
Conventional Thinning

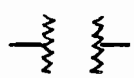


"Hot Yarding"



Where:  = Start

 = Individual Activity

 = break in the flow of Activities

— touching figures indicate those activities occur during the same time period.

COR - Felling and Clearing the skyline corridor.

TBL - Topping, limbing and bucking commercial stems.

THN - Thinning trees to be removed.

YD - Yarding cut stems to the landing.

DK - Decking yarded stems into piles ready for loading.

Figure 6. Flow of Thinning Activities.

Table 2. Treatment Assignments and Crew Size.

Corridor No.	Treatment		Crew Size (No. Persons)
	Thinning Method	Corridor Width	
10-210-12	Conventional	10 ft.	2 person
7-214-1[1]	Hot-Yarding	10 ft.	4 person[2]
7-214-3	Hot-Yarding	10 ft.	4 person
7-214-5	Hot-Yarding	10 ft.	4 person
7-214-7	Hot-Yarding	20 ft.	4 person
7-214-9	Hot-Yarding	20 ft.	4 person

[1]Used as a practice unit for crew to become familiar with the technique.

[2]Includes skidder operator.

CREW ASSIGNMENTS

In this study it was assumed that the same crew size was utilized in all phases of the thinning operation, except corridor felling. This activity was to employ only two persons. The other pair in the four person crew were assumed to be involved in various rigging and road change activities during this time. This was used for a more realistic comparison in the corridor falling element. Differences in road change times or associated cost were not used in this comparison due to a lack of valid data. In this operation crew members switched jobs from day to day, except the skidder operator. Table 3 identifies the specific assignments for each crew member during each phase of the thinning operation.

Table 3. Crew Assignments.

Crew Member ... 1 - Yarder operator
2 - Choker setter
3 - Faller
4 - Skidder operator

⬡ = Activity assignment ▽ = Available for assistance

OPERATION: ACTIVITY	YARDING METHOD					
	Conventional		"Hot-Yarding"			
	1	2	1	2	3	4
Corridor Clearing:						
Falling	⬡	⬡		⬡	⬡	
Limb & Buck	⬡	⬡				⬡
Slashing	⬡	⬡		⬡	⬡	
Thinning:						
Falling	⬡	⬡		▽	⬡	
Limb & Buck	⬡	⬡				⬡
Yarding & Swing:						
Operate Yarder	⬡		⬡			
Pull line		⬡		⬡	▽	
Hook		⬡		⬡		
Resets		⬡		⬡	▽	
Unhook	⬡		⬡			▽
Deck Maintenance	⬡					⬡
Swing						⬡
Sort & Deck						⬡

DATA COLLECTION

Detailed time study data was collected on the following operational phases: conventional corridor felling, conventional thinning, whole tree felling and the yarding operation of each method. Times were recorded to the nearest 1/100th of a minute using the "snap back" procedure of continuous timing. The same person served as timer and recorder throughout the study. Each regular activity in a given operation was timed separately. Breaks in the normal flow of events were also timed and recorded under specific delay codes. Information was also recorded on a set of independent variables associated with each regular sequence of events. The definition of each activity element, independant variable and delay code remained constant throughout the study. These will be defined in subsequent discussions on each operation.

For efficiency in data collection all volume calculations used in this study are based on butt diameter measurements. In the conventional thinning portion, log length is also required. Volumes are estimated by use of regression equations based on these parameters (Appendix A). These regressions were developed from falling studies done in the immediate area specifically for this purpose (Gibbons, 1981).

The swing, processing and decking component of the "hot-yarding" method was not examined in detail as part of this study. The swing operation takes place concurrent with the yarding function. A previous study showed that the production capacity of the swing operation far exceeded that of the Koller yarder (McIntire, 1981). Therefore only those instances where swing activities interfered with the normal flow of the "hot-yarding" process, were recorded.

FELLING AND BUCKING OPERATIONS

Differences in the timing and location of various activities associated with the felling and bucking operation is a distinguishing feature between "hot-yarding" and conventional thinning. In general this operation entails three distinct functions; skyline corridor clearing, thinning the remaining area and processing felled commercial stems into a state ready for transport. Both techniques follow this same sequence of events but as the diagram in Figure 7 illustrate definate differences exist.

On the setting using conventional thinning detailed time studies were conducted on both the corridor clearing operation and regular thinning. Total falling, limbing and bucking time per commercial tree was the dependent variable of interest. This time is the sum of the following elemental activity times recorded for each tree:

Move & Select (MS)	This is the time expended in moving from the completion of the previous activity, selecting the next tree to be cut, and preparing to fall the tree. It ends when the first cut on the new tree is started.
Cut & Wedge (CW)	This is the time it takes to cut, wedge and fall the tree to the ground. It ends when the tree hits the ground or the faller walks away from it unfelled.
Buck & Limb (BL)	This includes the time spent sizing up the tree, limbing, measuring and bucking it. It ends when the bucker walks away from the downed tree.

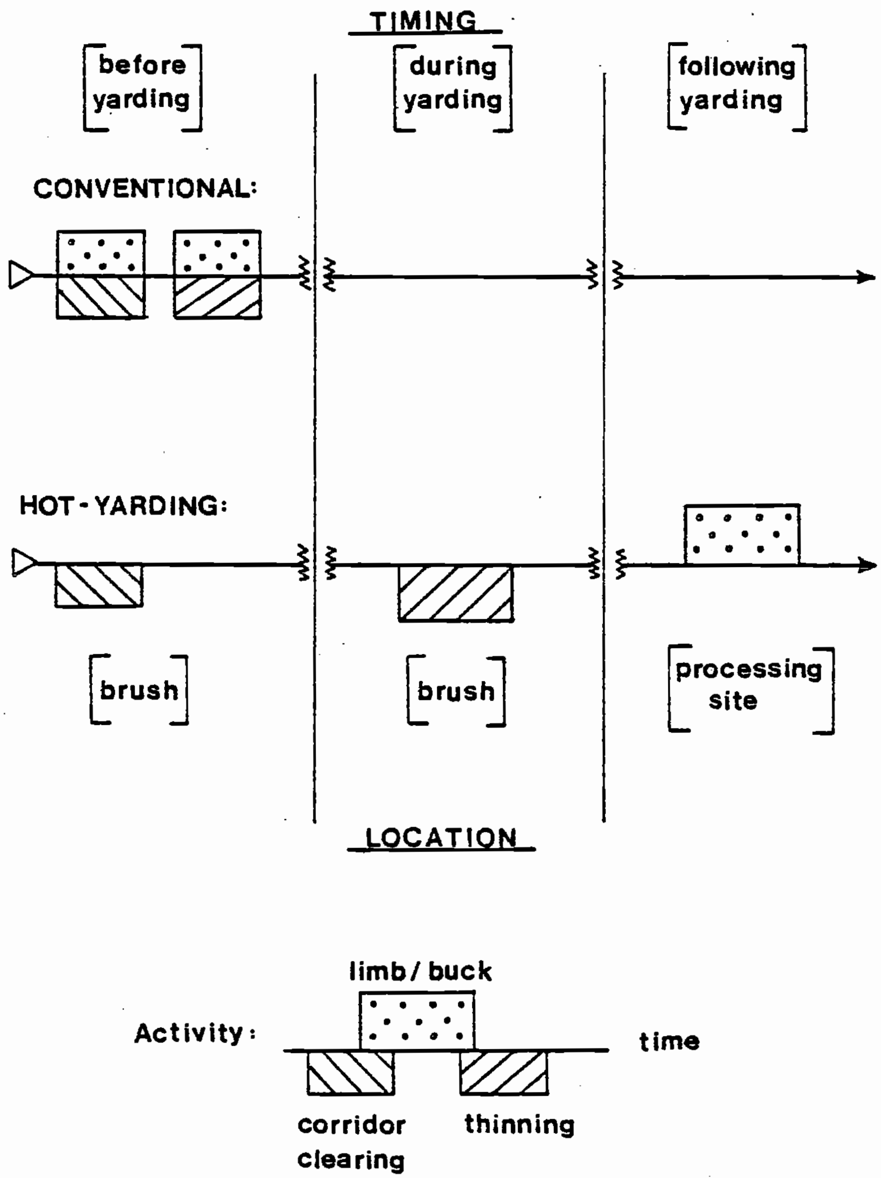


Figure 7. Felling & Bucking Location and Timing Comparison.

Data was also collected on five independent variables, delays and codes recorded for two indicator variables. Indicator variables are often used to code information that is non-quantifiable or to group data into characteristic sets or classes. In this study the indicator variables used were:

Left Hung (LH)	Indicating that the tree was initially left hung (not felled to the ground) following the cutting element.
Stand Condition (SC)	A numeric code expressing the relative degree to which the stands density impeded the felling process.

The independent variables recorded were measurable factors that were suspected to influence the time required to fell a given tree. These were recorded for both the corridor and thinning operations of the conventional approach. The following describes the information gathered on each:

Diameter (DIA)	This is the inside bark, butt diameter of the felled tree recorded to the nearest inch. Diameters and lengths of each log segment were also taken to calculate gross volume.
Number of Buck Cuts (NB)	The number of log segments bucked from the felled tree.
Move Distance (MD)	The estimated total distance (in feet) traveled by the feller during the move & select element.

Number of Limbs (NL)	The approximate number of limbs per tree removed by the faller.
Volume (VOL)	Total gross volume per tree (in cubic feet) as estimated by the derived regression equations.

Delay time was also recorded to the nearest 1/100th of a minute. The type of delay, the tree number it was associated with and the regular falling element in which it occured were noted. The same delay codes were used in all falling and thinning studies conducted for this project. Table 4 lists the various types of delays encountered in these activities.

FELLING AND BUCKING OPERATIONS (HOT-YARDING)

In "hot-yarding" the corridor is first cleared, felling trees downhill and leaving them in a whole tree state. The remaining area is thinned in conjunction with the yarding operation. Trees are yarded to the landing, whole tree, then taken to a processing site where they are topped, limbed and bucked (Figure 7).

Because the two operations occur simultaneously and in the same area, thinning was included as part of the yarding operation in the "hot-yarding" approach. No effort was made to determine the felling time per tree. Instead, an additional element (cut) was added to the yarding cycle. This element was defined as the time that the regular yarding cycle was held up by the thinning operation. In this way thinning activities are merged into the yarding, yielding only one operation.

In a similar sense the limbing and bucking acitivites on

Table 4. Felling Delays.

Delay Code	Description
MTC	Equipment (saw) maintenance.
INSP	General inspection of area.
SLSH	Slashing - felling and treating hardwoods or unmerchantable stems.
HGUP	Hang up - time spent trying to get a tree down after initial efforts.
LBH	Limbing and bucking Hang ups.
WLK	Walking in/out.
AID	Assisting another cutter.
BRK	Break, rest or visiting.
PREP	Preparation - organizing or moving equipment to a new location.
FUEL	Fuel/oil saw.
INST	Instructional - direction or consultation.
SUP	Supervisor delay.
EQP	Equipment delay - thrown chain, broken saw, repairs or adjustments.
WDG	Wedged saw bar.
NTCH	Cutting and notching anchor or guyline stumps.
LGB	Long Butt - extra buck cut to size logs to Yarder capacity.

previously yarded trees occur at this same time. In this study they are accounted for by the swing operation. The swing function was presumed to be time dependent on the yarding, which proved to be the case. Therefore the felling and clearing of the corridor is the only falling and bucking activity not accounted for by yarding time in the "hot-yarding" study.

Because of scheduling conflicts, data on the actual clearing of the "hot-yarding" corridors was not obtained. To compensate for this, falling data on whole tree felling from another study was substituted in its place. The study was conducted on an adjacent unit and utilized the same fallers. It examined a whole tree thinning operation where no extra effort was taken to get hangups to the ground. Because of this it was felt production rates derived from this data would be a conservative estimate of whole tree felling in a corridor. Therefore all corridor felling rates and figures in the "hot-yarding" portion of this study are based on this data.

YARDING

The yarding operation of both the conventional and "hot-yarding" techniques was examined in detail. Times were recorded for each element in the yarding cycle along with any delays that occured. Information was also collected on a set of independent and indicator variables for each turn. Both yarding operations had similar activities and sequence of events. However, the "hot-yarding" includes one additional element in the total cycle time and whole trees are yarded to the landing. Again variable definitions and codes remain constant for both studies. The dependent variable in each operation is total (delay free) turn time. In this study "resets" were included as an element in total turn time because of their frequency of occurrence and large impact in total yarding time.

In conventional yarding the delay free turn time equals the summation of the times involved in seven distinct events. Figure 8 shows the typical flow of these events through a yarding cycle and the general location in which they occur. In the time study these events were called elements and were specifically identified in the following way:

<u>Outhaul</u> (OH)	Time required for the carriage to travel from the landing to the location along the corridor where the next turn was to be hooked. It began when the carriage was released at the landing and ended when it was clamped to the skyline and the bell released.
<u>Lateral Out</u> (LO)	Time taken to pull the line and choker from the carriage position to the farthest log to be hooked. It ended when the first log to be hooked was touched by the choker setter.
<u>Hook</u> (HK)	This was the time taken to set the chokers (hook) on each piece to be included in turn. It was completed when the signal was blown for the yarded operator to begin bringing in the turn.

<table>
<tr><td><u>Lateral In</u>
(LI)</td><td>The time it took to yard the turn from the hook site to the carriage. Often this element was interrupted by resets or hooking additional pieces. In such cases timing was stopped, then resumed when the turn was again moving towards the corridor. This element ended when the turn was clamped into the carriage, and the carriage unclamped from the skyline.</td></tr>
<tr><td><u>Reset</u>
(RS)</td><td>The reset element did not occur on every turn. It is defined as the time required to manipulate an obstructed or otherwise delayed turn until it again regained it's normal movement. It began when the STOP signal was given the yarder operator and concluded when the turn was again moving properly.</td></tr>
<tr><td><u>Inhaul</u>
(IH)</td><td>This element began when the incoming turn was secured to the carriage and the carriage was unclamped from the skyline. It ended when the carriage was again clamped and the turn released from the carriage at the landing.</td></tr>
</table>

Unhook (UK) — This element was the time required for the yarder operator/chaser to unhook the turn and start the next cycle. It began at the end of Inhaul and ended when the carriage was again released from the skyline.

As was noted, the yarding cycle in the "hot-yarding" technique contains an additional element. This was needed to account for the effect the coincident thinning operation might have on the yarding. Therefore the following element is included in the set of dependent variables for the "hot-yarding" method:

Cut (CT) — Defined as any time during the regular yarding cycle where the normal flow of events are suspended because of the thinning operation. It begins when normal yarding activities cease and ends when the current yarding element starts again.

Generally this situation occured between the Lateral Out and Hook elements. Occasionally however, the falling of trees would interrupt other activities, but this was not found to be a frequent problem.

INDEPENDENT YARDING VARIABLES

In the yarding study information was collected on a set of seven independent variables [Table 5 (a)] and four indicator variables [Table 5 (b)]. These were recorded on a turn by turn basis. Some of the variables such as Surface Condition and Deck influence would

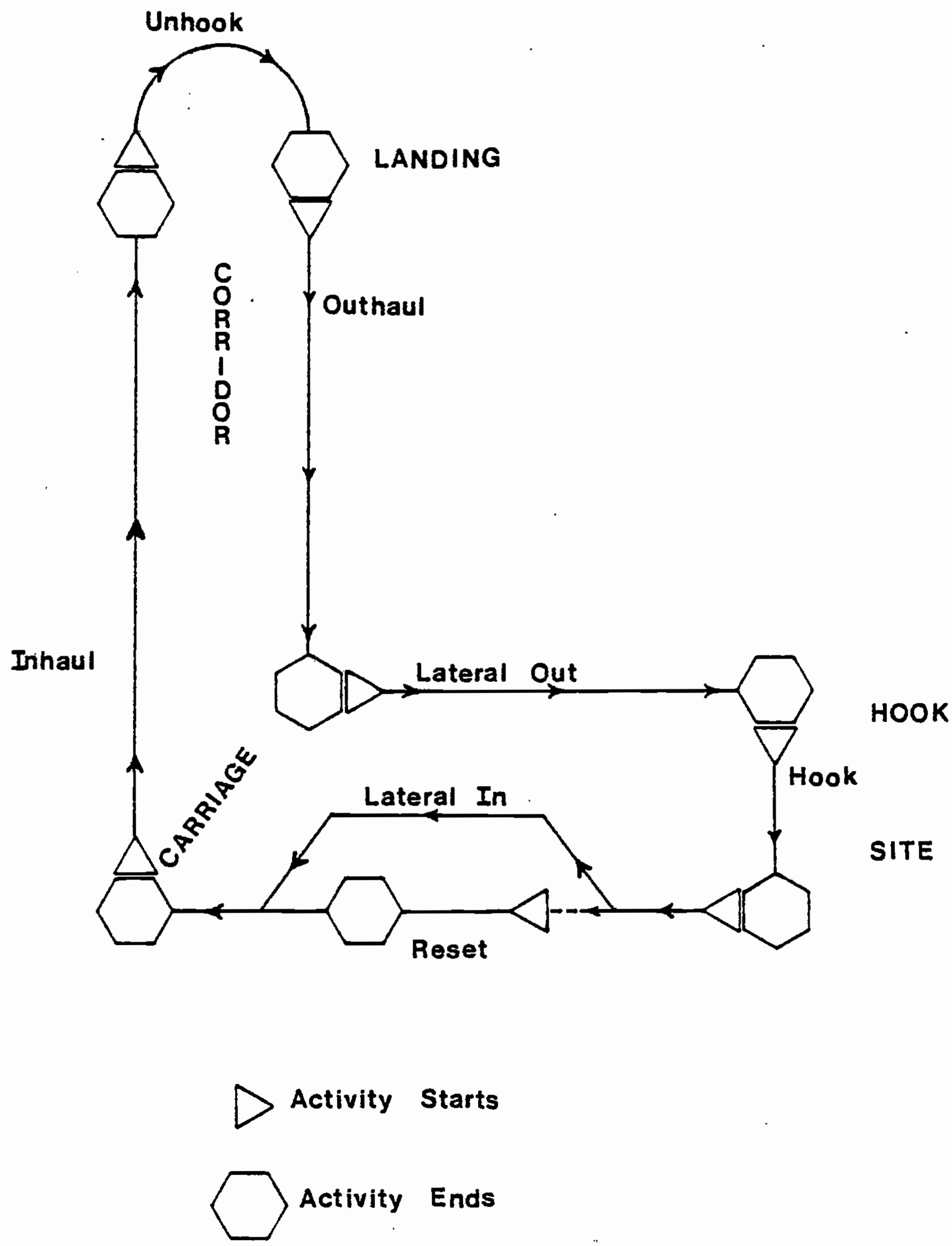


Figure 8. Yarding Cycle Activities.

Table 5(a). Measurement Variables.

Variable	units	Description
Slope Distance (SD)	feet	Slope distance from the landing to clamped carriage position.
Line Distance (LD)	feet	The length of line pulled from the carriage to the hook site.
Number logs (NL)	pieces	The number pieces (logs or whole trees) successfully yarded per turn.
Lead Angle (LE)	degrees	The lower angle made between the tag line and sky line.
Log Angle (LG)	degrees	The angle made between the log axis and tag line extension on the most critical log per turn.[1]
Volume (VOL)	cubic feet	The sum of the volume of all pieces per turn calculated to two decimal places.
Reset (RE)	number	The number of resets per turn.

1 - "Critical log" is the log in each turn that appears to exert the greatest opposition to being moved, due to its size and/or its lay.

Table 5(b). Indicator Variables Used in the Yarding Studies.

Indicator Variable	Description and Codes
Deck (DK)	Rates the degree to which the landing deck size and shape appear to hamper the yarding operation 1 - little or no deck maintenance needed 2 - infrequent deck maintenance needed 3 - frequent deck maintenance required
Surface Condition (SC)	Rates the moisture condition of the ground surface 1 - dry, firm soil 2 - moist, slightly wet 3 - very wet, muddy and slippery
Surface Type (ST)	Rates the comparative number of surface obstructions (old logs and stumps)[1] 1 - less than an estimated 100 per acre. 2 - estimated 100-200 per acre. 3 - estimated greater than 200 per acre.
Hot Yard (HY)	Identifies those turns where trees were yarded off the stump or from a "hung up" position.[2] "blank" - normally yarded turns. 1 - "Hot-Yarded" turns.

1 - Estimates made only periodically not on a turn by turn basis.

2 - When "hot-yarded" from a vertical position greater than 45° with the horizontal the Log Angle was recorded as zero.

remain constant for extended periods of time. Volume, Lead Angle and Log Angle were calculated from data obtained during the study. Volume again was based on butt end diameters and the regression equations mentioned before (Appendix A.). Angles were derived from compass readings taken in the field and apply as shown in the following figure.

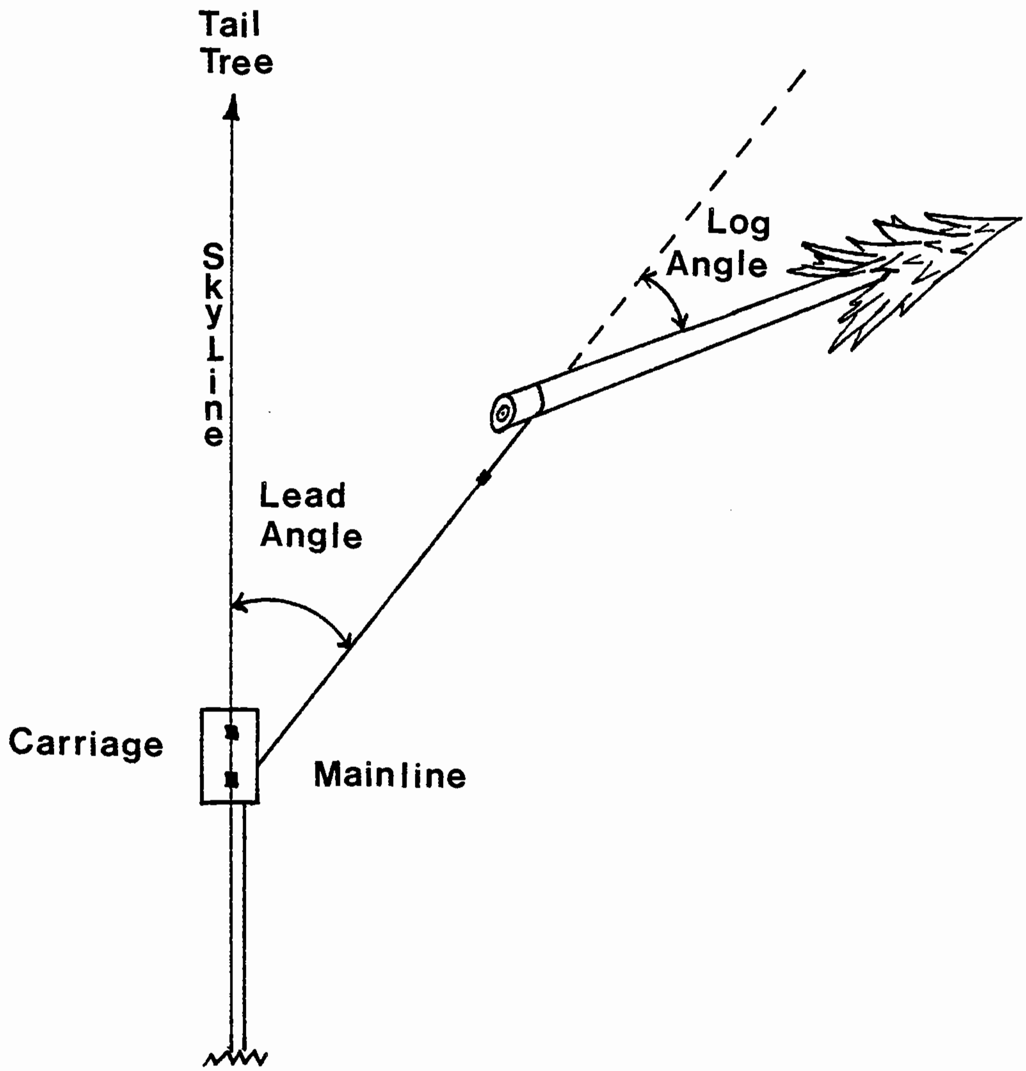


Figure 9. Lead Angle and Log Angle.

Slope Distance and Line Distance were estimated to the nearest five feet. This was done by premeasuring and marking distances along the skyline corridor and by painting the mainline in 25 foot intervals. Actual line distance, from the carriage to the hook site, was used in this study rather than lateral distance perpendicular to the corridor. It was felt that this measurement of the lateral parameter would yield a better predictor in regression development as it more accurately represents distances involved.

The Hot Yard indicator was used only in the "hot-yarding" studies. It was added following observation of the trial unit where the crew became familiar with the "hot-yarding" technique. It was noted at that time that the inhaul elements of the yarding cycle seemed to go smoother when trees were yarded from an upright position. The significance of this assumed effect are presented in the analysis portion of this paper.

YARDING DELAYS

Each delay in the normal yarding cycle was recorded as to type, the turn number and yarding element in which it occured and time until a regular yarding activity was resumed. A total of 39 specific types of delays were recorded during the study. For convenience these were later grouped into the nine categories described in table 6.

SWING OPERATION

As was noted, the swing operation in the "hot-yarding" technique was not studied in detail. Only the time that this operation caused delays in the yarding cycle was recorded. For analysis the production

Table 6. Yarding Delay Categories.

Delay Category	Types of Delays Included
Equipment	1) Yarder or Carriage maintenance. 2) Yarder or Carriage malfunction. 3) Yarder or Carriage repair.
Landing	1) Landing deck maintenance. 2) Choker or turn caught in the deck. 3) Non-identified delays at the landing.
Line & Rigging	1) Line repair. 2) Fouled line or hang up on lines. 3) Raise/lower skyline. 4) Lost choker. 5) Wait for rigging. 6) Problems with tail tree or intermediate support.
Operation	1) Carriage cycling/reposition. 2) Resets in excess of 10 minutes. 3) Cutting required to free turn. 4) Pull main line slack to lower chokers. 5) Lost log. 6) Non-specified working delay.
Instruction	1) Supervision, instruction, consultation.
Personnel	1) Wait on yarder operator. 2) Rests /water breaks.
Felling	1) All delays caused by the thinning operation not included in the cut element.
Swing	1) All delays caused directly by the swing operation.
Miscellaneous	1) Gathering/moving equipment. 2) Walking in and out. 3) Area surveillance and turn planning.

rate for the swing, processing, sorting and decking activities were assumed equal to the yarding rate on a volume per time basis. In addition it was assumed that yarding and swing operation times were equal. All costs of the swing operation were to be added to the other thinning costs.

Actual production rates from studies on other swing operations indicate the above assumptions are very low. McIntire (1981) suggested that the skidder and operator could be utilized in other activities for as much as 70 percent of the yarding time. This suggests that costs charged to the thinning project from the swing operation in this study, may be higher than would normally need to be charged. This however would only be the case if the skidder and operator could be partially financed by some other activity.

ROAD CHANGES

Pre-rigging and road change activities were not included in this study. Because of various interruptions and outside assistance during these operations the data collected was not considered representative. Therefore the comparisons made in this study are based on stump to loading deck activities for a single setting only. Differences in road change times may exist between the two methods but this would have to be identified by future studies.

PROCEDURES PECULIAR TO THIS STUDY

The following section documents those aspects of the study that seemed peculiar to this individual operation. This is done to give the reader a better feel for what actually took place. As a research project, there were several features that were not felt to be characteristic of an actual operation. The first of these was crew experience. The crew consisted of forest engineering students working as a crew for the first time. Though dedicated and hard working, they lacked the practical woods experience of a seasoned crew. Another concern was work time consistency. Because the crew was employed by the school forest they were often required to perform other jobs throughout the course of the project. This resulted in many partial work days. In this respect it was not indicative of a regular operation. As the operation had visitors from time to time, there was a tendency for good willed outside help with various tasks. If this interference was significant, information recorded during that time was identified and later dropped from the data base prior to analysis. No attempt was made to account for the other aspects mentioned above.

ANALYSIS PROCEDURES AND TESTS

REGRESSION MODELS

The main objective of this analysis was to compare the production and costs of the thinning techniques studied. For this comparison to be meaningful an estimate of the performance of both techniques on the same set of conditions is needed. Multiple linear regression was used to derive equations that could provide these estimates. Based on the data obtained from the time studies, a regression equation was developed for each operation. This was done using the REGRESS subsystem of the Statistical Interactive Programming System (SIPS) and the forward STEPWISE procedure (Rowe, 1981). The Control Data Corporation 3300 computer (Cyber Operating System) at the Milne Computer Center, Oregon State University was used for this and other computer functions.

The general multiple linear regression model is presented in figure 10. In addition the basic assumptions of least squares regression are outlined. Appendix B details the various statistical tests used in connection with the regression models and other aspects of this analysis.

The process of selecting the "Best" model (regression equation) endeavored to:

a) maximize the coefficient of multiple determination (R^2).

b) minimize the mean square of residuals (MSE).

c) minimize Mallows' (Cp) criterion (Snedecor and Cochran, 1980). (Appendix B)

<u>General Linear Regression Model</u>

$$\boxed{Y_i = B_o + B_1X_{i1} + B_2X_{i2} + \cdots + B_pX_{ip} + E_i}$$

where: i = the $i^{\underline{th}}$ observation out of n total observations.

p = the number of independent variables in the model.

Y_i = value of the dependent (response) variable in the $i^{\underline{th}}$ observation.

$X_{i1}, \cdots, X_{ip}$ = set of values for the independent variables in the $i^{\underline{th}}$ observation.

$B_o, B_1, \cdots, B_p$ = model parameters (coefficients).

E_i = random error associated with the $i^{\underline{th}}$ observation.

<u>Assumptions in Least Squares Regression</u>

1) Values for independent variables ($X_{i1}, \cdots, X_{ip}$) are measured without error.

2) That (E_i)
   a) are independent.
   b) have a mean = "0".
   c) have a constant variance σ^2.
   d) are normally distributed.

Figure 10. Multiple Regression Model and Least Squares Assumptions.

In addition only variables with regression coefficients significantly different from zero at the 0.05 probability level were retained in the model. This was determined using the students "t" test statistic (Appendix B).

These models estimate average delay free times based on a given set of independent variables. For the thinning and corridor felling operations these times represent the total felling time per tree. The equations for yarding estimate average turn time. Through algebraic manipulation, equations estimating average time per unit volume were constructed for each operation. In this form it is possible to estimate delay free activity times per unit volume based on the same set of conditions. By combining the appropriate equations for each alternative, production estimates were arrived at and confidence intervals determined. Hourly costs associated with each operation can be applied to these results for economic comparison.

VALIDATION

The "prediction bias" in the yarding models was evaluated to determine their suitability as estimators (Netter and Wasserman, 1974). A random subset of approximately 80 percent of the total data in each yarding study was used to build the regression models. The remaining 20 percent was used to test the predictive power of the models. This was done using a paired "t" test (Appendix B) on the means of the observed values paired with estimated values from applying the models to this data. If the difference between the means proved significantly different from zero it would indicate that the use of that equation outside the set of data upon which it was based should be suspect.

Due to lack of replications and a limited data base, the falling regression models were not validated in the above way. Instead they were tested for "Lack of Fit" (Appendix B) to determine their applicability to the data sets from which they were derived (Netter & Wasserman, 1974). These equations were only to be used in estimating values for sets of data found within the original record. Therefore it was felt this approach was suitable.

DELAYS

Delay times were equated to a percentage of total productive time for each operation. This assumes that delay times represent a constant proportion of expected times throughout the range of the operation. Under this assumption average delay time for any estimate of the dependent variable is simply a matter of multiplication. Though the above assumption is not truly valid, a realistic way to more accurately account for delays, especially random delays like yarder breakdown, was not found. An effort was made however to eliminate some of the effects of random, non-treatment related delays in the yarding study. It was noted that delays of this type, though not related to the treatment under investigation, had a large influence on total time production rates. To eliminate this effect, delays in this category were combined from all treatments and expressed as a percentage of the combined total productive time (Figure 11). It was felt that this allowed for a better comparison of treatment effects in the analysis.

A) Type of Delays Included:

- Yarder repairs
- Carriage repairs
- Line repairs
- Maintenance
- Supervision
- Broken tailtree
- Pulling slack
- Equipment malfunction
- Rigging
- Reset intermediate support

B) Non-treatment Delay Time Summary

Thinning Method	*Σ Turn Times	NON-TREATMENT DELAYS % Frequency[1]	*Σ Delay Times	% of Total Delay Time
KYREG[2]	1,122.64	13.2%	327.79	53.8%
HYTEN[3]	1,761.91	7.0%	171.42	34.8%
HYTNY[4]	1,279.11	20.9%	133.32	37.7%
Total Σ =	4,163.66		632.53	

C) Percent of Productive Time (% PT)

$$(\%\ PT) = \frac{\text{Total } \Sigma \text{ Delay Times}}{\text{Total } \Sigma \text{ Turn Times}} (100\%)$$

$$= \frac{632.53 \text{ min.}}{4{,}163.66 \text{ min.}} (100\%)$$

$$\boxed{= 15.19\% \text{ of Productive Yarding Time.}}$$

1. Percentage of turns having non-treatment delays.

2. Conventional yarding, 10 ft. corridor.

3. "Hot-yarding", 10 ft. corridor.

4. "Hot-yarding", 20 ft. corridor.

Figure 11. Non-treatment Related Delays.

ELEMENTAL ANALYSIS

The objective of this analysis was to identify specific differences between the procedures and determine what factors appeared to be significant. The approach used was to examine the individual elements of the dependent variable. Regression models were developed for each element to identify the independent variables most closely associated with its variation. Mean values between treatments were tested for significant differences using a non-paired "t" statistic (Appendix B). If these values proved significantly different the average values of the predictor (independent) variables were tested. When these were shown to be unequal, expected values over the same set of predictor variables were determined from the regressions. These values were then compared between treatments to see if there was still a disparity. In this way specific differences between the methods were identified. Possible factors influencing these differences were also isolated, allowing speculation as to areas where improvements in the technique might be made.

STUDY RESULTS

FELLING STUDIES

In the felling operations total delay free felling time (TOT) per tree was used as the dependent regression variable. This variable (TOT) was defined as the sum of all elemental activity times per tree. In the conventional thinning (KFTHN) and corridor felling (KFCOR) operations this included the times for Move & Select (MS), Cut & Wedge (CW) and Buck & Limb (BL). For whole tree felling (WTFALL), used to estimate corridor felling time in the "hot-yarding" procedure, it comprised only Move & Select and Cut & Wedge times. Table 7 contains a summary of the results of these studies for the time elements.

The independent variables used to build the regression models for the falling studies are described in the Study Procedures. In the whole tree study only Diameter (DIA), Move Distance (MD) and Volume (VOL) could be used as potential predictor variables. The other variables either remained constant during the study or did not apply to the whole tree operation. Table 8 describes the average and range of values encountered in the study.

The final regression equations developed for the falling operations are presented in Table 9. From ANOVA tables generated for each model the coefficients of multiple determination were obtained. The regressions were then tested for significant linear relationships using the "F" statistic at the 0.01 significance level (Appendix B). Tests for "Lack of Fit" were then performed. Results of these tests are outlined in Appendix C. Graphical analyses and computer functions were used to evaluate the "residuals" compliance with least squares

Table 7. Descriptive Statistics for Felling Time Elements.

Time Element	Operation	n[1]	Maximum Time (Min.)	Maximum Time (Min.)	Average Time (Min.)	Standard Error of Mean
Move & Select (MS)	KFTHN[2]	49	7.39	0.00	1.5798	0.21127
	KFCOR[3]	37	6.36	0.00	1.7868	0.20838
	WTFALL[4]	105	5.83	0.00	1.3072	0.11442
Cut & Wedge (CW)	KFTHN	48	6.69	0.51	2.2815	0.22191
	KFCOR	37	9.64	0.00	2.7843	0.39832
	WTFALL	104	5.33	0.44	1.6734	0.09903
Buck & Limb (BL)	KFTHN	48	7.34	0.62	3.2408	0.22879
	KFCOR	38	15.69	1.32	4.4455	0.48692
Total Time per Tree (TOT)	KFTHN	46	17.47	2.32	7.1133	0.47754
	KFCOR	37	23.02	2.13	9.1011	0.85160
	WTFALL	104	9.63	0.81	2.9859	0.17272

1 - number of observations.

2 - conventional thinning with limbing & bucking.

3 - conventional corridor felling with limbing & bucking.

4 - whole tree felling.

Table 8. Summary of Independent Variables from Felling Studies.

Variable	Felling Operation	Range		Average or Mode	Standard Error of Mean	n
		Max.	Min.			
Diameter (DIA) (in.)	KFTHN	14	6	8.49	0.2753	49
	KFCOR	20	6	11.11	0.5680	38
	WTFALL	16	6	8.30	0.2088	105
Move Distance (MD) (ft.)	KFTHN	135	2	42.60	4.8645	50
	KFCOR	120	-0-	48.65	5.3083	37
	WTFALL	130	-0-	30.0	2.6985	105
Volume (VOL) (ft^3)	KFTHN	34.86	2.88	10.91	0.9809	48
	KFCOR	53.00	3.94	19.31	2.1781	38
	WTFALL	38.15	4.02	9.32	0.6081	105
Number Buck Cuts (NB)	KFTHN	2	1	1.35	0.0759	48
	KFCOR	2	1	1.5	0.0822	38
Number of Limbs (NL)	KFTHN	95	-0-	36.72	3.3560	43
	KFCOR	126	5	57.97	5.4351	31
Stand Condition (SC)	KFTHN	3	1	2 (mode)	-	50
	KFCOR	3	1	2 (mode)	-	38
Left Hung (LH)	KFTHN	1	0	0.44	0.0709	50

Table 9. Final Regression Models for Felling Operations.

Falling Operation	n[1]	MODEL	Regression Coefficient	Independent variable	coef. sig. level[2]	From A NOVA Table
THINNING (KFTHN)	46	TOT[3] =	+ 2.44263	constant		R^2 = 0.6416
			+ 1.44443	(LH)	*	
			+ 0.28333	(VOL)	***	MSE = 4.0281
			+ 0.00036	$(MD)^2$	***	
CORRIDOR FELLING (KFCOR)	37	TOT =	- 4.95373	constant		R^2 = 0.7091
			+ 1.25308	(DIA)	***	MSE= 8.0277
WHOLE TREE FELLING (WTFALL)	104	TOT =	+ 1.31151	constant		R^2 = 0.3889
			+ 0.03357	(MD)	***	
			+ 0.07097	(VOL)	**	MSE = 1.93345

1 - number of observations on which the model is based.

2 - level that regression coefficients significantly differ from zero.

* = .05 significance level
** = .01 significance level
*** = .001 significance level

3 - expected average (delay free) felling time in minutes per tree.

assumptions (Appendix B).

Falling delays were totaled for each study and expressed as a percentage of total productive time. Time spent clearing unmerchantable stems and non-commercial species (slashing) was treated as a delay in all three operations. Also included with regular falling delays was time taken to notch guyline anchor stumps for the tailtree and intermediate support. Figure 12 lists pertinent information on falling delays and outlines the procedure followed to determine the percentage factors.

YARDING STUDIES

The development of regression equations from the yarding data used total (delay free) turn times (TTT) as the independent variables. The various elements that comprise this time are described in the Study Procedures. As noted, the time normal yarding activities waited on the thinning operation (CT) was included in total turn time in the "hot-yarding" method. Total turn time (TTT) is expressed in delay free minutes per complete yarding cycle. Individual element times were recorded to the nearest 1/100th of a minute. Descriptive values for these time elements are given in Table 10 for conventional yarding (KYREG), "hot-yarding" with a 10 foot corridor (HYTEN) and "hot-yarding" with a 20 foot corridor (HYTNY). Figure 13 graphically compares the average percent of total turn time utilized in each elemental activity for the three operations.

To avoid some of the problems of multicollinearity (Netter & Wasserman, 1974) in regression formulation, the coefficient of correlation (r) between all independent variables and with the

FELLING DELAYS

Felling Operation	Ave. (DT) Per Tree	Σ (TOT)	Σ (DT)	% Total Productive Felling Time
(KFTHN)	3.904	327.21	179.58	54.9%
(KFCOR)	4.356	336.74	161.16	47.9%
(WTFALL)	1.547	310.53	160.91	51.8%

$$\% \text{ Total Productive Felling Time} = \frac{\Sigma\ (DT)}{\Sigma\ (TOT)}\ (100\%)$$

where ... Σ (DT) = the sum of the individual delay times in minutes.

Σ (TOT) = the sum of delay tree felling times per tree in minutes.

(KFTHN) = conventional thinning.

(KFCOR) = conventional corridor felling.

(WTFALL) = whole tree corridor felling.

Figure 12. Felling Delay Summary.

Table 10. Descriptive Statistics for Yarding Time Elements.

Time Element	Yarding Operation	n	Maximum Time (Min.)	Minimum Time (Min.)	Average Time (Min.)	Standard Error of Mean
Outhaul (OH)	KYREG	200	1.56	0.00	0.7393	0.0247
	HYTEN	404	1.78	0.00	0.6468	0.0093
	HYTNY	294	1.24	0.00	0.6168	0.0141
Lateral Out (LO)	HYREG	195	2.39	0.09	0.5861	0.0285
	HYTEN	405	3.05	0.03	0.4941	0.0179
	HYTNY	298	2.50	0.00	0.4505	0.0179
Hook (HK)	KYREG	194	3.65	0.17	0.9584	0.0404
	HYTEN	405	3.20	0.19	0.7261	0.0228
	HYTNY	300	3.58	0.00	0.7790	0.0277
Lateral In (LI)	HYREG	199	1.26	0.06	0.3915	0.0180
	HYTEN	409	1.25	0.00	0.2616	0.0088
	HYTNY	300	1.38	0.00	0.2380	0.0096
Reset (RS)	KYREG	204	9.99	0.00	0.5961	0.0895
	HYTEN	413	9.99	0.00	0.5654	0.0671
	HYTNY	302	9.99	0.00	0.5682	0.0841
Inhaul (IH)	HYREG	204	2.26	0.18	1.0775	0.0366
	HYTEN	411	1.55	0.00	0.8776	0.0140
	HYTNY	301	1.55	0.00	0.7109	0.0189
Unhook (UH)	KYREG	202	3.94	0.19	1.0431	0.0434
	HYTEN	405	1.41	0.00	0.3907	0.0079
	HYTNY	297	1.42	0.00	0.3410	0.0089
Cut (CT)	HYTEN	414	6.05	0.00	0.2775	0.0367
	HYTNY	302	9.86	0.00	0.4898	0.0676
Total Turn Time (TTT)	KYREG	180	15.68	1.41	5.4763	0.1710
	HYTEN	388	17.38	1.33	4.2558	0.1069
	HYTNY	287	19.91	1.50	4.2355	0.1510

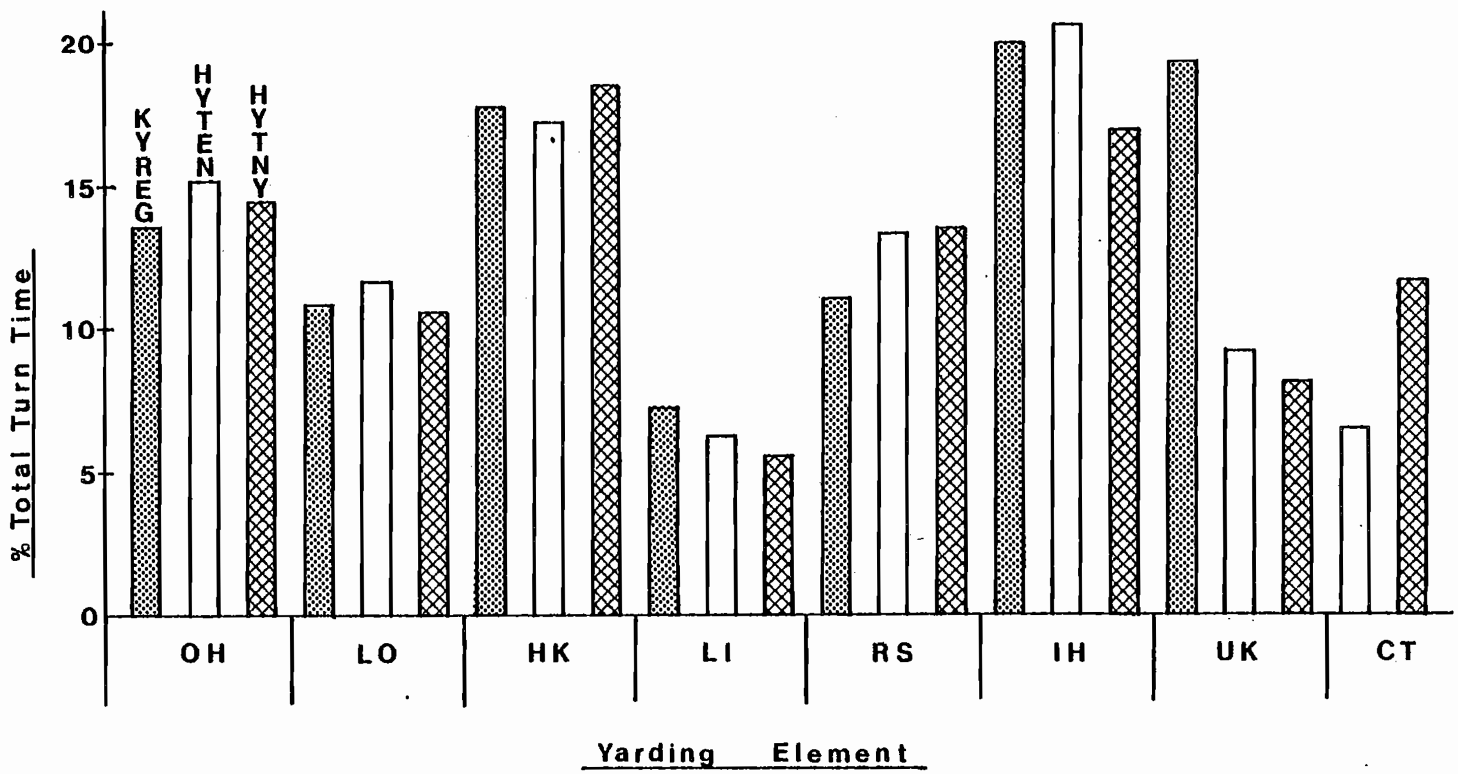


Figure 13. Per Cent Total Turn Time By Activity Elements.

dependent variable (TTT) were examined. Highly correlated independent variables (r>.50) were introduced into the model building process separately. Final model selection was based on the criteria specified in the Analysis Procedures.

Table 11(a) lists the range, average values and standard errors for the quantitative independent variables introduced in the model building process. These variables are described in Table 5(a) under Study Procedures. Indicator variables used are similarly described in Table 5(b). Summary values from the study data for these variables are presented in Table 11(b).

Final regression models developed from the yarding study data are presented in Table 12. These models were tested for significant linear relationships and validated using the method described in the Analysis Procedures. From the results of these tests it was concluded that all three models showed a significant linear relationship with total turn time at the 0.01 significance level. The validation process also showed that these models could be used as valid estimators on sets of independent variables different from those upon which they were based. Specific details on these tests are given in Appendix C. Again, the compliance of residuals to least squares assumptions were examined by graphical analyses and computer methods.

An oddity in the "hot-yarding" 20 foot corridor model (HYTNY) is that the variable Slope Distance (SD) did not enter the final model. This variable was dropped as it failed to meet the established criteria for regression coefficients being significantly different from zero at the 0.05 level (actual significance level was 0.20). Because it was not the next variable entering the stepwise procedure,

Table 11(a). Summary of Quantitative Independent Variables from Yarding Studies.

Variable	Yarding Operation	Range		Average Value	Standard Error of Mean	n
		Max.	Min.			
Slope Distance (SD) (ft.)	KYREG	795	25	382.07	15.9791	199
	HYTEN	605	15	336.50	6.5282	411
	HYTNY	510	5	287.05	8.8276	302
Line Distance (LD) (ft.)	KYREG	165	15	60.93	2.4197	199
	HYTEN	180	10	59.83	1.6766	410
	HYTNY	185	-0-	59.83	1.9960	301
Number Logs (NL)	KYREG	4	1	1.92	0.0452	205
	HYTEN	4	-0-	1.35	0.0289	412
	HYTNY	3	1	1.35	0.0315	299
Lead Angle (LE) (degrees)	KYREG	165	-0-	45.72	2.2450	202
	HYTEN	167	-0-	45.04	1.3605	412
	HYTNY	125	-0-	40.88	1.6289	301
Log Angle (LG) (degrees)	KYREG	166	-0-	39.54	2.6549	201
	HYTEN	172	-0-	18.96	1.4442	412
	HYTNY	155	-0-	11.50	1.4330	301
Volume (VOL) ($ft.^3$)	KYREG	58.07	2.88	19.99	0.7627	205
	HYTEN	50.42	-0-	15.80	0.4378	412
	HYTNY	98.27	4.02	19.16	0.6159	299
Resets (RE)	KYREG	4	-0-	0.45	0.0560	205
	HYTEN	4	-0-	0.35	0.0311	414
	HYTNY	3	-0-	0.27	0.0341	302

Table 11(b). Summary of Indicator Variables from Yarding Studies.

Variable	Yarding Operation	Observed Values		Mode	Numeric Average	n
		Max.	Min.			
Deck (DK)	KYREG	3	1	2	2.1366	205
	HYTEN	3	1	1	1.1763	414
	HYTNY	3	1	1	1.1490	302
Surface Condition (SC)	KYREG	1	1	1	1.0	205
	HYTEN	3	1	1	1.3019	414
	HYTNY	3	1	2	2.2583	302
Surface Type (ST)	KYREG	2	2	2	2.0	205
	HYTEN	3	1	2	2.1135	414
	HYTNY	2	2	2	2.0	302
Hot-Yard (HY)	HYTEN	1	-0-	1	0.5048	414
	HYTNY	1	-0-	0	0.4967	302

Table 12. Final Regression Models for Yarding Operations.

Yarding Operation	n^1	MODEL	Regression coefficient	Independent Variable	Sig. Level[2]	From ANOVA Table
Conventional (KYREG)	127	TTT^3 =	+ 1.47734	constant		R^2 = 0.7392
			+ 0.00561	(SD)	***	
			+ 0.01342	(LD)	***	MSE =
			+ 0.00725	(LG)	*	1.57184
			+ 1.72311	(RE)	***	
Hot-Yard 10 Foot (HYTEN)	299	TTT =	- 0.08495	constant		R^2 = 0.6384
			+ 0.00407	(SD)	***	
			+ 0.01397	(LD)	***	MSE = 1.6458
			+ 0.76795	(NL)	***	
			+ 1.97755	(RE)	***	
			- 0.54048	(SC)	***	
			+ 0.51800	(ST)	*	
Hot-Yard 20 Foot (HYTNY)	217	TTT =	+ 1.25244	constant		R^2 = 0.6247
			+ 0.02276	(LD)	***	
			+ 0.04407	(VOL)	***	MSE = 2.6419
			+ 2.52378	(RE)	***	

1 - Number of observations on which the model is based.

2 - Level that regression coefficients significantly differ from zero.

* = .05 significance level.
** = .01 significance level.
*** = .001 significance level.

3 - Expected avearge (delay free) yarding cycle time in minutes per turn.

it was added to the model independently at various stages. In these trials it still failed to pass the test. The correlation between (SD) and other variables in the final equation was not different than the correlation found between those variables. In the end no concrete explanation could be found as to why Slope Distance was not a good predictor in this study so it was left out of the model.

Yarding delays were also summarized as a percent of total productive yarding time. However, as discussed in the Analysis Procedures and detailed in Figure 11, certain delays that were not felt to be influenced by the treatments under study were pooled and applied as a general factor over all the studies. The remaining delays were treated in the same manner as outlined for falling delays. By combining the general delay factor with those obtained from the remaining (treatment) dealys, total "adjusted" delay factors for each yarding method were obtained. Figure 14 outlines this process and lists the final "adjusted delay factors for each yarding study. Specific information on actual delays encountered in the study (by delay catagory) is given in Appendix D.

Treatment Delays

Yarding Operation	n	m	Ave. (DT) per turn	Σ (TTT)	Σ (DT)	% Factor
(KYREG)	180	120	1.375	985.73	247.56	25.1%
(HYTEN)	388	127	0.777	1,651.26	301.46	18.2%
(HYTNY)	287	77	0.729	1,215.58	209.34	17.2%

n = total # of complete observations.

m = total # of delays.

(DT) = individual delay times in minutes.

(TTT) = delay free turn time in minutes

Adjusted Yarding Delay Factors

(Adjusted Factor = General % Factor + Treatment % Factor)

For...	Total Adjusted Delay Factor =		
(KYREG)	(15.2) + (25.1)	=	40.3%
(HYTEN)	(15.2) + (18.2)	=	33.4%
(HYTNY)	(15.2) + (17.2)	=	32.4%

Figure 14. Adjusted Yarding Delay Factors.

COMPARATIVE ANALYSES

BASIS FOR COMPARISON

To compare the different thinning procedures looked at in this investigation, some common denominator between felling, yarding and swing operations must be employed. For this study, operation time per unit volume of total thinning output was used as this measure. Thinning output in this sense, is defined as volume that reaches the loading deck ready for transport. This implies that this hypothetical unit of volume has been through all four processes covered in the scope of this study, that is...

a) it has been felled.

b) it has been yarded to the landing.

c) it has been topped, limbed and bucked.

d) and it has been placed in a loading deck.

Operation time, in the above sense, refers to the amount of time required to process this unit of volume in each particular operation. As the processes involved in each operation differs between conventional thinning and "hot-yarding" the following will serve as the specific description for each operation in this comparison:

1) Conventional Thinning ...

   a) COR - Felling and clearing the skyline corridor, including the limbing and bucking of commercial stems.

   b) THIN - Regular thinning, including limbing and bucking.

   c) YARD - The regular yarding of log length pieces and decking them at the landing ready for loading.

2) "Hot-Yarding" ...

   a) HCOR - The whole tree felling of the skyline corridor.

   b) HYARD - Whole tree yarding and thinning at the same time.

   c) SWING - The removal of the whole trees from the landing, limbing and bucking them and placement of the processed logs on the loading deck.

Given these preceding definitions it is now possible to make a variety of comparisons that from which the operation times per unit volume of output can be derived.

The regression equations developed in the previous section conform to the operation descriptions stated above. However, they yield expected average times per unit activity (felling or yarding cycle) rather than unit volumes. Yet associated with each activity is some amount of volume that is destined to become thinning output. A single unit of this volume would eventually satisfy the definition for unit volume output when it finally reaches the loading deck. Therefore dividing both sides of a specific regression equation by the volume associated with that activity yields a model that estimates average operation time per unit volume of output. This is the basis for the development of the production equations used in upcoming comparisons.

One other aspect, pertaining to the volume itself, needs to be considered before the production equations can be properly constructed. Because the volume needed for this approach must be a unitized measure of total thinning output, it must be characteristic of all the volume generated from the thinning process. In this respect it is non-defined as to its origin. However, a specific unit of volume originates from one of two distinct operations; either it is felled in the corridor clearing activity or it is thinned from the remaining area. Therefore a means is needed to combine the influence of both of these initial operations into the characteristic unit volume being used. As the yarding operations and swing activity in the "hot-yarding" procedure must handle all thinning output, this problem does not apply to these operations.

To account for the above situation with the felling, a weighting factor was developed for each specific corridor felling and thinning operation. This factor expresses the estimated proportion of total volume output originating in each operation. These factors are specific to an individual setting, being a function of unit geometry, stand characteristics, corridor width and thinning intensity. Figure 15 outlines the specific information needed and steps involved in calculating these factors.

PRODUCTION EQUATIONS

Production equations, for delay free time per unit volume of thinning output, were developed from each regression model. These account for all operational activities connected with each thinning method except for the swing and processing operation. For these comparisons the production rate of the swing activity was assumed to correspond to the yarding rate on an operational time per volume basis. As listed, the production equations estimate minutes operation time per cubic foot output. Tables 13(a), 13(b), 13(c) document the final production equations for each operation in the thinning techniques being examined. Expected values from a set of average conditions (discussed below) are also listed along with the appropriate weighting

<u>Need estimates of</u>:

a) Percent of total area (setting) in the corridor. (% AC)

b) Average volume per acre (commercial volume). (V)

c) Average number of stems thinned per acre. (ST)

d) Average volume per stem thinned. (VS)

Unit Volume Adjustment Factors:

1. For Corridor (UVAC) = $\dfrac{[(\%\ AC)\ (V)]}{[(\%\ AC)\ (V)] + [(1-\%\ AC)\ (ST)\ (VS)]}$

2. For Thinning (UVAT) = [1.0 - (UVAC)]

<u>Example:</u>

For average study conditions (10 foot corridor)

(% AC) ≐ 6.8%

(V) ≐ 6,700 cu. ft.

(ST) ≐ 165 stems/acre

(VS) ≐ 10.91 cu. ft/stem

$$(UVAC) = \frac{[.068(6700)]}{[.068(6700)] + [(1-.068)(165)(10.81)]} = \underline{\underline{0.215}}$$

$$(UVAT) = [1.0 - (0.215)] = \underline{\underline{0.785}}$$

Figure 15. Calculating Unit Volume Adjustment Factors for Falling Operations.

Table 13(a). Production Equations for Conventional Thinning.

Operation	DELAY FREE TIME				DELAY TIME		Total Ave. Time per Ft^3 output	Average Values
	Vol. Factor	Regression coefficient	variable	Average min./ft^3	% factor	Average min./ft^3		
	(1)	(2)	(3)	(4)[1]	(5)	(6)[2]	(7)[3]	
COR	0.215	-4.95373 +1.25308 (VOL)/tree	 (DIA)	0.10999	47.9%	0.05269	0.16267	(DIA) = 12.0 (VOL) = 19.71 $S^2_{\hat{y}}$ = 0.22827
THIN	0.785	+2.44263 +1.44443 +0.28333 +9.99936 (VOL)/Tree	 (LH) (VOL) $(MD)^2$	0.49360	54.9%	0.27099	0.76459	(LH) = 0.44 (VOL) = 10.81 $(MD)^2$ = 1814.76 $S^2_{\hat{y}}$ = 0.09187
YARD	1.0	+1.47734 +0.00561 +0.01342 +0.00725 +1.72311 (VOL)/Turn	 (SD) (LD) (LG) (RE)	0.39024	40.3%	0.12462	0.43386	(SD) = 325.0 (LD) = 60.0 (LG) = 39.53731 (RE) = 0.45854 (VOL) = 16.75941 $S^2_{\hat{y}}$ = 0.01417

[1] $(4) = \frac{(1)\ \Sigma[(2)(3)]}{(Vol)/Tree\ or\ Turn}$ = operation minutes/cubic foot output (delay free).

[2] $(6) = [(4)(5)]$ = Expected delay time per operation/cubic foot output.

[3] $(7) = [(4) + (6)]$ = Total expected operation minutes/cubic foot output (with delays).

Table 13(b). Production Equations for "Hot-Yarding" (10 Foot Corridor).

Operation	DELAY FREE TIME				DELAY TIME		Total Ave. Time Per Ft^3 Output	Average Values
	Vol. Factor	Regression Coefficient	Variable	Average min./ft^3	% Factor	Average min./ft^3		
	(1)	(2)	(3)	(4)[1]	(5)	(6)[2]	(7)[3]	
HCOR	0.215	+1.31151 +0.03357 +0.07097 (VOL)/Tree	 (MD) (VOL)	0.04055	51.8%	0.02100	0.06155	(MD) = 30.0 (VOL) = 19.71 $S^2\hat{y}$ = 0.07205
HYARD & SWING	1.0	-0.08495 +0.00407 +0.01397 +0.76795 +1.97755 -0.54048 +0.51800 (VOL)/Turn	 (SD) (LD) (NL) (RE) (SC) (ST)	0.26541	33.4%	0.08865	0.35405	(SD) = 325.0 (LD) = 60.0 (NL) = 1.35034 (RE) = 0.34541 (SC) = 1.0 (ST) = 2.0 (VOL) = 16.16790 $S^2\hat{y}$ = 0.00793

[1] $(4) = \dfrac{(1)\,\Sigma\,[(2)(3)]}{(\text{Vol})/\text{Tree or Turn}}$ = operation minutes/cubic foot output (delay free).

[2] $(6) = [(4)(5)]$ = Expected delay time per operation/cubic foot output.

[3] $(7) = [(4) + (6)]$ = Total expected operation minutes/ cubic foot output (with delays).

Table 13(c). Production Equations for "Hot-Yarding" (20 Foot Corridor).

Operation	DELAY FREE TIME				DELAY TIME		Total Ave. Time Per Ft^3 Output	Average Values
	Vol. Factor (1)	Regression Coefficient (2)	Variable (3)	Average min./ft^3 (4)[1]	% Factor (5)	Average min./ft^3 (6)[2]	(7)[3]	
HCOR	0.372	+1.31151 +0.03357 +0.07097 (VOL)/Tree	 (MD) (VOL)	0.07016	51.8%	0.03634	0.10650	(MD) = 30.0 (VOL) = 19.71 $S^2\hat{y}$ = 0.07205
HYARD & SWING	1.0	+1.25244 +0.02276 +0.04407 +2.52378 (VOL)/Turn	 (LD) (VOL) (RE)	0.23238	32.4%	0.07529	0.30767	(LD) =60.0 (VOL) =17.54057 (RE) = 0.27152 $S^2\hat{y}$ = 0.01264

[1] $(4) = \dfrac{(1)\ \Sigma\left[(2)(3)\right]}{\text{(Vol)/Tree or Turn}}$ = operation minutes/cubic foot output (delay free).

[2] $(6) = \left[(4)(5)\right]$ = Expected delay time per operation/cubic foot output.

[3] $(7) = \left[(4) + (6)\right]$ = Total expected operation minutes/cubic foot output (with delays).

factors for delays and volume proportions.

For an equal comparison of treatments, these equations must be applied over the same set of conditions. Though conditions on the areas involved in each particular study were very similar, the average value of each significant predictor variable differed between the studies. For some factors this variation could be shown not to be statistically significant, yet in most cases it was. For some variables, such as Slope Distance and Surface type, these differences were simply a function of the variation in the physical characteristics associated with the study areas. Others however, appeared to differ because of some response to the particular treatment. It was noted that Log Angle (LG), Number of Resets (RE), Number of Pieces per turn (NL), Volumes per Turn or Tree (VOL), Move Distance (MD) and Butt Diameter (DIA) all seemed dependent on the thinning method and/or specific operation. Therefore, the general set of conditions that were used to make comparisons had to account for these differences.

The set of average values for the independent variables used in this evaluation [see tables 13(a) (b) (c)] were based on the following assessment criteria. Those factors that were only dependent on the physical characteristics of the setting or area were estimated by appropriate weighted averages or modes (for coded indicators) over the entire study area. These included Slope Distance (SD), Line Distance (LD), Surface Condition (SC) and Surface Type (ST). The corridor was estimated to occupy 6.8% of the setting area (10 foot corridor) using the same approach. Stand conditions were set at 340 stems/acre averaging 12 inches butt diameter. Thinning intensity was figured at 165 stems/acre with an average 9 inch butt diameter. Variables that were unique to a given operation or method were retained at average values observed in the associated studies. This was determined by testing for a significant difference between mean values using a "t" test (Appendix B). If they were different, a regression model was developed using the variable under question as the independent variable. If this model could account for >30% of the variation associated with this variable, it would be used to estimate its expected value for these conditions. No valid regressions were able to be formed, so average values were used. Log Angle (LG), Number of Resets per Turn (RE), Number of Pieces per Turn (NL), and the falling variables Left Hung (LH) and Move Distance (MD) were assessed in the above manner.

Determining appropriate estimates of volumes per tree and per turn was the last step in this process. Preliminary analysis showed these factors to be very critical to the final outcome. It was noted in the study results that average volumes per turn differed markedly between treatments. However, this difference was not strongly related to the number of pieces per turn. An in depth look at this situation revealed that percentage of unit area in the corridor, variation in thinning intensity and minor variations in stem size distribution could account for approximately 85 percent of this difference. The percent of unit area in the corridor was the most significant of these due to its concentrated influence on volume production. In accounting for these influences in calculating average volumes for comparisons, it was necessary to start with a set of assumed stand conditions, setting geometry, and thinning intensities (values given in preceding paragraph). From this point it was possible to calculate estimates for Volume per Tree and Volume per Turn for each method. Details of these calculations are given in Appendix E.

PRODUCTION COMPARISONS

With the derived set of variable values, that approximate average conditions over the entire study and account for specific treatment differences, production estimates for each activity were calculated. These values, expressed in minutes of operation time per cubic foot of thinning output, are those given in Tables 13(a), (c) for each operation. This is the average time spent in an activity to eventually get one cubic foot of wood to the landing. Other meaningful ways to express production, for comparison of techniques, are in man hours per cunit of thinning output and in operation (crew) hours per cunit of output. Also actual operation production (not adjusted for unit volume output) was calculated for general information. Total expected production rates, stump to loading deck, were determined for each method by combining the appropriate operational rates associated with that approach. The expected values, based on the same set of conditions, for each of the above measures of production are given in Tables 14(a) for conventional thinning, 14(b) for "hot-yarding" with a 10 foot corridor, and 14(c) for "hot-yarding' with a 20 foot corridor.

Some amount of variation is associated with each of the expected (average) values derived from the initial regression equations. The expected value represents only the mean response of a distribution that encompasses a population of possible average values. The amount of variation surrounding the expected value is a measure of how accurately this value can be estimated. Therefore it should be considered when making comparisons. Cofidence intervals, based on an allowable

Table 14(a). Production Estimates for Conventional Thinning.

Operation	No. in Crew	Production per Unit Volume Output[1]				Operation Production[2]	
		Man Hours per Cunit	± 95% Confidence Interval	Crew (Operation) Hrs./Cunit	± 95% Confidence Interval	Cunits per Working Hour	± 95% Confidence Interval
Corridor Felling	2	* 0.18332	±0.01737	0.09166	±0.00869	2.34568	±0.22430
		0.27112	0.02569	0.13556	0.01285	1.58599	0.15167
Felling	2	0.82267	0.07337	0.41134	0.03669	1.90841	0.17156
		1.27432	0.11365	0.63716	0.05683	1.23203	0.11076
Yarding	2	1.03079	0.04735	0.51540	0.02368	1.94026	0.08932
		1.44620	0.06643	0.72310	0.03322	1.38293	0.06366
Total Operation Stump to Loading Deck		2.03678	0.08903	1.01840	0.04452	0.98193	0.04301
		2.99164	0.13412	1.49582	0.06707	0.66853	0.03004

1 - Production in terms of operation time per unit volume of thinning output.

2 - Actual Production rate of the operation - Not weighted for unit volumes.

* - Delay Free / With Delays

Table 14(b). Production Estimates for "Hot-Yarding" Ten Foot Corridor.

Operation	No. in Crew	Condition	Production per Unit Volume Outpout[1]: Man Hours per Cunit	± 95% Confidence Intervals	Crew (operation) Hrs./Cunit	± 95% Confidence Interval	Operation Production[2]: Cunits per Working Hour	± 95% Confidence Interval
Corridor Felling	2	Delay Free	0.06758	± 0.00976	0.03379	± 0.00488	6.36258	± 0.93841
		With Delays	0.10259	0.01482	0.05130	0.00741	4.19142	0.61825
Felling & Yarding	3	Delay Free	1.32704	0.05508	0.44235	0.01836	2.26067	0.09399
		With Delays	1.77027	0.07348	0.59009	0.02449	1.69466	0.07046
Swing & Process	1	Delay Free	0.44235	0.01836	0.44235	0.01836	2.26067	0.09399
		With Delays	0.59009	0.02449	0.59009	0.02449	1.69466	0.07046
Total Operation Stump to Loading Deck	X	Delay Free	1.83697	0.07409	0.47614	0.01900	2.10022	0.08394
		With Delays	2.46295	0.09907	0.64139	0.02559	1.55911	0.06230

1 - Production in terms of operation time per unit volume of system output.

2 - Actual production rate of the operation - not weighted for unit volumes.

Delay Free
With Delays

Table 14(c). Production Estimates for "Hot-Yarding" Twenty Foot Corridor.

Operation	No. in Crew	Production per Unit Volume Output[1]				Operation Production[2]	
		Man Hours per Cunit	± 95% Confidence Interval	Crew (operation) Hrs./Cunit	± 95% Confidence Interval	Cunits per Working Hour	± 95% Confidence Interval
Corridor Felling	2	0.11693	± 0.01689	0.05847	± 0.00844	6.36258	± 0.93854
		0.17751	0.02564	0.08875	0.01282	4.19142	0.61833
Felling & Yarding	3	1.16191	0.06410	0.38730	0.02137	2.58195	0.14286
		1.53837	0.08486	0.51279	0.02829	1.95012	0.10791
Swing & Process	1	0.38730	0.02137	0.38730	0.02137	2.58195	0.14286
		0.51279	0.02829	0.51279	0.02829	1.95012	0.10791
Total Operation Stump to Loading Deck		1.66614	0.08708	0.44577	0.02298	2.24331	0.11593
		2.22867	0.11594	0.60154	0.03106	1.6624	0.08606

1 - Production in terms of operation time per unit volume system output.

2 - Actual production rate of the operation - not weighted for unit volume.

Delay Free
With Delays

margin of error (significance level)are often used to express this accuracy.

Included in Tables 14(a), (b) and (c) are approximate values for the 95 percent confidence interval surrounding the given expected value. These indicate that unless a one in twenty chance has occured, the average value for the given set of conditions will lie somewhere between the expected value and plus or minus the interval value. Because of the complexities involved in precisely calculating these intervals, the ones given are approximations based on the following simplifying assumptions:

1) Predictor variables and volumes were constant values.
2) Covariance between operations was zero.
3) Delay time considered directly proportional to average activity time for this comparison.
4) A "t" value of 2.0 used to approximate "t" at the .05 significance level for all calculations.

The specific details of how these confidence intervals were developed are outlined in Appendix B under Confidence Intervals. Figure 16 compares estimated total man hours required per cunit output, along with a graphical representation of the confidence intervals over a range of slope distances.

COST COMPARISONS

Comparative costs for each thinning alternative were calculated from estimates of crew (operation) hours per cunit output and from hourly operating costs developed for each crew function. These costs were based on 1981 average rates used in Western Oregon and include

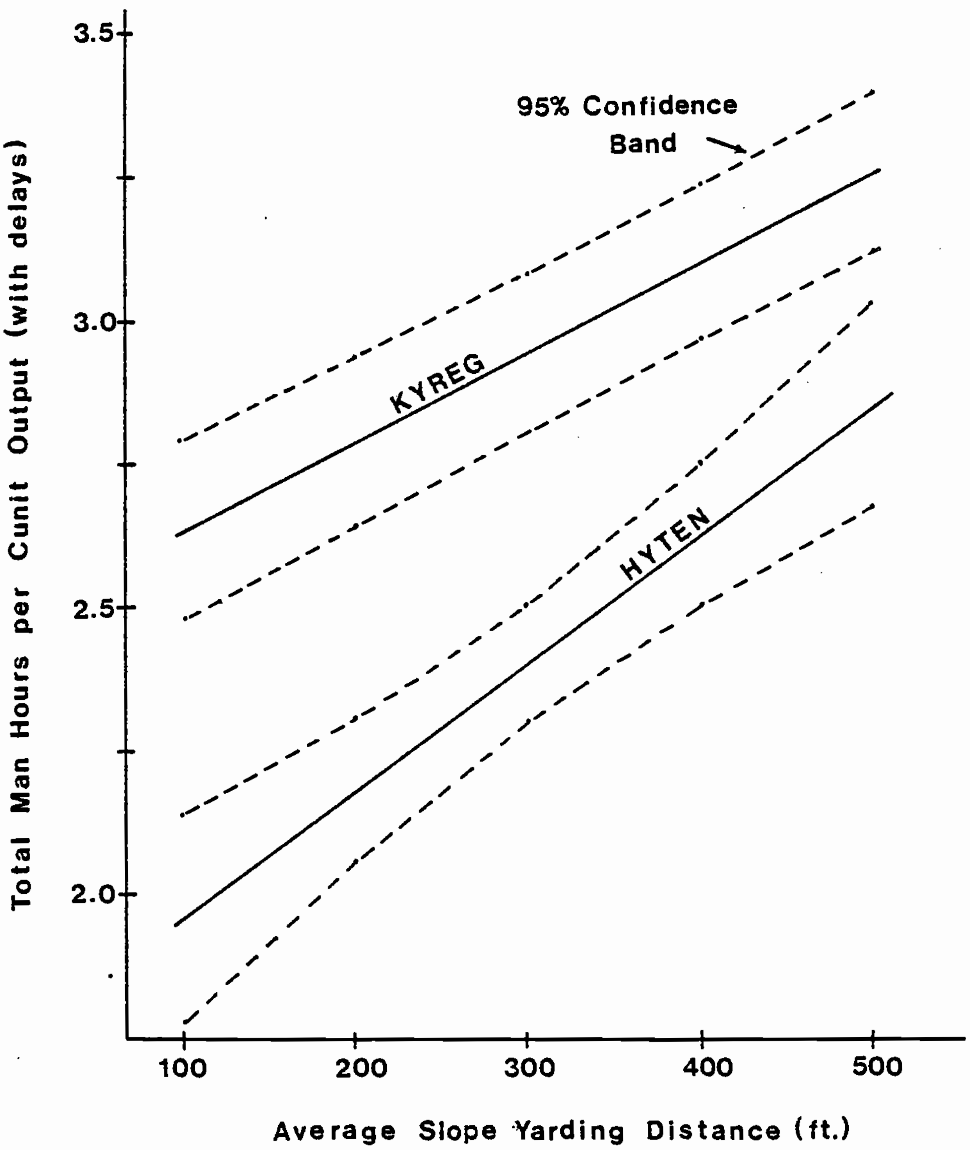


Figure 16. Estimated Man Hours Required per Cunit Output.

equipment fixed costs, operating cost and labor costs (Appendix F). By multiplying the total hourly costs of each operation by it's estimated production, expressed in hours operation per cunit output, an estimate of cost per cunit output was obtained. The expected average costs for each operation and total costs per method are given in Table 15. This table also lists the range average costs are likely to be within based on the 95% confidence interval. These costs are based on expected production rates for the same set of conditions described earlier. Figure 17 graphically compares these cost estimates for the functional operations employed in each thinning technique. It is important to note that these costs do not reflect actual expenses incured in this study. Actual costs for this or any other operation would depend on actual pay scales used, equipment costs and crew production specific to that operation.

A more useful approach in comparing final costs between conventional thinning and the "hot-yarding" technique is by use of breakeven analysis. For any given set of equipment and labor costs the only real differences between the techniques are production rates and the cost of the swing operation in "hot-yarding". Given that production rates can be estimated for this particular crew working in these types of conditions, it is possible to construct a breakeven equation with swing operation costs as the descriptive indicator. If actual costs of the swing operation per hour are greater than the derived value, then conventional thinning would prove more economical in these conditions. However if actual swing costs were less, then "hot-yarding" would be more cost effective. Another benefit with this approach is that it can be used to determine how much any factor, cost or production,

Table 15. Cost Estimates and Comparisons.

Operation	No. in Crew	Hourly Crew & Equipment Rate ($/Hr.)	Estimated Cost per Cunit of Thinning Output: KYREG Expected Average	KYREG Range - 95% Conf. Int. (High - Low)	HYTEN Expected Average	HYTEN Range - 95% Conf. Int. (High - Low)	HYTNY Expected Average	HYTNY Range - 95% Conf. Int. (High - Low)
Corridor Felling	2	$41.28	3.78	4.14 - 3.42	1.39	1.59 - 1.19	2.41	2.76 - 2.07
			5.60	6.13 - 5.07	2.12	2.42 - 1.81	3.66	4.19 - 3.13
Thinning	2 (Reg) 1 (Hy)	$41.28 $20.64 for H.Y.	16.98	18.49 - 15.47	9.13	9.51 - 8.75	7.99	8.43 - 7.55
			26.30	28.64 - 23.96	12.18	12.68 - 11.67	10.58	11.17 - 10.00
Yarding	2	$47.67	24.57	25.70 - 23.44	21.09	21.96 - 20.21	18.46	19.48 - 15.46
			34.47	36.05 - 32.87	28.13	29.30 - 26.96	24.44	25.79 - 23.10
Swing & Process	1	$34.02			15.05	15.67 - 14.42	13.18	13.90 - 12.45
					20.07	20.91 - 19.24	17.45	18.41 - 16.48
Total Operation Stump to Loading Deck			45.33	47.25 - 43.40	46.66	47.82 - 45.50	42.04	43.41 - 40.67
			66.37	69.25 - 63.49	62.50	63.92 - 61.07	56.13	57.96 - 54.30

1 - Basis for Hourly rates outlined in Appendix F.

Delay Free
With Delays

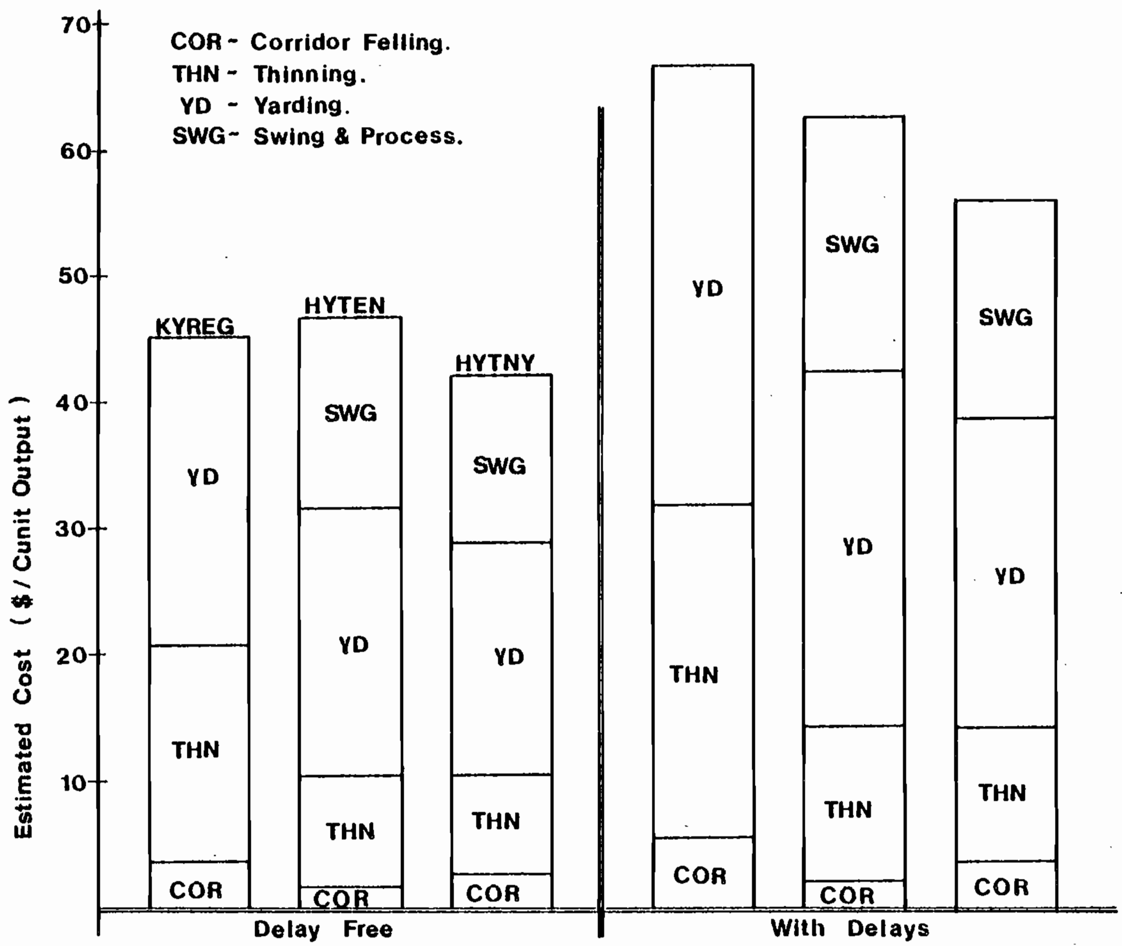


Figure 17. Operation Cost Comparison.

must change before it makes one method competitive with the other. Figure 18 outlines the general development of this equation and compares conventional thinning with the 10 foot corridor "hot-yarding" based on the average conditions and costs previously established.

Using the above approach with conditions and costs as stated, a breakeven analysis was made on combined falling production in the conventional method. For conventional thinning the combined production rate from corridor felling and thinning, expressed in crew hours per cunit output, would need to be reduced by -0.09366 crew hours per cunit to be competitive with "hot-yarding" in this situation. This is equivalent to reducing falling time by over 12 percent. A similar analysis on the yarding rate showed that a 11.2 percent reduction in yarding time would result in a breakeven condition with the 10 foot "hot-yarding" operation.

I. Definitions:

A) Production	Conventional	"Hot-Yarding"
1) Corridor Felling (crew hours per cunit output)	(CP)	(HCP)
2) Thinning (crew hours per cunit output)	(TP)	*(HTP)
3) Yarding (crew hours per cunit output)	(YP)	(HYP)
4) Swing & Processing (crew hours per cunit output)	—	*(HSP)

B) Costs * Note (HTP) = (HYP) = (HSP) in crew hours per cunit output.

1) Felling - 2 man crew (cost per crew hour)	($F)	.5($F)
2) Yarding - 2 man crew (cost per crew hour)	($Y)	($Y)
3) Swing & Processing - 1 man crew (cost per crew hour)	—	($S)

II. Breakeven Cost Formula:

$$\underbrace{[(CP)(\$F)] + [(TP)(\$F)] + [(YD)(\$Y)]}_{\text{Conventional}} = \underbrace{[(HCP)(\$F)] + [(HTP)(.5\$F)] + [(HYP)(\$Y)] + [(HSP)(\$S)]}_{\text{"Hot-Yarding"}}$$

Set (HTP) & (HSP) = (HYP) Combine and set equal to zero

$$(\$F)[(HCP)-(CP) + .5(HYP)-(TP)] + (\$Y)[(HYP)-(YP)] + (\$S)(HYP) = 0$$

III. Breakeven Cost for the Swing Operation (using costs outlined in Appendix F).

$$(\$S) = \frac{-(\$41.28)[(0.0513) - (0.1356) + .5(0.5901) - (0.6372)] - (\$47.67)[(0.5901) - (0.7231)]}{(0.5901)}$$

($S) = $40.58/hour (Maximum hourly rate for swing operation, to be competitive).

Figure 18. Breakeven Analysis ... "Hot-Yarding" versus Conventional Thinning.

ELEMENTAL ANALYSIS

MEAN DIFFERENCE

The first step in this analysis was to identify those time elements that differed significantly between treatments. This was done using mean values from the study data, observed variation and a non-paired "t" statistic to test for difference between the means (Appendix B). The 0.01 level was set as the minimum significance level for these tests and others to follow. Only the average reset time per turn (RS) proved to be non-significant between all three studies. However, total turn time (TTT) and average hook time (HK) did not vary significantly between the two "hot-yarding" options. In the felling operations all time elements differed significantly except Move & Select (MS) and Cut & Wedge (CW) times between the conventional thinning and corridor felling activities.

REGRESSION ANALYSIS

Having established where potential differences between the methods exist, the next step was to develop a regression equation on each time variable for each technique. This was done to identify those independent variables that appeared to have the greatest association with variability in that particular time element. This allowed not only determination of those factors important to all three methods but also helped identify those which were unique to a given treatment. Values from the regression models applied over the same set of variable values were compared. This helped indicate whether the observed difference between methods was due primarily to treatment effects or lack of conformity between variables. The derived set of average conditions for the study area [Table 13(a), (b), (c)] were used for these comparisons. An approximate 95% confidence interval was constructed around each expected value. This was done using the associated mean squared error term (MSE) as an estimate of the variance of the mean. The only other variance associated with this value is variance of the regression plane as to it's slope parameters at that point. Because the set of predictor variables are at or near their average values this variation was assumed minimal. Table 16 lists the regression equations for each time element. Expected values and approximate standard errors are also given. Variables with regression coefficients significant at the 0.05 level were included in these models. Table 16 contains information on the yarding operations only. Because a large difference in element times is to be expected in whole tree versus log length felling, this approach was considered unnecessary with the felling operations.

By comparing the confidence intervals generated for each method on a particular yarding activity (time element), specific differences between treatments were identified. Figure 19 portrays these comparisons graphically for each time variable in the yarding operations. These confidence bands illustrate the range of values that the average is expected be within, given that a one in twenty chance occurrence does not take place. In this way comparisons are made by looking for any overlap between the intervals of the treatments in question. If an overlap exists then the average times cannot be assumed different. However, if they do not overlap then there is a good chance that a true difference exists between the expected values. In general it

Table 16. Regression Equations for Yarding Time Elements.

Yarding Time Element	Thinning Method	n	Regression Equations		Expected Value	Est. Variance (MSE)	R^2
			Constant	Regression Coefficient (Predictor Variable)			
Outhaul (OH)	KYREG	200	+.32531	+.00111(SD)	0.68606	0.05596	.531
	HYTEN	404	+.41047	+.00099(SD)+.00051(LD)-.06039(ST)	0.64204	0.01887	.461
	HYTNY	294	+.46688	+.00124(SD)-.00060(LD)-.06703(SC)-.04147(HY)	0.74625	0.01937	.675
Lateral Out (LO)	KYREG	195	+.03561	+.00750(LD)+.05043(RE)+.00018(SD)	0.56723	0.07505	.496
	HYTEN	405	-.24579	+.00679(LD)+.12897(ST)+.00126(LE)	0.47642	0.06857	.471
	HYTNY	298	+.02429	+.00641(LD)+.06711(RE)-.00016(SD)+.05008(NL)	0.44274	0.03730	.612
Hook (HK)	KYREG	194	+.17770	+.29136(NL)+.10197(DK)	0.95413	0.27479	.157
	HYTEN	405	+.01503	+.39699(NL)+.00245(LD)+.07209(RE)	0.72300	0.13526	.365
	HYTNY	300	-.13022	+.41900(NL)+.00315(LD)+.08850(RE)+.00682(VOL)	0.76823	0.13743	.413
Lateral In (LI)	KYREG	199	+.14594	+.00405(LD)	0.38894	0.04774	.277
	HYTEN	409	-.16660	+.00254(LD)+.10359(RE)+.00252(V)L)+.03372(DK)+.00058(LG)	0.11297	0.01523	.530
	HYTNY	300	-.00459	+.00269(LD)+.09242(RE)+.00296(VOL)	0.23382	0.01172	.582
Reset (RE)	KYREG	204	-.53024	+1.26988(RE)+.00421(LG)+.17687(DK)	0.59640	0.53573	.688
	HYTEN	413	-1.53926	+1.52055(RE)+.50567(ST)+.25447(NL)+.00276(LD)	0.50651	0.76020	.599
	HYTNY	302	+.00640	+1.96891(RE)	0.54100	0.62642	.687
Inhaul (IH)	KYREG	204	+.24485	+.00220(SD)	0.95985	0.02444	.910
	HYTEN	411	+.24626	+.00186(SD)+.02237(RE)	0.85849	0.01809	.769
	HYTNY	301	-.02133	+.00182(SD)+.00484(VOL)+.09655(DK)+.02707(RE)	0.77335	0.01707	.844
Unhook (UK)	KYREG	202	+.17737	+.21261(NL+.00121(SD)	0.97821	0.27367	.291
	HYTEN	405	+.04622	+.04569(NL)+.00016(SD)+.14167(DK)+.000721(LG)+.00325(VOL)	0.39277	0.01788	.301
	HYTNY	297	+.33667	+.04169(NL)-.00018(SD)	0.84117	0.02245	.043

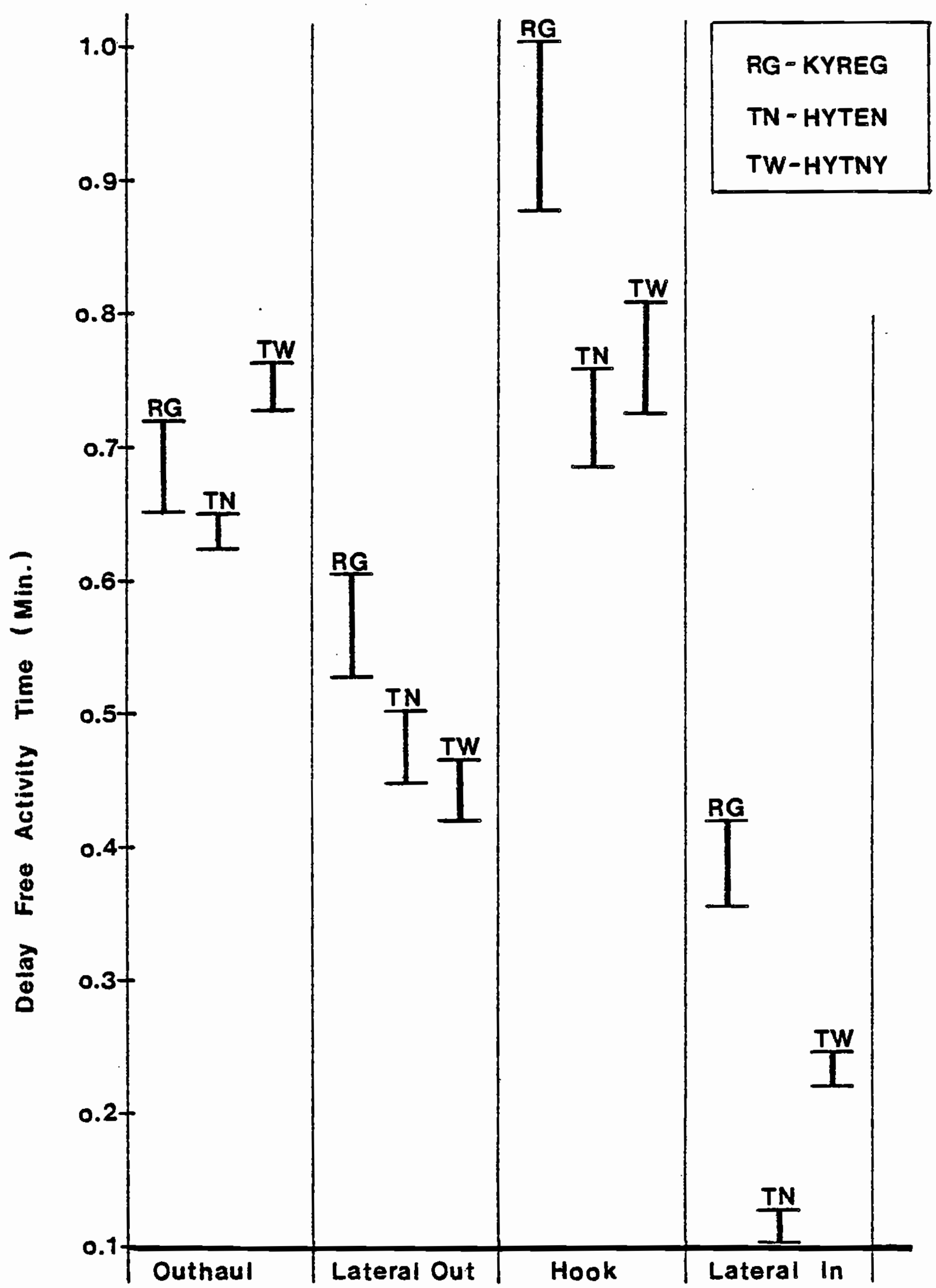


Figure 19. 95% Confidence Intervals ... Yarding Time Elements.

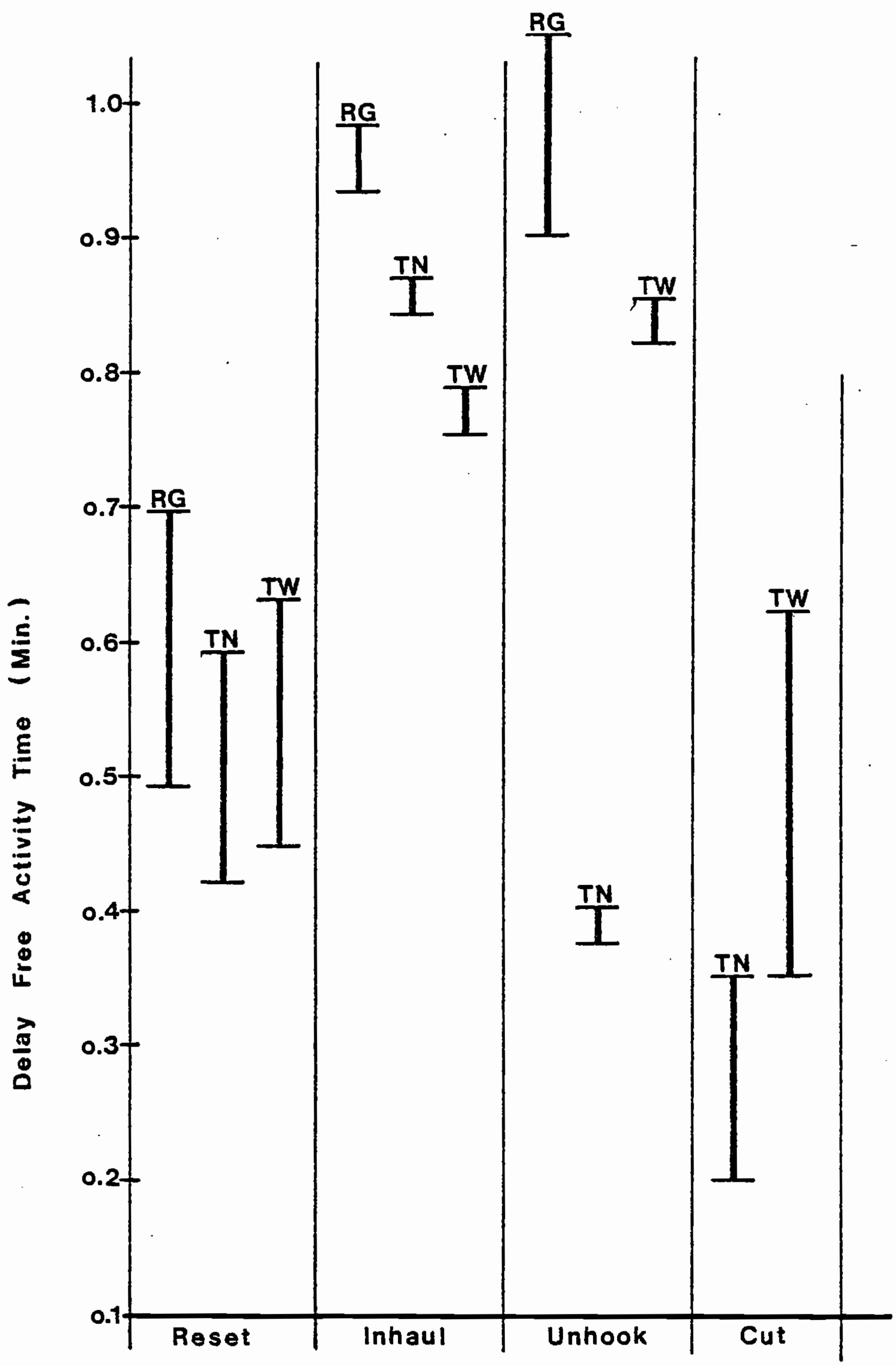


Figure 19. - Continued.

was found that if a difference was noted between the conventional thinning and "hot-yarding" with a 10 foot corridor, there was also a difference in the 20 foot "hot-yarding". This gives support to the inference that at least some of this variation is related to the technique. It was also evident from these comparisons that the expected values and confidence bands for the "hot-yarding" options were generally lower than the corresponding values for conventional thinning. This trend however, is offset to some degree by the Cut (CT) time in the "hot-yarding" methods.

The spread between confidence bands was used as a conservative indicator of expected difference between the thinning methods. On this basis the activities of Lateral Inhaul (LI) and Unhook (UK) showed the greatest deviation from conventional yarding when compared with the "hot-yarding" 10 foot corridor. Smaller differences were noted between Hook (HK) and Inhaul (IH) times along with a slight disparity in the Lateral Out (LO) element. By examining the corresponding regression equations and using common sense, various factors affecting these differences may be postulated. For example, Hook (HK) time was strongly associated with the number of pieces hooked per turn (NL) in all three regression models. When equal values for (NL) were used in the equations the confidence intervals overlaped nicely. This suggests that this difference between methods was largely influenced by the number of pieces hooked per turn.

Using the above approach, the following factors appeared to be associated with at least some of the variation between conventional thinning and the "hot-yarding alternative:

1) In the Lateral In (LI) activity the number of Resets (RE)

per turn, Log Angle (LG) and to a lesser degree volume per turn (VOL). Even though average reset time per turn did not differ significantly between treatments, the number of resets per turn were significantly lower in "hot-yarding". Also the Log Angle was definitly improved over conventional thinning.

2) For Inhaul (IH) the Deck condition (DK) and number of Resets per turn (RE). Again, setting reset values equal, reduces the margin between treatments. Deck conditions in the "hot-yarding" methods were significantly better because of the swing operation.

3) Unhook showed the largest difference between the confidence intervals. The Number of Pieces per turn (NL) and Deck condition (DK) showed a strong association with variations in unhook time. The effect of the swing operation in keeping deck heights down would also be an influence in this activity.

4) No demonstrable factor was found that could explain the difference in Lateral Out (LO) times between the three methods. It is speculated that some learning effect may have an influence here. However an effort made to identify a learning curve on the yarding operations as a whole gave no such indication.

Comparing the two "hot-yarding" treatments found a difference in activity times for five yarding elements. These were; Outhaul (OH), Lateral In (LI), Inhaul (IH), Unhook (UK) and Cut (CT). Examination of these elements using the procedures outlined above failed to identify any probable influence except difference in volumes for the Lateral In and Cut times. Turns in the 20 foot corridor average higher volumes than from the 10 foot, even though there is no significant difference between average number of pieces per turn (NL). Because essentially twice the proportion of the unit area is clearcut in the 20 foot corridor a higher concentration of volume is available for yarding. In addition average stem diameter increases because of the larger trees felled in the corridor that would normally be left in thinning. A possible factor influencing the higher Outhaul and Unhook times associated with the 20 foot corridors was the uncommon amount of problems with the carriage during these operations. The carriage problems stemmed from a badly cracked part in the mechanism which eventually broke. The resultant delays generally occured while trying to release the carriage at the landing. Though the majority of this time was properly coded in delays, it is likely that both Outhaul and Unhook times reflect some of this.

DELAY ANALYSIS

Total delay times, even when adjusted for non-treatment related delays, were substantially higher in conventional thinning than in the "hot-yarding" methods. This was true for both the falling and yarding operations. In these studies delay times ranged from about 30% to over 50% of actual productive time. This amount of influence on total production warrants an indepth look into these differences.

In the conventional thinning operation, time spent trying to free hang ups accounted for 32.2 percent of total dealy time recorded in that study. This averaged out to about 1.26 minutes spent in hang up delays per tree felled. In "hot-yarding", hang ups are yarded from whatever position they may be in therefore there is little time spent trying to get them on the ground. Though a detailed study was not conducted on the thinning activity in "hot-yarding" it is obvious that other delays associated with regular thinning would not be a problem in this method. However it was noted that thinning activities in this approach were at times interrupted by situations not encountered in conventional thinning, such as waiting until hung trees were safely yarded from the work area and freeing occasional turns by cutting out obstructions. Because no actual data was obtained for whole tree corridor felling no valid comparisons could be made between delays in this operation.

A review of yarding delays recorded in these studies (Appendix D) reveal several distinct differences between techniques. These differences occur not only in the frequency and magnitude of specific delays but also in certain types of delays associated with each method. With all recorded delays considered, the average delay time per turn was greater by a factor of almost 2.5 in conventional yarding than in "hot-yarding". Even after adjustment for those delays judged not to be directly influenced by the yarding treatments (Figure 14), regular yarding delays were 70 percent higher. The remainder of this investigation will deal only with those delays that could possibly have been influenced by differences in yarding technique.

In conventional yarding landing delays, including deck maintenance, were the most frequent and time consuming delays. Landing delays occured on slightly more than one out of every five turns. Combined, they accounted for 33.05 percent of the total adjusted delay time for yarding. McIntire, 1981 described similar results for a Koller operation where logs were decked at the landing. He found landing delays represented about 31 percent of all operating delay time. He further suggested that most of these delays stemmed from the presence of the log deck. The 10 foot "hot-yarding" study showed landing delays occuring about once every 16 turns with a combined effect of 5.36 percent of total adjusted delay time. This was the largest difference noted between yarding delays. It is presumed that most of this change results from the activities of the swing skidder in the "hot-yarding" operation.

The next most common delay was cycling or repositioning of the carriage. This occured with about equal frequency in all three studies but average delay time was slightly higher in both the "hot-yarding" treatments (average of + .224 minutes higher per delay). Cycling was the most frequent delay in both the 10 foot and 20 foot "hot-yarding" studies. Minor differences were noted in other delay catagories. Nine of which showed a decrease with the "hot-yarding" method while six increased. Because of their low frequency of occurance and small difference in magnitude their individual impact was not considered significant.

In "hot-yarding" four types of delays were recorded that were specific to this treatment. Two of these were related to the felling operation while the other two were delays caused by the skidder at the landing. The felling related delays (fueling, maintenance, saw repair) occured on less than 1.3% of the turns and totaled about 3.3% of adjusted delay times. The delays caused by the swing operation were mainly from the mainline getting snagged by a limb as trees were being swung from the landing. On occasions, the yarder operator would wait to bring in a turn while the skidder operator was hooking trees on the landing. These delays happened on about 2.8 turns out of one hundred and combined represented 3.5 percent of total adjusted delay time in the "hot-yarding" studies.

One other factor that had a significant effect on the "hot-yarding" operation was Cut (CT) time. Though not classed as a delay in this study, it does represent non-productive time to the yarding operation. This element accounted for 6.5 percent of the total productive yarding time in the 10 foot corridor study and slightly over 11.5 percent in the 20 foot. No definite explanation could be found for this observed difference. However, this time was noticeably longer, from field observations, when large diameter (>16 inches DBH) trees were being thinned.

HOT-YARDED TREES

It was suspected that "hot-yarded" trees, those that were yarded from a hung up position, were advantageous to the inhaul portion of the yarding cycle. This did not prove to be the case. A comparative analysis of the study data grouped into "hot-yarded" and non "hot-yarded" classes showed no statistical difference between inhaul yarding elements. It did, however, indicate a definite improvement in Log Angle and a significant decrease in average turn Volume for "hot-yarded" turns.

SUMMARY

SYNOPSIS

This study compared a conventional cable thinning operation in a young growth stand of Douglas-fir with a procedural alternative labeled "hot-yarding". The two techniques differ in four main areas:

1) the sequence of the felling activity with respect to the yarding operation.
2) the condition of the pieces yarded (whole tree or logs).
3) the need for a swing, processing and decking operation in the "hot-yarding" method.
4) the number of persons employed in each technique.

Detailed time studies on operations using the same logging crew, equipment and in similar areas were conducted on each procedure. The data from these studies was used to build regression models that could be used to estimate expected production rates for a given activity. These in turn were combined to form production equations for each technique.

By applying these equations over the same set of conditions it was possible to compare the expected production from each method. A comparative analysis was made on these operations for average conditions that were representative of the entire study area. This analysis showed the "hot-yarding" alternative to be the most productive. Based on delay free production, expressed in cunit output per man hour, production in the "hot-yarding" method, with a 10 foot corridor width, was 10.88 percent higher than conventional thinning. This disparity was even higher when delays were added in. With delays, the 10 foot

"hot-yarding" method had an expected production of 0.406 cunits per man hour. This represents a 21.47 percent increase when compared to expected conventional production. These production figures reflect all thinning activities from the stump to the loading deck for one skyline corridor but do not take road change times into account.

One other option was looked at in the "hot-yarding" procedure. This option used a 20 foot skyline corridor instead of the more common ten foot. It was hypothesized that the wider corridor would reduce the number of hangups when yarding whole tree turns into the corridor. However, in these studies the anticipated problems of getting whole trees into the corridor did not appear. Hence there was no demonstrable benefit, in this respect, from using the 20 foot width. This option did however result in significantly higher production rates than the other two operations. Expected production in the 20 foot "hot-yarding" option was greater than that in the 10 foot by a factor of 1.105, based on total time (with delays) production in cunits output per man hour. It was determined that this jump in production did not stem from some increased efficiency in operation but rather from the larger volume concentrated in the corridor resulting from the additional width cleared.

By expressing production in crew (operation) hours per cunit output and expanding by an appropriate hourly operating cost for each functional activity, relative costs of each method were compared. Based on a derived set of representative costs for the 1981 work season, "hot-yarding" was determined to be slightly more economical in these studies. A more indepth look into costs and production relationships was proposed using breakeven analysis. This approach revealed that in these particular conditions, the extra cost of the swing operation is offset by 42 cent savings for every dollar in hourly falling costs, and by 13 cent savings for every dollar in hourly yarding costs. This would indicate that the economic desirability of using the "hot-yarding" approach is most sensitive first, to the cost of the swing operation itself and next to changes in falling expenses.

Several factors were identified that seemed to be associated with differences between these methods. This was done by comparing individual activities within each operation and assessing which factor appeared important in any difference at this level. It was noted that thinning and corridor felling production, per man hour, was greater in the "hot-yarding" method than with conventional thinning. This was true even when the total swing time was added in for limbing and bucking. Much of this difference is associated with time normally spent dealing with hangups in a conventional thinning operation. In the yarding operation the number of resets, log angle, number of pieces per turn and landing deck condition were all found to be related to improvements in delay free turn time with the "hot-yarding" method. The greatest difference in times between elements results from the presence of the swing skidder. The two largest differences between methods were in the unhook yarding element and in landing delays. Both of these were closely associated to swing operation keeping the landing deck in a workable condition.

OTHER CONSIDERATIONS

Safety was emphasized in all activities throughout this study.

There was initial concern about potential hazards in felling trees and setting turns in the same area. Because of this, close communication between the faller and choker setter was stressed in the "hot-yarding" operations. Observation by the time recorder showed this procedure to run smoothly with no accidents occuring in this portion of the study.

Other safety aspects were improved using the "hot-yarding" procedure. The landing deck remained in a much safer condition for unhooking turns because of the swing operation. This also eliminated the somewhat dangerous activity of deck maintenance on high, unwieldy landing decks common in conventional yarding. This technique satisfies the Oregon State Safety Code which specifies that woods workers are not to work alone in the brush. (The two person yarding crew used in the conventional thinning may be in violation of this regulation).

The "hot-yarding" procedure removes thinned stems as whole trees. This results in cleaner stand conditions following thinning. For some areas this would be beneficial from a fire protection point of view. In other situations it may help in preventing build-ups of harmful insects that utilize green slash. However, the slash created at the processing site must still be removed. In some instances this may present a serious problem, but in this operation it was simply pushed into piles off the roadway.

The yarding of whole trees results in other potential benefits. It was noted that many limbs, which would normally have to be trimmed from the bole, were broken off during the yarding operation. This may reduce the amount of limbing required before transport. Because processing occurs in a more desirable environment than in the bush, trees can potentially be limbed cleaner and more preferred product lengths result from conscientious bucking. Since trees are brought to a specified area for limbing and bucking this may be conducive to the use of mechanical processing equipment in some instances. But there is a possibility that whole tree yarding may result in slightly higher stand damage than yarding log length pieces (Caccavano, 1982). In addition the effective payload, the amount of merchantable material per load, may be reduced per turn due to the weight of limbs and tops. This was not found to be a problem in these operations; instead, most turns were far below the maximum payload possible with this system.

Other considerations, that were outside the scope of this project, but may have a bearing on a comparison of conventional versus "hot-yarding" thinning techniques are:

1) any differences in road change costs.
2) the sorting of logs in the swing operation and decking them in a more accessible manner was shown to reduce loading time by about 14 minutes per load in similar conditions, (McIntire, 1981).
3) crew size in the "hot-yarding" method provides more versatility to tackle other types of operations; deal with problems that arise and would not have to shut down if a crew member called in sick.
4) the total output with the "hot-yarding" operation could be more than twice that of a conventional show for the same period of time. This potentially allows for better utilization of loading and hauling equipment.

CONCLUSION

This study has examined the feasibility of an alternative approach to the conventional method of thinning, in small diameter stands using cable harvesting techniques, currently employed in the Pacific Northwest. The successful application of the "hot-yarding" procedure in field trials during the summer of 1981 demonstrated its operational feasibility. Data gathered on these operations and on conventional thinning in the same area was used as the basis for a comparative analysis of the two techniques. From this analysis it was determined that for these particular operations the "hot-yarding" approach proved to be more productive than conventional thinning. In addition an economic assessment of relative operating costs indicated "hot-yarding" to be the most cost effective, unless abnormally high hourly rates were charged against the swing skidder and operator. The influence of the swing operation and procedural changes in the felling activities were identified as the major factors associated with the differences in production. Increasing the corridor width from 10 to 20 feet in the "hot-yarding" procedure was found to significantly increase production. However, this increase stems almost entirely from the additional volume concentrated in the corridor. No operational benefit was realized using the 20 foot width.

The results of this investigation show that the procedure referred to as "hot-yarding" in this paper, represents a viable alternative to conventional cable thinning in small diameter stands of Douglas-fir using the Koller K-300 yarder.

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APPENDICES

APPENDIX A

REGRESSION EQUATIONS USED TO ESTIMATE VOLUME

A. Log Length

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

B. Tree Length

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

where V_L = Log volume in cubic feet.

V_T = Whole tree volume in cubic feet 4 inch top.

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

L = Log length in feet.

APPENDIX B

MALLOWS' Cp CRITERION - (Snedecor and Cochran, 1980)

Cp is an estimator of Total Squared Error of a regression model. The objective is to identify the set of independent (x) variables that results in the model that minimizes Cp.

$$\boxed{Cp = \frac{SSEp}{MSE_k} - [n-2(p+1)]}$$

where

p = the number of independent variables in the set upon which the regression model in question was based.

n = number of observations that regression model is based on.

SSEp = Error sum of squares for model based on "p" independent variables.

MSE_k = Error mean square for the model based on the full set of "K" independent variables.

APPENDIX B

A test using the Student "t" statistic to determine if a regression model coefficient differs significantly from zero at a given probability level ($1-\alpha$).

Test   Ho: Bi=0 (not different from zero)

against Ha: Bi≠0

Bi $\overset{\circ}{=}$ bi   Bi = true value of Model $i^{\underline{th}}$ parameter.

Test Statistic $t^* = \dfrac{bi-0}{\sqrt{CiiMSE}}$ at [n-(p+1)] degrees of freedom (df)

where n = number of observations

(CiiMSE) = the variance of (bi)

p = number of independent variables in the model.

Critical Value   "t"crit. = $t\alpha$ at [n-(p+1)] df

Conclude If $|t^*|$ > "t"crit Reject Ho: and conclude that the regression coefficient is significantly different from zero at the ($1-\alpha$) probability level.

$|t^*|$ < "t"crit Do not reject Ho: and conclude that at ($1-\alpha$) probability level that the regression coefficient cannot be shown to differ significantly from zero.

---

*t values where calculated and given for each regression coefficient by the computer program used.

APPENDIX B

PAIRED "t" TEST ON MEANS (Freese, 1967)

This test uses a "t" statistic to determine if the difference between means from paired samples prove significantly different from zero.

Test Ho: $\mu d = 0$ (No difference between means)

Against Ha: $\mu d \neq 0$

where: μd = True difference between means

$\mu d \doteq (\overline{X}_A - \overline{X}_R)$ - observed value minus regressed value.

Test Statistic $$t = \frac{(\overline{X}_A - \overline{X}_R)}{\sqrt{\frac{S^2d}{n}}}$$ at (n-1) df

where: $\overline{X}_A$ = Average of observed values.

$\overline{X}_R$ = Average of Regressed values.

S^2d = Variance of the individual differences between the paired (A and R) values.

n = Number of paired observations.

Critical Value "t"crit = $t\alpha$ at (n-1) df

Conclude IF $|t| >$ "t"crit Reject Ho: and conclude that a significant difference exists between the two means at the $(1-\alpha)$ probability level.

$|t| \leqslant$ "t"crit Do not Reject Ho: and conclude that no significant difference between the two mean can be shown at the $(1-\alpha)$ probability level.

APPENDIX B

TESTING MODEL FOR "LACK OF FIT" (Netter and Wasserman, 1974)

This test helps assess the aptness of the regression model to the set of data upon which it was based.

Test Ho: $E(y) = B_0 + B_1X_{i1} + \cdots + B_pX_{ip}$ (Model Correct)

against Ha: $E(y) \neq B_0 + B_1X_{i1} + \cdots B_pX_{ip}$ (Model not Correct)

Test Statistic $F = \frac{MSLOF}{MSPE}$ at $\frac{[n-(p+1)-N_e]}{(N_e)}$ df

where *MSPE = Mean Square component of the Error term due to "pure error".

MSLOF = Mean Square component of the Error term due to the "Lack of Fit" of the regression Model.

n = number of observations.

P = number of independent variables.

N_e = degrees of freedom of the pure Error term.

Critical Value "F"crit = $F\alpha$ at $\frac{[n-(p+1)-N_e]}{(N_e)}$ df

Conclude If

F > "F"crit Reject Ho: and conclude that at $(1-\alpha)$ probability level the Model is not correct.

F $\leqslant$ "F"crit Do not reject Ho: and conclude that the expected value of (y) does not significantly differ from that given by the model at the $(1-\alpha)$ probability level.

---

* this test requires multiple observations on the same set of values of the independent variables to determine the Pure Error Component.

APPENDIX B

<u>NON-PAIRED "t" TEST ON MEANS</u> (Snedecor and Cochran, 1980)

Used to test for significant differences between mean values of two sets of data.

<u>Test</u> $H_o: \mu_1 = \mu_2$ (means are equal)

against $H_a: \mu_1 \neq \mu_2$

<u>Test Statistic</u>

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - \overset{0}{(\mu_1 - \mu_2)}}{\sqrt{\left[\dfrac{S_1^2\,(df_1) + S_2^2\,(df_2)}{(df_1 + df_2)}\right]\left[\dfrac{N_1 + N_2}{N_1 + N_2}\right]}}$$

where

$\bar{x}$ = sample mean
S^2 = sample variance
N = number of observations
df = degree of freedom = $(N_1 + N_2 - 2)$

<u>Critical Value</u> "t"crit. = $t\alpha$ at $(n_1 + n_2 - 2)$ df.

<u>Conclude If</u>

$|t| >$ "t"crit Reject Ho: and conclude that the means are significantly different at the $(1-\alpha)$ probability level.

$|t| \leq$ "t"crit Do not reject Ho: and conclude that there cannot be shown a significant difference between the means at the $(1-\alpha)$ probability level.

APPENDIX B

TEST FOR SIGNIFICANT LINEAR RELATIONSHIP

An "F" test used to determine if a significant linear relationship exists between one or more of the independent variables and the dependent variable.

Test Ho: $B_1 = B_2 = \cdots B_p = 0$ (No linear relationship)

Against Ha: $B_a \neq B_2 \neq \cdots B_p \neq 0$ at least one variable exhibits a linear relationship with "Y"

Test Statistic $F = \frac{MSR}{MSE}$ at $\left.\begin{matrix} p \\ [n-(p+1)] \end{matrix}\right\}$ df

where p = number of independent variables

n = number of observations on which the regression model was based.

MSR = Regression Mean Square - from ANOVA Table.

MSE = Error Mean Square - from ANOVA Table.

Critical Value "F"crit = $F\alpha$ at $\left.\begin{matrix} p \\ [n-(p+1)] \end{matrix}\right\}$ df

Conclude If F > "F"crit. Reject Ho: and conclude that a significant linear relationship exists at $(1-\alpha)$ probability level.

F $\leqslant$ "F"crit. Do not Reject Ho: and conclude that no significant linear relationship can be shown at $(1-\alpha)$ probability level.

APPENDIX B

PROCEDURES USED TO CHECK RESIDUALS COMPLIANCE WITH LEAST SQUARES ASSUMPTIONS (see Figure 10.)

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1) That residuals (ej) are independent
   - Compliance with this assumption is assured through the random nature of the sampling process used.
2) That (ej) have a mean of zero
   - This was checked by a computer function which computed and stored all residuals for a given model. Next the Mean was computed and checked to see if it was approx. zero.
3) That (ej) have a common variance (σ^2)
   - For this a SCATTER diagram of (ej) over ($\hat{Y}$) was done using the computer. If the (ej) have a common variance then this will produce a scatter diagram with the values for (ej) randomly distributed in a band centered on zero. The coefficient of correlation (r) was also checked. It should have a value of zero or close to it.
4) That (ej) are normally distributed.
   - A frequency histogram of the residuals (ej) was plotted by computer function. From this plot the general distribution pattern could be discerned. A normal distribution would yield a symmetrical mounded or bell shaped pattern.

APPENDIX B

CONFIDENCE INTERVALS

The following outlines the procedure used to develop the approximate confidence intervals around estimated values.

Standard form of the Confidence Interval Estimate for multiple linear regression.

$$\boxed{L(\hat{Y}|\underline{x}_k) = (\hat{Y}|\underline{x}_k) \pm t\alpha \sqrt{V(\hat{Y}|\underline{x}_k)}}$$

where L = the confidence interval estimate

$(\hat{Y}|\underline{x}_k)$ = point estimate of the expected value of (Y) for a given set of independent variables $(\underline{x}_k)$.

$t\alpha$ = value of the "t" statistic at the $(1-\alpha)$ probability level.

$V(\hat{Y}|\underline{x}_k)$ = the variance of $(\hat{Y}\ \underline{x}_k)$, which is estimated by the standard Error Squared $(S^2\hat{Y})$.

- The production values for Unit Volume Output combine several regression equations to arrive at the expected value. Associate with each is a variance that must be accounted for. This was done by expressing each activity in the desired unit of measure, using a numeric conversion factor. The variance associated with each activity was combined (added) and an overall Standard Error derived. The following illustrates this approach using the basic production measure of Man Hours/Cunit Output.

APPENDIX B - CONFIDENCE INTERVALS

- Unit Conversion Factors:

a) Corridor Felling & Thinning - (TOT) = min/tree

$$\frac{\text{min/tree}}{\text{ave. ft}^3\text{/tree}} \quad \frac{100 \text{ ft}^3\text{/Cunit}}{60 \text{ min/Hr.}} \quad \text{(No. Men in Crew) = Man Hrs./Cunit}$$

b) Yarding & Swing - (TTT) = min./turn

$$\frac{\text{min/turn}}{\text{ave. ft.}^3\text{/turn}} \quad \frac{100 \text{ ft.}^3\text{/Cunit}}{60 \text{ min/Hr.}} \quad \text{(no. Men in Crew) = Man Hrs./Cunit}$$

Activity	Formulation	Conversion Factors		
		Delay Free	Delay Factor	With Delays
COR	$\frac{10 \text{ (wt.)*}}{6 \text{ (Vol)}}$	0.01818	1.479	0.02689
THN	$\frac{10 \text{ (wt.)}}{6 \text{ (Vol)}}$	0.12103	1.549	0.18748
KYREG	$\frac{20}{6 \text{ (Vol)}}$	0.19889	1.403	0.27904
WT 10	$\frac{10 \text{ (wt.)}}{6 \text{ (Vol)}}$	0.01818	1.518	0.02760
HYTEN	$\frac{40}{6 \text{ (Vol)}}$	0.41234	1.334	0.55006
WT 20	$\frac{10 \text{ (wt.)}}{6 \text{ (Vol)}}$	0.03146	1.518	0.04776
HYTNY	$\frac{40}{6 \text{ (Vol)}}$	0.38007	1.324	0.50321

* wt. = Unit Volume Adjustment factor (see Figure 15).

- With the above Conversion Factors (CF) and based on the following assumptions: a) The values of predictor variables for any given estimate are constant. b) Delay time considered a constant, directly proportional to expected activity time. c) Covariance between the activities is zero due to the independence of the samples.

(Freese,1962) confidence intervals were constructed in the following manner.

Appendix B - Confidence Intervals

$$L(E_j) = \sum_{i=c}^{Y} (CF)_{ij}(E_{ij}) \pm t\alpha \sqrt{\sum_{i=c}^{\hat{Y}} (CF)^2_{ij}(S^2\hat{Y})_{ij}}$$

Where E_j = Estimated (Ave.) man hours/cunit output for a given technique (j).

j = Study technique. Conventional Thinning, "Hot-Yarding" 10 ft. corridor or "Hot-Yarding" 20 ft. corridor.

E_{ij} = Estimated activity time from regression equations for a given set of conditions.

i = Individual thinning activity used in conjunction with each technique.

$\sum_{i=c}^{\hat{Y}}$ = Sum of all activities (c) Corridor felling (Thn) Thinning and (Y) Yarding/swing.

$t\alpha$ = The value of the "t" statistic at the (α) significance level.

$(CF)_{ij}$ = The unit conversion factor derived for each (ij) activity.

$(S^2\hat{Y})_{ij}$ = The variance associated with each (E_{ij}) for a given set of conditions. This was derived by squaring the standard error of the estimate given for estimate using the regression equations.

TESTS ON FELLING REGRESSION MODELS

Test*	Test Statistic	Model	α	d.f.	Critical Value	Test Value	Conclusion
- For significant linear relationship Ho: $B_1=B_2=\cdots B_p=0$ Ha+ $B_1\neq B_2\neq\cdots B_p\neq 0$	$F = \frac{MSR}{MSE}$	KFTHN	.01	3/42	4.29	25.064	Reject Ho: Conclude that a significant linear relationship exists.
		KFCOR	.01	1/35	7.41	85.334	Reject Ho: Conclude that a significant linear relationship exists.
		WTFALL	.01	2/101	4.82	32.141	Reject Ho: Conclude that a significant linear relationship exists.
- For "Lack of Fit" Ho: $E(y)=B_0+B_1X_{i1}+\cdots+B_pX_{ip}$ Ha: $E(y)\neq B_0+B_1X_{i1}+\cdots+B_pX_{ip}$	$F = \frac{MSLOF}{MSPE}$	KFTHN	.05				No multiple "Y" values for same set of "x" ∴Cannot estimate MSPE
		KFCOR	.05	16/19	2.21	0.8478	-Do not Reject Ho: -Cannot show model does not fit the data.
		WTFALL	.05	83/18	1.99974	1.91217	-Do not Reject Ho: -Cannot show model does not fit the data.

* See Appendix B for Test description

APPENDIX C

TESTS ON YARDING REGRESSION MODELS

Test	Test Statistic	Model		df.	Critical Value	Test Value	Conclusion
- For Significant linear relationship Ho: $B_1 = B_2 = \cdots B_p = 0$ Ha: $B_1 \neq B_2 \neq \cdots B_p \neq 0$	$F = \frac{MSR}{MSE}$	KYREG	.01	$^4/_{122}$	3.47	86.429	Reject Ho: Conclude a significant linear relationship exists.
		HYTEN	.01	$^6/_{292}$	2.88	85.912	Reject Ho: Conclude a significant linear relationship exists.
		HYTNY	.01	$^3/_{213}$	3.88	118.177	Reject Ho: Conclude a significant linear relationship exists.
- For Validating use of regression outside of data base. Ho: $\mu d = 0$ Ha: $\mu d \neq 0$	$t = \frac{(\bar{x}_A - \bar{X}_R)}{\sqrt{\frac{S^2 d}{n}}}$	KYREG	.05	44	2.015	-1.434	Do not Reject Ho: No difference between means can be shown.
		HYTEN	.05	80	1.990	-0.377	Do not Reject Ho: No difference between mean can be shown
		HYTNY	.05	62	1.999	0.836	Do Not Reject Ho: No difference between means can be shown.

OBSERVED YARDING DELAY SUMMARY

Delay Category	Yarding Operation								
	KYREG			HYTEN			HYTNY		
	% freg.[1]	Ave.min.[2] /delay	Ave delay[3] min./turn	% freg.	Ave.min. /delay	Ave.delay min/turn	% freg.	Ave. min /delay	Ave.delay min./turn
Equipment	7.32	7.679	0.562	1.20	16.094	0.193	10.92	3.942	0.420
Landing	22.44	3.325	0.746	9.42	1.556	0.147	7.28	1.546	0.113
Line & Rigging	4.89	21.219	1.038	3.38	8.348	0.282	1.66	3.262	0.054
Operation	17.07	1.641	0.280	14.73	1.591	0.234	16.21	1.790	0.290
Instruction	0.98	2.290	0.022	1.21	0.788	0.010	-0-		
Personnel	1.47	3.997	0.059	-0-			-0-		
Felling	N/A			0.96	4.647	0.045	1.98	2.372	0.047
Swing	N/A			4.59	1.774	0.081	1.99	0.883	0.018
Miscellaneous	4.39	4.813	0.211	4.35	4.545	0.198	7.61	2.838	0.216

1 - Observed number of occurrences per 100 turns.

2 - Average delay time (minutes) per occurrence.

3 - Total Category delay time averaged over all observed turns.

APPENDIX E

DETERMINING STANDARDIZED VOLUMES PER TREE AND TURN

Stand Conditions:

- 340 stems/acre
- 12 in. average butt diameter
- 19.71 ft^3. volume per average stem.
- 165 stems per acre thinned
- 9 in. average butt diameter of thinned stems.
- 10.81 ft^3. volume per average stem thinned
- 6.8% of area in corridor (10 ft wide)
- 13.6% of area in corridor (20 ft wide)
- 93.2% of area Thinned (10 ft wide corridor)
- 86.4% of area thinned (20 ft wide corridor)

Let
V = Volume in ft^3.
Psc = Pieces (# logs)
Trn = Yarding cycle (turn)
Ac = Acre
Stm = Stem (tree)
Wt = Unit Volume weighting factor
COR = Activity in the corridor
THN = Activity in the Thinning area.

KYREG from falling data
Ave. 1.5 pieces/tree from the corridor
Ave. 1.35 pieces/tree from Thinning
Ave. 1.917 pcs./turn

Vol/turn

$$= (V/Pc)(\#Pcs./Trn)$$

$$= \frac{(V/Ac)}{(\#Pcs./Ac)} (\#Pcs./Trn)$$

$$= \frac{(V/Ac \text{ from COR}) + (V/Ac \text{ from THN})}{(\#Pcs./Ac \text{ from COR}) + (\#Pcs./Ac \text{ from THN})} (\#Pcs/Trn)$$

$$= \frac{[Wt(Stm/Ac)(V/Stm) \text{ from COR}] + [Wt(Stm/Ac)(V/Stm) \text{ from THN}]}{[Wt(Stm/Ac)(\#Pcs./Stm) \text{ from COR}] + [Wt.(Stm/Ac)(\#Pcs./Stm) \text{ from THN}]} (\#Pcs/Trn)$$

$$= \frac{[.068(340)(19.71)] + [.932(165)(10.81)]}{[.068(340)(1.5)] + [.932(165)(1.35)]} (1.917)$$

<u>Vol/turn = 16.75941 ft^3/turn</u>

APPENDIX E

HYTEN from yarding data Ave. 1.3503 stems/turn.

Vol/Turn

$$= (V/Stm)(Stm/Trn)$$

$$= \frac{(V/Ac)}{(Cut\ Stm/Ac)} (Stm/Trn)$$

$$= \frac{(V/Ac\ from\ COR) + (V/Ac\ from\ THN)}{(Stm/Ac\ from\ COR) + (Stm/Ac\ from\ THN) \longrightarrow (cut\ stems)} (Stm/Trn)$$

$$= \frac{[Wt(Stm/Ac)(V/Stm)\ from\ COR] + [Wt(Stm/Ac)(V/Stm)\ from\ THN]}{[Wt(Stm/Ac)\ from\ COR] + [Wt(Stm/Ac)\ from\ THN]} (Stm/Trn)$$

$$= \frac{[.068(340)(19.71)] + [.932(165)(10.81)]}{[.068(340)] + [.932(165)]} (1.3503)$$

$Vol/Turn = 16.16790\ ft^3/turn$

HYTNY from yarding data Ave. 1.3503 stems/turn.

Vol/Turn

$$= \frac{[Wt(Stm/Ac)(V/Stm)\ from\ COR] + [Wt(Stm/Ac)(V/Stm)\ from\ THN]}{[Wt(Stm/Ac)\ from\ COR] + [Wt(Stm/Ac)\ from\ THN]} (Stm/Trn)$$

$$= \frac{[.136(340)(19.71)] + [.864(165)(10.81)]}{[.136(340)] + [.864(165)]} (1.3503)$$

$Vol/Turn = 17.54057\ ft^3/turn$

APPENDIX F

OPERATION COST DERIVATION

A) Equipment Depreciation:

Item		Equipment		
		Koller K-300 Yarder w/SKA 1 Carriage	Small Rubber Tired Skidder (less tires)	Talkie Tooter Model 30-2
Initial Cost (NC)		$48,500 [1]	$62,090 [1]	$4,523 [1]
Salvage life (n)		4 yrs.	6 yrs.	4 yrs.
Salvage Value	% (NC)	20%	20%	10%
	Amount (SV)	$9,700	$12,418	$452.30
Yearly Depreciation $= \frac{NC-SV}{n}$		$9,700	$8,278.67	$1,017.68
Average Annual Investment (AAI) $= \frac{(NC-SV)\ (n+1)}{2n} + (SV)$		$33,950	$41,393.33	$2,996.49

B) Operation Costs

I. Falling Operations (Corridor felling & Thinning)

Faller with saw
(wages, fringe, transportation and operation)[2] - $20.64/Hour

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1 - From Cost Guide for Empirical Appraisals, Revision 10, November, 1981, U.S. Forest Service, Region Six.

2 - From Union Labor Rates using a Fringe Benefit and Burden Factor of 1.40 and Travel Pay of (0.75/Hr.).

APPENDIX F

II. Yarding Operations

- Average operating season - 1600 Hrs/Yr.

	$/Yr.	$/Hr.
Fixed Costs: (Yarder, Carriage & Radio)		
Depreciation	10,717.68	
Interest at 16% (AAI)	5,911.44	
Insurance at 3% (AAI)	1,108.39	
Taxes at 3% (AAI)	1,108.39	
Σ =	18,845.90	$11.78

Variable Costs:	$/Yr.	$/Hr.
Maintenance & Repair at 50% (Dep/Yr) (Yarder)	4,850.00	
Fuel (1.6 Gal/Hr.) (1600 Hrs/Yr) ($1.25/Gal)	3,200.00	
Lube, Filters, Grease at 10% (Fuel)	320.00	
Miscellaneous (Rigging, radio batteries, climbing gear, tools, etc.)	830.00	
Σ =	$9,200	$5.75

Labor Costs:

Two Yarding Crew Members at ($15.07/Hr)[3] = $30.14/Hr

Total Yarding Operation	=	$47.67/Hr

3 - From Union Labor Costs averaged for a Chaser, Choker Setter and Yarder Operator.

APPENDIX F

III. Swing Operations

Fixed Costs: (Swing Skidder)	$/Yr.	$/Hr
Depreciation	8,278.67	
Interest at 16% (AAI)	6,622.93	
Insurance & Taxes at 6% (AAI)	2,483.60	
Σ =	$17,385.20	$10.87

Variable Costs:	$/Yr.	$/Hr
Maintenance & Repair at 50% (Dep/Yr)	4,139.34	
Fuel (1.5 Gal/Hr) (1600 Hrs/Yr) ($1.10/Gal)	2,640.00	
Filter, Lube & Oil at 50% (Fuel)	1,320.00	
Tires - one per year at $1500/tire	1,500.00	
Cable and Choker: 150 ft. at $1.76/ft 6 chokers at $26.63 Ea.	423.78	
Miscellaneous: (Saw, tools, safety equip equip., etc.)	660.00	
Σ =	$10,683.12	$ 6.68

Labor Costs:

One Skidder Operator at ($16.47/Hr.) = $16.47/Hr

Total Swing Operation = $34.02/Hour