Swinging and Processing Whole Tree, Tree Length, and Log Length Pieces in a Douglas-fir Thinning

by

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Title: Swinging and Processing Whole Tree, Tree Length, and Log Length Pieces in a Douglas-fir Thinning

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This paper describes a study done on swinging and processing whole tree, tree length and log length pieces in a smallwood Douglas-fir thinning. Two machines were evaluated, a 70 horsepower rubber tired skidder and a hydraulic loader mounted on a 6 x 4 live tandem truck.

The study took place in the foothills of the Coast Range in western Oregon. The stand averaged 217 trees/acre and 15 ft^3/tree. Skidder and loader swinging occurred on rock surfaced truck roads.

Both the loader and skidder were analyzed using work sampling and detailed time study techniques. Regression analysis was used to develop an equation to predict delay free turn time for the skidder.

The whole tree/tree length skidder operation produced 2.74 cunits/scheduled hour at $16.45/cunit for a two man crew and $22.61/cunit for a three man crew.

There was no difference in production rates. A comparable two man log length operation produced 3.41 cunits/scheduled hour at $23.51/cunit. This higher cost included limbing and bucking done at the stump. The whole tree/tree length loader operation produced 3.21 cunits/scheduled hour at $16.15/cunit.

Crew interaction was evaluated using work sampling. For the skidder operation, interference was nonexistent, the equivalent of almost one man was idle (93.8%) on the three man crew, and idle time ranged from 35-52% for the chaser and 12-18% for the skidder operator. For the loader operation, interference time was 7.1% for the loader and 9.7% for the chaser, and idle time was 30.1% for the loader and 37.5% for the chaser. All percents were based on total scheduled time.

For the skidder assisted operation, limbing and bucking production and cost rates were 1.82 cunits/scheduled hour for $13.19/cunit at the stump and 6.54 cunits/scheduled hour for $6.02/cunit on the landing.

Fallers removed an average of 30.27 limbs/tree at the stump while landing crews removed 5.23 limbs/tree. Yarding and swinging knocked off the difference.

Slash, consisting of limbs and tops, averaged 4.95 ft^3/tree. Slash handling accounted for 2% of total time for the skidder and 18% for the loader.

All breakage occurred on the skidder operation. Eleven pieces were broken resulting in 0.2% of the total gross volume being lost. All of these were on corridors where the angle with the truck road required the logs to be turned more than 90 degrees.

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I. INTRODUCTION

Trends in forest management in western Oregon indicate shorter rotations and more intermediate entries in stands 20 to 70 years old (Aulerich, 1975). The majority of the trees harvested from these stands will be small sawtimber (less than 20 inches dbh). Tedder (1979) estimates that by 2075 the average dbh of all timber harvested in Oregon will be 14 inches.

Unfortunately, these small trees generally produce lower grade logs. Combining this with lower volumes removed per acre makes smallwood harvesting marginally profitable. To further compound the problem, one-third of the operations are conducted with cable systems where yarding costs are 2.25 to 2.75 times higher than ground based systems (Aulerich, 1974).

To reduce costs per cunit of wood, greater volumes yarded per turn and less handling per piece can be accomplished by leaving the tree in one piece. There are two harvesting systems that produce longwood. These, along with the traditional log length method are described below.

Log Length Method(LL) - Trees are felled, limbed and bucked in the stump area.

Tree Length Method(TL) - Trees are felled, topped to a predetermined diameter (4 inches), limbed at the stump, and yarded as a tree length piece.

Whole Tree Method(WT) - Trees are felled and the full tree with limbs and top is yarded.

Once these longer pieces reach the yarder landing they will require processing (limbing and bucking) to manufacture them into merchantable logs and poles. These procedures are both unsafe and impractical to do on the small yarder landings that are common in thinning operations. These pieces must be moved to an area where they can be processed, decked and later loaded on trucks. Traditionally logs have been swung with ground vehicles (skidders or crawlers) or swing boom loaders (Cottell et al., 1976).

As part of a larger research project that investigated other aspects of longwood harvesting, this study examined swinging and processing whole tree, tree length, and log length pieces with a loader and rubber tired skidder to determine if the material handling problems associated with processing longer pieces could be offset by increased production, resulting in lower harvesting costs per cunit of wood.

II. LITERATURE REVIEW

Swinging operations have not been well documented in the literature. Pease (1972) reported on thinning coastal Douglas-fir with a cable yarder and swinging tree length pieces with a grapple skidder to a hydraulic bunk where loads were formed ahead of truck arrival. The Western Conservation Journal (1973) reported on cable yarding, and grapple skidder swinging of tree length pieces in western Washington. Several species were processed. Loads were built in a hydraulic bunk on this operation also. McIntire (1981) observed a rubber tired skidder with chokers swinging log length pieces in a Douglas-fir thinning in Oregon. He reported a mean production rate of 7.3 cunits/hour. He determined the skidder could be used elsewhere during 70 percent of scheduled time. Cottell et al., (1976) described eight cable logging operations in British Columbia and Alberta. Four had swing operations on them. Two were involved in swinging tree length spruce, balsam fir, and a variety of other species to another landing for bucking and decking. The other swing operations involved moving logs from yarder decks to keep the landing from plugging. No production rates were given, but costs from $4.10/cunit to $5.30/cunit (1976 Canadian dollars) were reported.

Cottell et al., (1976) also briefly discussed selection of the proper swing machine. They stated that heel boom loaders were commonly used where piece size was large and yarder production was high. When used in operations where piece size was small and yarder production low, they were inefficient. The small work area (determined by boom length) also limited their effectiveness. Skidders were also inefficient when their production was limited by yarder production. However, they were less expensive to operate than loaders and were more maneuverable.

While some published information exists on felling and bucking log length pieces in Douglas-fir thinnings, none exists on whole tree or tree length.

Aulerich (1975) studied felling and bucking in Douglas-fir thinnings. Results from his study indicated that limbing and bucking time was not related to thinning intensity. Delay free times ranged from 1.24 to 2.57 minutes for 10 inch dbh timber.

Two other reports indicate limbing and bucking Douglas-fir on the landing may be more productive.

Zasada and Benzie (1970) found that limbing and bucking at the landing was more productive (6.25 cords/hour versus 5 cords/hour) than at the stump in red pine (Pinus resinosa) strip thinnings (ave dbh: 6-18 inches) in Minnesota.

The *Western Conservation Journal* (1973) found that "delimbing seems to accomplish itself" during yarding and swinging tree length pieces in a mixed species operation in western Washington.

While these papers touch on aspects of swinging and processing young growth Douglas-fir, none specifically address it. It is hoped that the work summarized in this paper will help to answer these questions.

III. OBJECTIVES

1. For a John Deere 440-C rubber tired skidder, develop a regression equation that predicts delay free cycle time for swinging and processing whole tree, tree length and log length pieces.

2. Compare loader and skidder swinging and processing systems in cunits/scheduled hour and dollars/cunit.

3. Compare limbing and bucking at the stump versus limbing and bucking on the landing in dollars/cunit and cunits/scheduled hour.

4. Determine the volume of slash produced for a given volume of logs.

5. Determine the volume of wood lost due to breakage when handling longwood pieces on the landing.

IV. PROCESSING METHODS

A. Skidder Work Cycle

This operation consisted of a yarder, skidder, and chaser. To begin, the skidder backed to the yarder deck. The bull line was pulled to the logs and choker setting began. Chokers were set by the skidder operator and chaser. When the carriage neared the deck, both men got clear until the turn was dropped on the deck. One of them then unhooked the turn. After the lines and carriage were clear of the deck, they resumed hooking logs. After all chokers were set, the turn was winched to the skidder, broken out of the yarder deck, and skidded to the processing area. Once there, the bull line was released and chokers were unhooked from all nonsort pieces. The chaser and skidder operator then limbed, bucked and topped the pieces. Sort logs were skidded to the sort processing area, unhooked, processed, and piled. When returning to the yarder landing, any undecked logs were piled and slash was pushed off of the road. The cycle repeated when the skidder stopped at the yarder deck. Turns of clean (no branches or ragged ends) logs were not processed.

B. Loader Work Cycle

This process involved three components, the yarder, swing boom loader, and chaser. To start, the yarder brought a turn to the deck. Once the lines had stopped and the turn was dropped on the yarder deck, the chaser unhooked it. He then moved to a safe position. The carriage was sent back to the woods for another turn. When the yarder deck was clear of men and lines, the loader swung to it, selected pieces, picked them up, and swung them to the processing deck. This turn was set on the processing deck. The loader then either swung back for another turn or held the pieces to facilitate limbing and bucking. Next, the chaser climbed the processing deck and measured, limbed, bucked and topped the pieces. When he finished, he got off the processing deck. The loader then stacked the cut logs on the the processing deck, removed slash from the work area, and straightened the deck. The chaser went to the yarder deck, unhooked another turn, and the cycle repeated itself.

V. EQUIPMENT STUDIED

Four machines were used in the study. Logs were yarded with the Schield-Bantam T-350 yarder equipped with a Wyssen carriage.

The skidder operation used a John Deere 440-C (70 net flywheel H.P.) cable skidder with four chokers. The loader operation used a Ramey hydraulic loader mounted on 6 x 4 live tandem truck. Since no specifications were available on the loader, cost data for a loader of similar boom length and lift capacity were used.

Stihl 041 chain saws with 32 inch bars were used for limbing and bucking.

The reader is reminded that the use of trade, firm or corporation names in this paper is for the convenience of the reader and does not constitute endorsement or approval by the author or Oregon State University of any product or service to the exclusion of others which may be suitable.

VI. STUDY CONDITIONS

The study took place on sections 15, 16, 21, and 22, Range 5 West, Township 10 South, Willamette Meridian in Dunn State Forest approximately 10 miles North of Corvallis, Oregon (Figures 1 and 2).

The area was forested primarily in Douglas-fir (Pseudotsuga menziessii (Mirb. Franco) (90% by volume). Bigleaf maple (Acer macrophyllum Pursh.), grand fir (Abies grandis (Dougl.)Lindl.), bitter cherry (Prunus emarginata Dougl.), red alder (Alnus rubra Bong.), and madrone (Arbutus menziessii Pursh) formed minor components in varying densities.

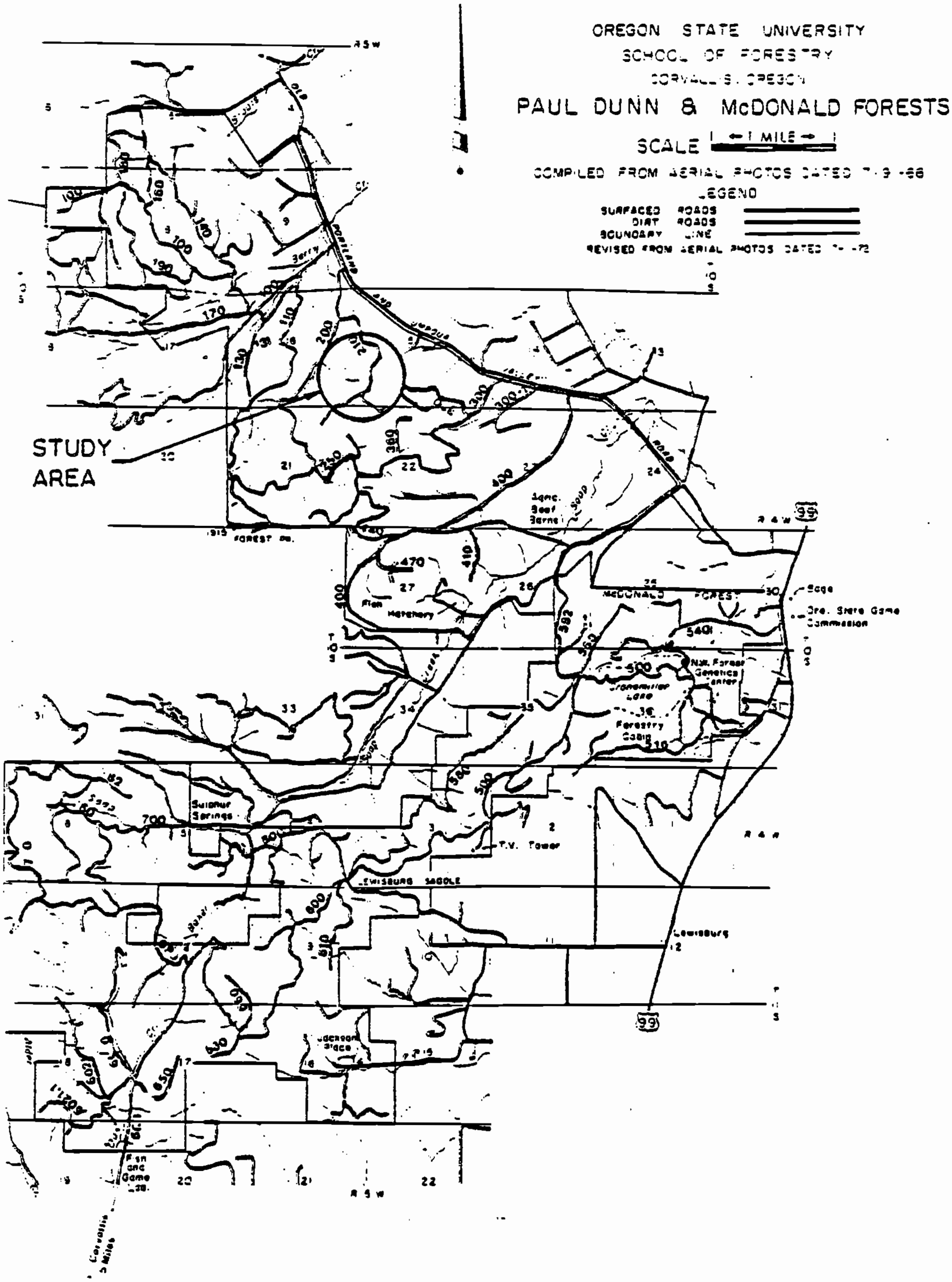
Stand characteristics were:

Site Class:	III (Douglas-fir)
Age:	35 years
DBH:	5-27 inches (12.7 ave.)
Tree Height:	38-111 feet (77 ave.)
Volume/Tree:	15 ft^3
Trees/acre:	217
Volume/acre:	2800-3900 ft^3/acre

A uniform removal of 40% of the stems was done by a local contractor. Fallers selected the trees to be cut by spacing and vigor; only Douglas-fir and grand fir were yarded.

Weather conditions were warm and dry for the duration of the study. The swing and limb and buck operations were conducted on rock surfaced truck roads. Surface conditions were dry. All grades were favorable

(1-12%). The skidder operator ran on an adverse of 6% for a few turns but abandoned it when he found his turn size was too small. No landing area construction was done. The skidder operator selected flat openings to deck logs in. The loader operator used the cleared chute area around the yarder to deck logs.



<u>Figure 1.</u> Area map

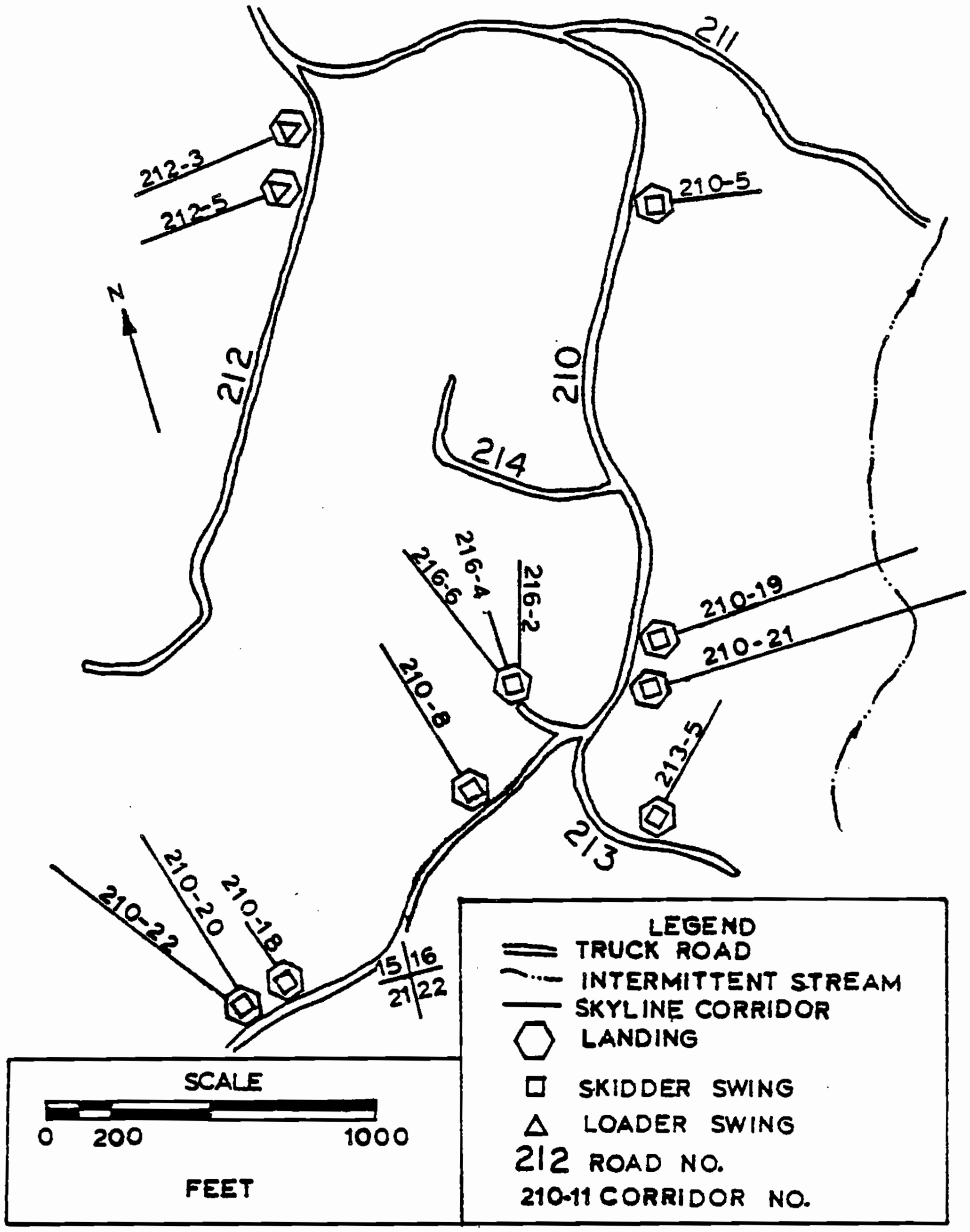


Figure 2. Study Location

VII. SKIDDER PRODUCTION STUDY

A detailed time study was undertaken to determine the length of each element of the work cycle and to develop production regression equations. The work cycle was broken into seven discernable elements; hook, travel loaded, unhook, limb and buck, deck, pile slash and travel unloaded. Delay free time was recorded for each of these dependent variables when they occurred in the work cycle. A series of independent variables, values used to explain the variation in delay-free time, were also observed and recorded for each turn. Delays were considered to be any cessation in the work routine that did not occur in the typical work cycle (Niebel, 1972) and were recorded for further analysis. Work sampling was used to generate information on the interaction of the yarder operator, skidder operator and chaser or chasers.

A. Continuous Time Study Procedure

Production data was gathered by the same person throughout the study. Skidding distances were short enough to allow the observer to see the whole operation. Dependent variables, independent variables, delays, and comments were recorded on a data sheet (Table A1). Times were measured with a stopwatch accurate to 1/100 of a minute. The "snap-back" timing technique, where the watch is reset to zero for each new element, was used. The criteria for determining each element, independent variable and delay is explained in the next three sections.

Timing started when the work crew arrived in the morning and ended at quitting time. Lunch breaks were not included as study delays because all equipment was down then. Because the objective of the study was to determine delays associated with productive activities, delays that caused the system to be down more than one hour were not included. Timing restarted when the system was working again.

1. Dependent Variables

The following variables were timed and recorded.

Hook - The time for the operator to get off the skidder, pull the bull line to the logs, attach chokers to the logs, get back on the skidder and winch in the bull line. The element started when the machine stopped and ended when the machine moved again.

Travel loaded - The time taken to move logs as payload. The element started when the machine first moved and ended when the machine stopped.

Unhook - The time required to remove chokers from the logs. The element started when the skidder stopped at the processing deck and ended when it moved again.

If preceded by limb and buck, it started when the operator set the saw dcwn. If followed by limb and buck it ended when the operator moved away from the chokers.

Limb and Buck - The time taken to measure, limb, and buck longwood pieces into logs. If it was the only element to occur when the skidder stopped, it began then and ended when the skidder moved again. If unhook preceded it, then the element started when the operator moved away from the chokers. If followed by unhook, it ended when the operator set down the saw. Unhook and limb and buck often occurred simultaneously when the chaser helped the skidder operator. To record both elements, the watch was set to zero when the skidder first stopped. The length of time to perform the shorter element was observed and written down and the watch was allowed to run until the longer element was finished. When completed, its time was recorded and the watch reset to zero for the next element.

Deck - The time required to pile logs. The element started when the skidder moved after unhook or limb and buck (if the logs were unhooked) and ended when it moved away from the log deck.

Pile Slash - The time taken to push limbs and tops clear of the yarder deck, truck road, and processing area. The element occurred irregularly and often during deck and travel unloaded. It began when the operator dropped the blade and ended when the operator raised the blade and moved away from the piled slash.

Travel unloaded - The time required to move without payload. The element started when the skidder moved while unloaded and ended when it stopped. It occurred after unhook, deck, and residue.

2. Independent Variables

The following independent variables were observed or calculated.

Volume - The gross cubic foot volume of the turn. Volume for each log was found using Smalian's equation:

$$V = 0.005454(L)((D_S^2 + D_L^2)/2)$$

Volume for whole tree and tree length pieces was determined using the cubic foot volume table for Douglas-fir (Table 32. Dilworth, 1981).

Pieces - Total number of pieces skidded per turn.

Backcuts - Number of bucking cuts made on a turn.

Limbs Removed - Number of limbs and stubs sawn off a turn.

Broken - Number of pieces broken during a processing cycle.

Loss - An estimate, in percent, of the volume lost due to breakage.

Road Grade - Percent slope, measured with a clinometer of the truck road. It was measured in the direction of loaded skidder travel. Adverse grade was negative and favorable was positive.

Deck-Road Angle - The angle (degrees) between the yarder deck and the truck road centerline in the direction of skidder travel (Figure 3). It was calculated

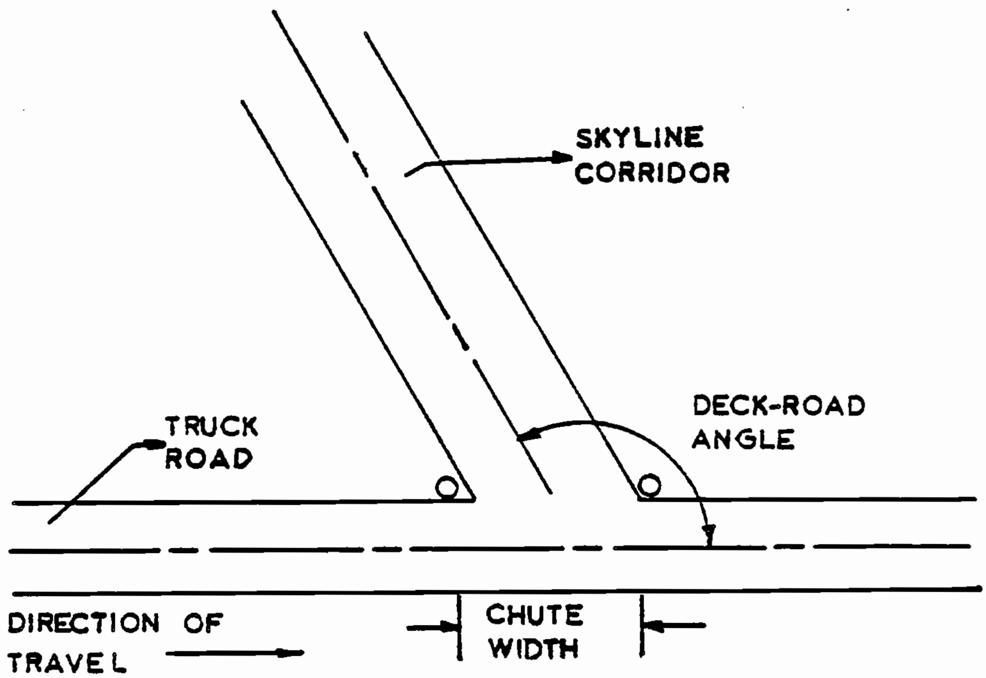


Figure 3. Deck-road angle and chute width

by measuring azimuths with a hand compass and taking the difference between them.

Chute Width - Distance (feet) measured with a tape, between the closest two obstructing trees nearest the truck road. (Figure 3) .

Douglas-fir Deck Width - Average width (feet) of the Douglas-fir processing deck after all pieces have been swung from the yarder deck.

Douglas-fir Deck Length - Average length (feet) of processing deck after all pieces were swung from yarder deck.

Grand Fir Deck Width - Average width (feet) of grand fir processing deck after all pieces were swung from yarder deck.

Grand Fir Deck Lengths - Average length (feet) of grand fir processing deck. Measured after all pieces were swung from yarder deck.

Douglas-fir Skid Distance - Slope distance (feet) from yarder deck hook point to Douglas-fir processing deck unhook point. Measured by pacing to the nearest foot.

Grand Fir Skid Distance - Slope distance (feet) from hook point at yarder deck to unhook point at grand fir deck. It can also be the distance from the Douglas-fir processing deck unhook point to the grand fir processing deck unhook point.

Whole Tree Pieces - Number of whole tree pieces in the turn.

Tree Length Pieces - Number of tree length pieces in the turn.

Yarder Landing Condition - A qualitative measurement of the yarder landing area based on space, congestion and layout. The values used are shown below:

0 - Swing operation not hampered by landing configuration.

1 - Swing operation continually hampered by a small or poorly managed landing.

Yarder Log Deck Condition - A qualitative measurement of the effect deck arrangement and structure had on the processing cycle. The values used were:

0 - Deck had logs generally even at the ends and parallel to each other. Swing operation not affected by deck configuration.

1 - Deck had practically no even ends and the logs were jackstrawed. The swing operation was hampered by deck configuration.

3. Delays

Delays were any cessation in the work routine that did not occur in the typical work cycle (Niebel, 1972). Delays were catagorized as follows:

Personal Delays - The time for necessary discussion between the skidder operator and other workers.

Operational Delays

Turn Stuck in Deck - Time required to break loose a stuck turn. This delay was started when it became apparent the turn would not come out of the deck without special treatment.

Saw Delays - Productive time lost due to chain saw being stuck or unavailable.

Lost Chokers - The time required to find and reconnect lost chokers.

Lost log - The time required to recover a log that came unhooked.

Chasing - Time lost when the skidder operator was chasing for the yarder. This occurred usually when the chaser had a personal delay.

Skidder Stuck - Time required to free the skidder when stuck.

Wait for Turn - Time spent waiting for enough pieces to build a turn.

Yarder Delays - Time spent waiting on the yarder due to interference.

Sort Chokers - Time required to untangle chokers.

Mechanical Delays

Yarder Repairs - Time lost due to repairs to the yarder, carriage and lines.

Skidder Repairs - Time spent repairing the skidder.

Fuel - Time needed to refuel or lubricate machinery.

B. Work Sampling Procedure

Work sampling was used to determine the percent of time each crew member spent in various work activities. This technique allows the observer to gather data on several individuals simultaneously.

Ten one hour samples of landing activity were taken by the same observer. At fixed intervals of 30 seconds, the activities of the skidder operator, yarder operator, and chaser were instantaneously observed and recorded on a data sheet (Table A2).

Twelve hundred total observations were made on each crew member.

1. Work sampling activity catagories

The activity categories used in this study, along with a description of the work elements contained in each, are listed below.

Yarding - Operated yarder or assisted in hooking logs.

Unhook Carriage - Unhooked chokers from logs. Spotted carriage to drop turn.

Hook Skidder - Pulled bull line to yarder deck. Hooked chokers around logs for skidder. Winched in bull line.

Travel - For skidder operator: drove skidder. All other crew members: traveled on foot.

Unhook Skidder - Undid chokers from logs at processing deck.

Limb and Buck - Measured, bucked and limbed trees.

Idle - Inactivity caused by no work.

Delay - Any other unproductive activity.

C. Results

1. Dependent and Independent Variables

Descriptive statistics for the dependent variables are found in Appendix B1. Calculation of mean times for each element was based on occurrence rather than the total number of turns. The percent of turns that each element appeared in is summarized in Table B2. It was felt that a more accurate description of the data results from this method of presentation. In calculating a total delay free turn time, only turns containing no missing values (a missing value is one where the event occurred but a time was not observed for it) were used.

A paired t-test of unequal sample sizes was used to determine if the mean total delay free turn time was different for whole tree, tree length, and log length treatments. The t-test data and results appear in Table 1.

Although paired t-tests determined there was no difference between mean turn times, regression analysis did. An indicator variable differentiating between longwood (any combination of whole tree and tree length pieces) and log length treatments increased R^2 15.45% and was significant at the 0.001 probability level. Two observed conditions helped explain similarities in turn time for the two longwood methods. First, nearly constant conditions (ground slope, distance traveled, surface conditions, piece size) caused travel, hook, and unhook times to be nearly identical. Second, a "fixed" time to perform duties (get saw, measure, buck, store saw) common to both processing methods reduced variation in limbing and bucking times.

TABLE 1. T-test For Difference In Mean Delay Free Turn Time

Ho: Ha:	Whole Tree (WT) vs Tree Length (TL) $\mu_{WT} = \mu_{TL}$ $\mu_{WT} > \mu_{TL}$		Tree Length (TL) vs Log Length (LL) $\mu_{TL} = \mu_{LL}$ $\mu_{TL} > \mu_{LL}$		Whole Tree (WT) vs Log Length (LL) $\mu_{WT} = \mu_{LL}$ $\mu_{WT} > \mu_{LL}$	
Treatment Type	Whole Tree	Tree Length	Tree Length	Log Length	Whole Tree	Log Length
Mean Cycle Time	9.67	9.05	9.05	8.14	9.67	8.14
Variance	20.25	10.96	10.96	11.49	20.25	11.49
Degrees of Freedom	77	17	17	8	77	8
Pooled Variance	18.57		11.13		19.43	
t-calculated	.5496		.659		.987	
t-critical	t(.005,94) 2.62		t(.05,25) 2.060		t(.05,85) 1.988	
Conclusion	No Significant Difference		No Significant Difference		No Significant Difference	

Procedure from Snedecor and Cochran (1980).

A final piece type not used in data analysis was mixed turns. These were any combination of whole tree, tree length, and log length pieces and occurred when the yarder was able to build large decks due to skidder breakdowns.

The independent variables are summarized in Table B3. Many of the variables had narrow ranges and only changed when the yarder moved to a new corridor. Among these were road grade, deck-road angle, chute width, Douglas-fir and grand fir deck length and width, and skidding distances to Douglas-fir and grand fir decks. Consequently, these parameters were not useful in explaining variations in delay free turn time.

2. Regression Analysis

Multiple linear regression analysis was used to determine a relationship between the dependent variable (time) and the independent variables measured.

The general linear regression model, with normal error terms, is (Neter and Wasserman, 1974):

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

where:

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

$X_{i1}, \ldots, X_{i,p-1}$ are known constants

ε_i are independent $N(0, \sigma^2)$

One regression equation was developed to predict processing and swinging delay free time. Indicator variables were used to determine statistical differences between treatments and operating conditions.

Selection criteria for acceptance of an independent variable in the model was based on the following criteria.

1. Regression coefficient was different than zero at 0.01 probability level. The test is (Neter and Wasserman, 1974):

   N.H.: $\beta_k = 0$

   A.H.: $\beta_k \neq 0$

   where the test statistic is $t^* = \frac{b_k}{s(b_k)}$

   and the decision rule is:

   If $|t^*| \leq t(1-(\alpha/2);\ n - p)$, conclude N.H., otherwise conclude A.H.

2. Coefficient of determination (R^2) improved at least 1% with the addition of the variable.

3. Mean square error must decrease with the addition of the variable. This insures minimum total squared deviation.

4. Cp criterion used to select the best model. Cp is an estimator of Γ_p (standardized total squared error) where:

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

The REGRESS subsystem of the Statistical Interactive Programming System (SIPS), (Rowe and Brenne, 1982) was used for regression analysis. The system was run on Oregon State University's CYBER 70/73 computer system. The regression equation is shown in Table 2.

The equation consists of a constant and five variables. Several points about the equation merit discussion. First, from observation the variable describing yarder log deck condition was important in explaining variations in hook time. As decks got larger and

TABLE 2. Skidder Regression Equation

Delay Free Turn Time (Minutes) =	5.6688
	+ 0.0377 (Volume/Turn) (ft.^{3})
	+ 1.0229 (Number Buck Cuts/Turn)
R^2 = .67	+ 1.9689 (Yarder Log Deck Condition)
n = 134	0 = Even and Parallel 1 = Uneven and Jackstrawed
	+ 2.1511 (Species Sort)
	1 = Skidding To Two Decks 0 = Skidding to One Deck
	- 2.9168 (Piece Type)
	1 = Any Combination of Longwood 0 = Log Length Pieces

All variables significant at the 0.01 probability level.

more uneven it was harder to set chokers and break the turn out of the deck. Second, the sort variable reflected the extra time needed to separate grand fir logs from Douglas-fir. Third, the coefficient on the piece type variable seemed incorrect. If a turn was composed of tree length or whole tree pieces, almost three minutes was deducted from the turn time, while no time was added or subtracted for log length pieces. However, approximately one minute was added for every bucking cut made. Since a mean of 4.25 buck cuts were made per whole tree/tree length turn and none were usually made on log length turns, whole tree/tree length turns would have been about 1.25 minutes longer if all other variables were constant. Finally, the narrow ranges reported for the independent variables necessitated the use of three indicator variables in the equation. Variations in turn time were partially caused by different procedures (sorts), treatments (whole tree/tree length or log length) or conditions (yarder log deck).

Estimation confidence intervals for example turn times are listed below (Table 3). Note the diverging nature of the confidence interval at the minimum and maximum values.

TABLE 3. Confidence Intervals For Estimated Turn Times

Variable	Range Minimum	Range Typical	Range Maximum
Volume/turn (FT^3)	10.00	71.13	224.58
Buck cuts/turn (1-12)	1	4.11	12
Turn Time (Minutes)	8.27	13.76	27.62
95% Confidence Interval	±1.72	± 1.58	± 2.88

3. Model Validation

The purpose of model validation is to test if the developed models predict delay free turn time for data other than that used to develop them. Ten percent of the turns were randomly removed for this purpose. A t-test comparing the mean observed versus mean predicted delay free turn time was used. Table 4 summarized the test.

TABLE 4. Model Validation

Yo = Observed delay free turn time
Yp = Predicted delay free turn time

Ho: $\mu_{Yo} = \mu_{Yp}$
Ha: $\mu_{Yo} \neq \mu_{Yp}$

N	15
μ_{Yo}	10.1757
μ_{Yp}	9.3036
Variance Yo	26.8842
Variance Yp	17.0453
Pooled Variance	21.96
t-calculated	.5096
t-critical	2.048
Conclusion	Model Validated

4. Delays

Delays are summarized in Table B4. Although delays are separated by treatment types, more credibility should be placed on the values generated for the whole system for two reasons. First, delays are random events. The largest sample size possible should be used to analyze them. Second, the turn types occurred on all corridors in an unpredictible manner. A delay attributed to a particular treatment type may have been caused by events occurring during another type.

The greatest amount of delay time for the processing system was caused by mechanical breakdown of the skidder. These accounted for 12.3% of total scheduled time. Yarder repairs caused delays during another 8.1% of total scheduled time and yarder-caused interference delayed the swing system for 2.4%. Almost 4% of the skidder's time was spent waiting for turns.

5. Utilization

Utilization is the percentage of scheduled hours the machine actually works (Miyata, 1980). To determine utilization for the skidder, the time the skidder was observed was assumed to be total scheduled hours. Utilization is then:

$$U = \frac{\text{Productive Time}}{\text{Total Scheduled Time}} = \frac{2219 \text{ MIN}}{3346 \text{ MIN}} = .66$$

6. Work Sampling Results

Work sampling results were used to generate percentage time distributions for the yarder operator, skidder operator, and chaser. Percentages were determined by dividing the number of observations of each activity by the total number of observations.

To determine the relative accuracy of work sampling, the formula for sample size (Miyata, 1981) is rearranged to give relative accuracy (E). The formula is then

$$E = \left(\frac{Z^2 Q}{N D}\right)^{1/2}$$

where E = Relative accuracy expressed as decimal
N = Sample size
D = Percentage occurrence of delay
Q = Percentage occurrence of nondelay
Z = Normal deviation (1.96 at C.I. of 95%)

Relative accuracy is then:

$$E_{Skidder} = \left(\frac{(1.96)^2(.66)}{(1200)(.34)}\right)^{1/2} = .078 \text{ or } \pm 8\%$$

$$E_{Yarder} = \left(\frac{(1.96)^2(.89)}{(1200)(.11)}\right)^{1/2} = .16 \text{ or } \pm 16\%$$

$$E_{Chaser} = \left(\frac{(1.96)^2(.46)}{(1200)(.54)}\right)^{1/2} = .052 \text{ or } \pm 5\%$$

Work sampling percentage time distribution graphs are shown in Figures 4-6 (two man processing crew) and Figures 7-10 (three man processing crew).

Some conclusions on crew interaction that can be drawn from this data are:

1. The two chaser crew was very inefficient. Chaser idle time was .938 on almost 1 person idle.
2. Interference was essentially nonexistent.

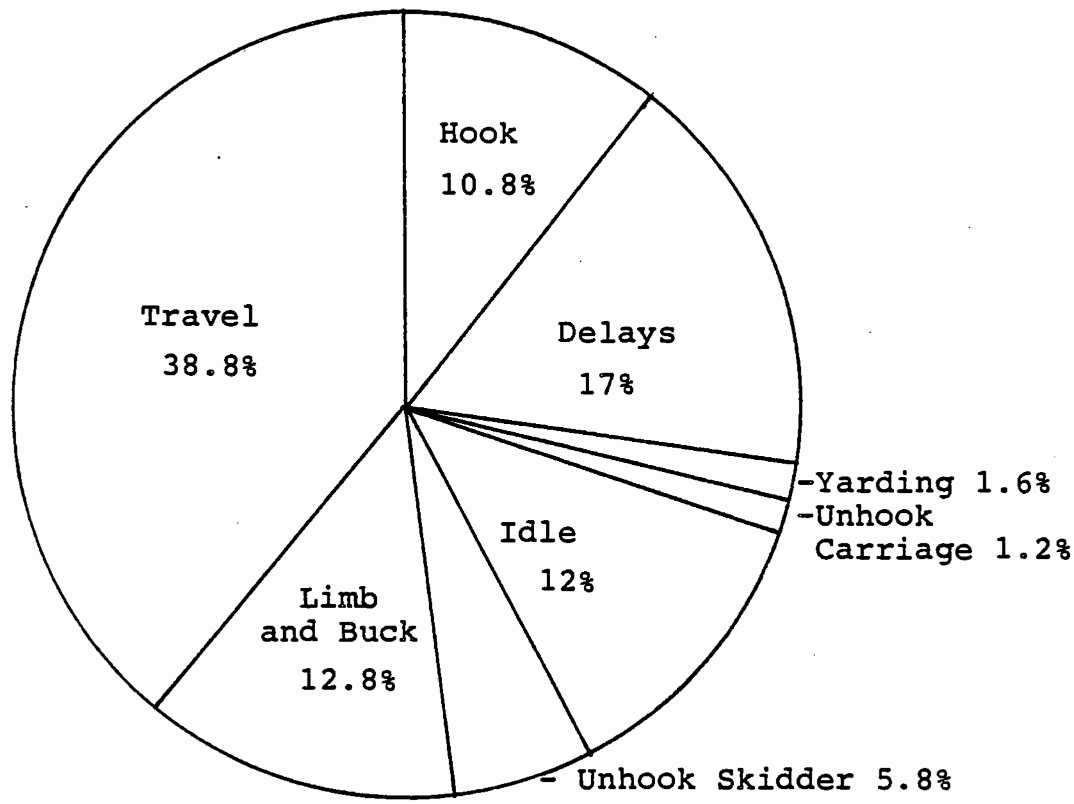


Figure 4. Skidder operator - two man crew

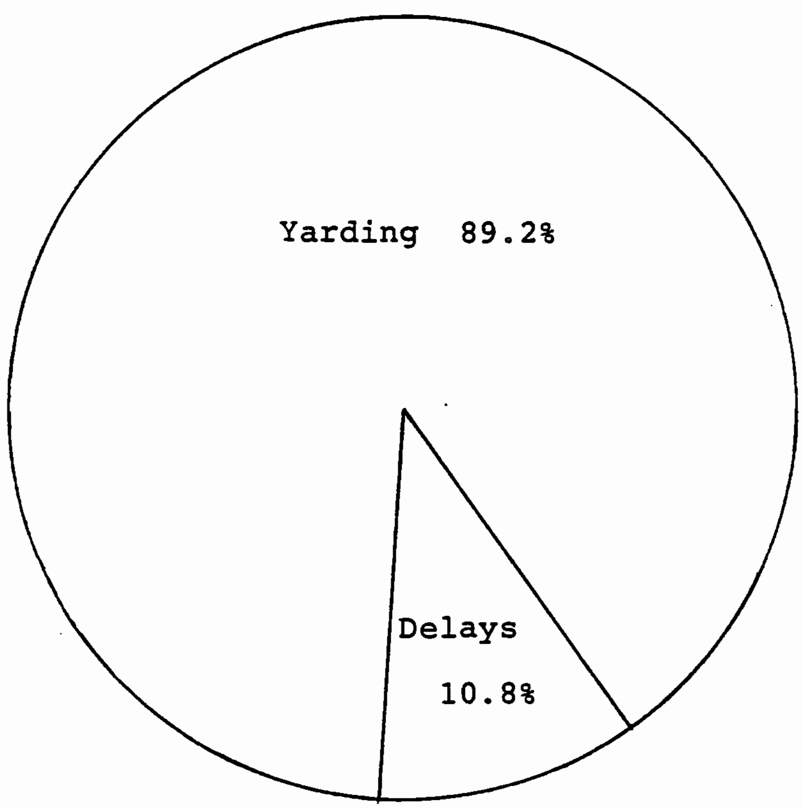


Figure 5. Yarder Operator - Two Man Crew (Skidder Swing)

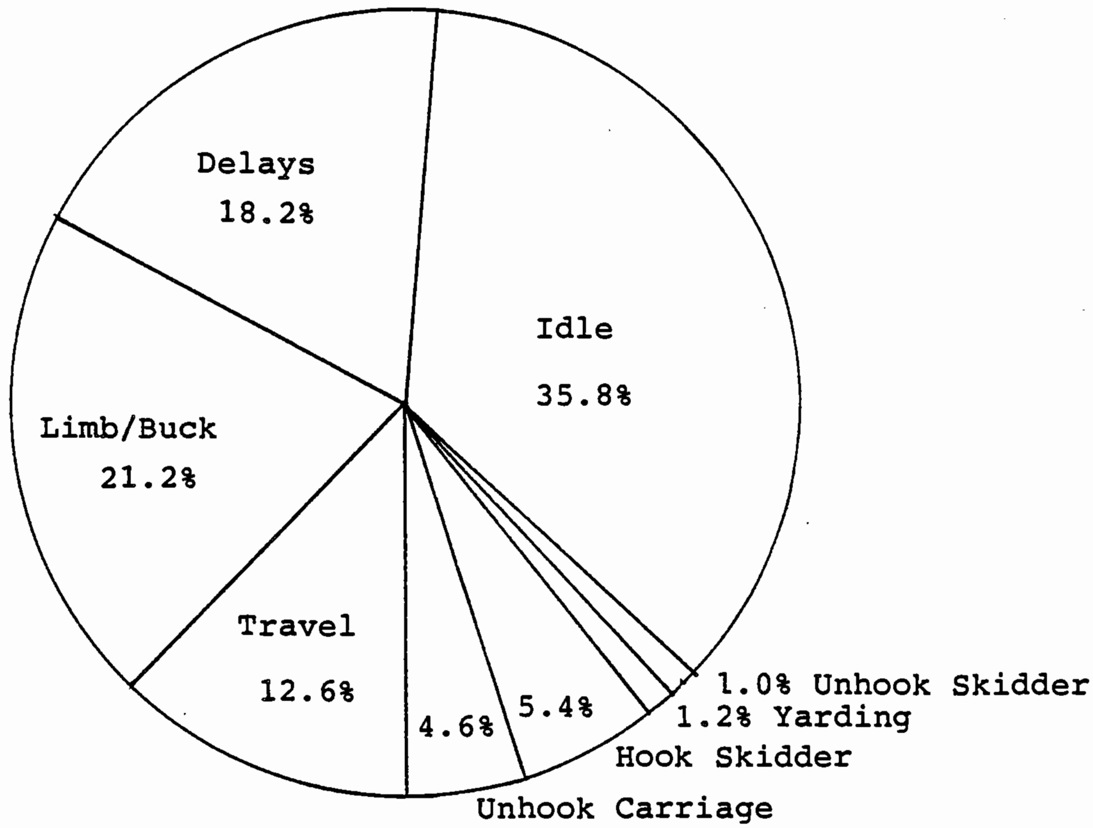


Figure 6. Chaser - Two Man Crew (Skidder Swing)

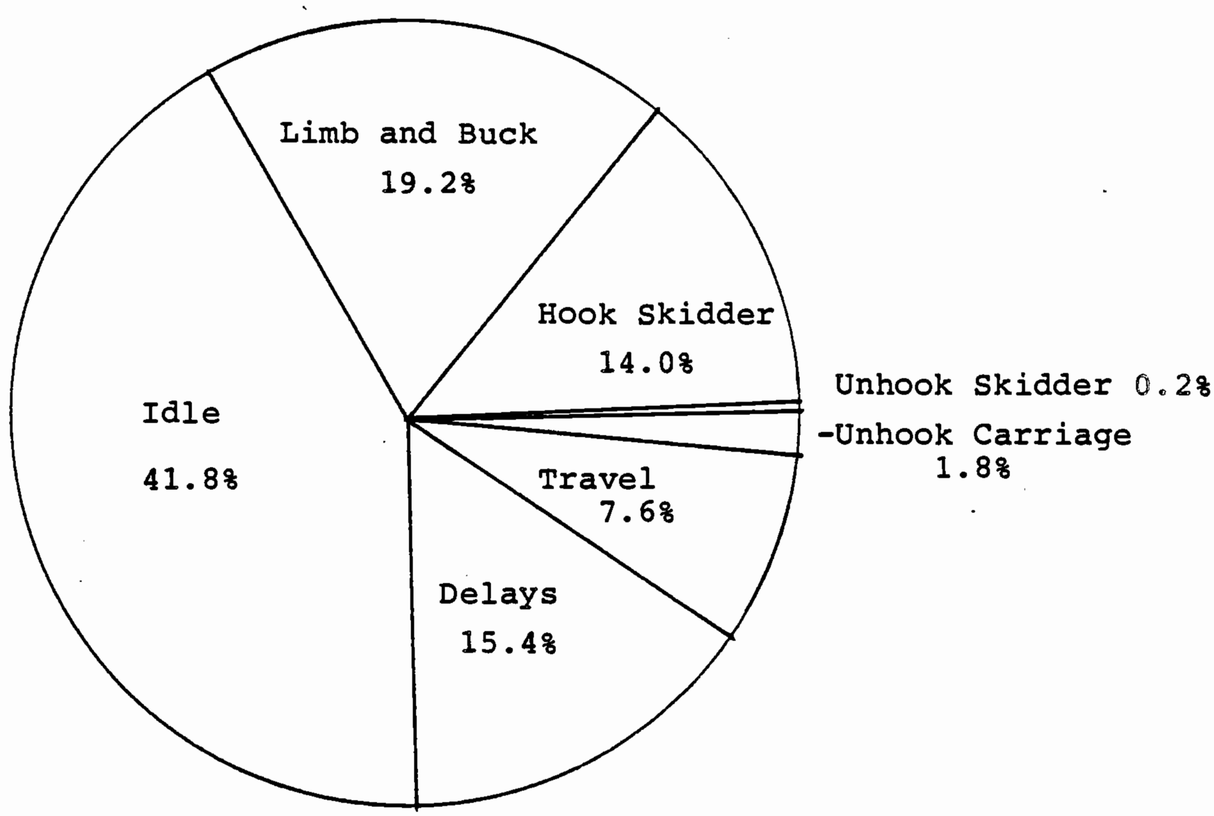


Figure 7. Chaser I - Three Man Crew (Skidder Swing)

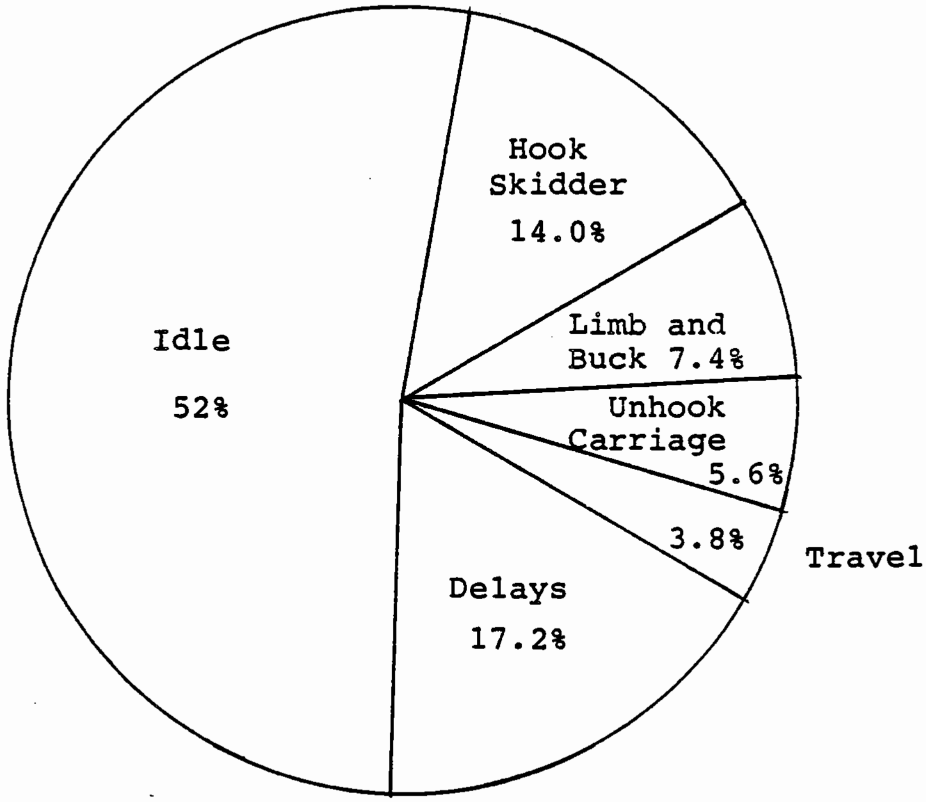


Figure 8. Chaser II - Three Man Crew (Skidder Swing)

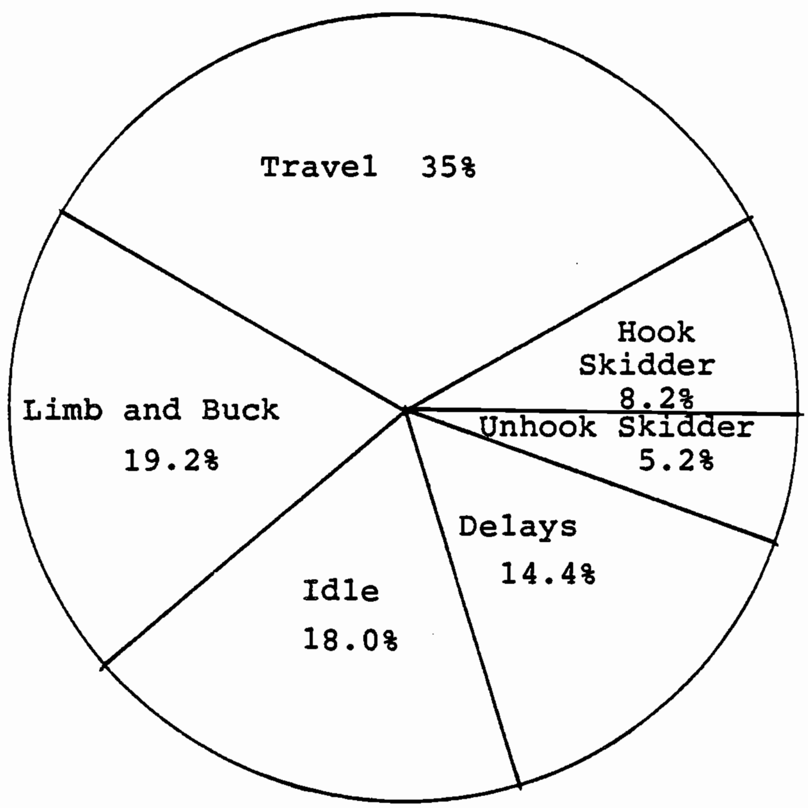


Figure 9. Skidder Operator - Three Man Crew

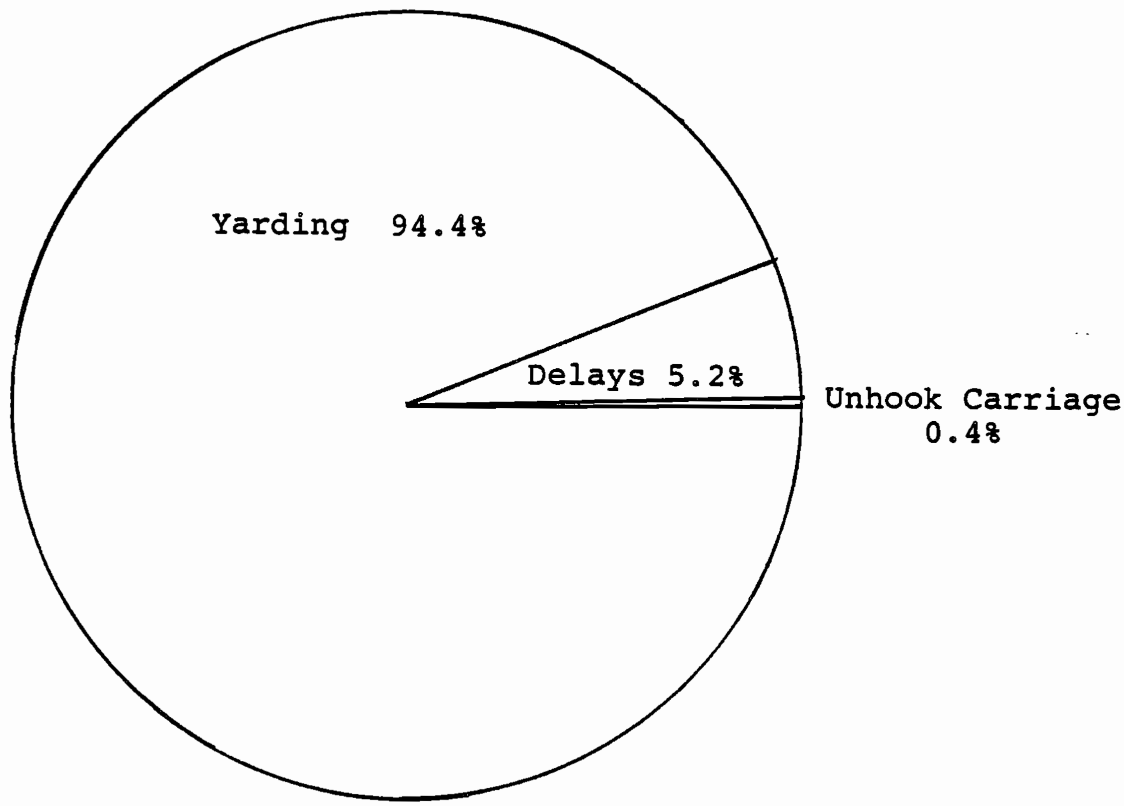


Figure 10. Yarder Operator - Three Man Crew (Skidder Swing)

3. The yarder operator had to unhook the carriage on the two chaser crew but not the one chaser crew. This reflects the clumsiness of the two chaser system.
4. Idle time ranged from 35-52% for the chasers and 12-18% for the skidder operator. The yarder operator was never idle.

7. Costs and Production Rates

Cost and production data are summarized in Table 5 and Figure 11 and developed in Appendix B5.

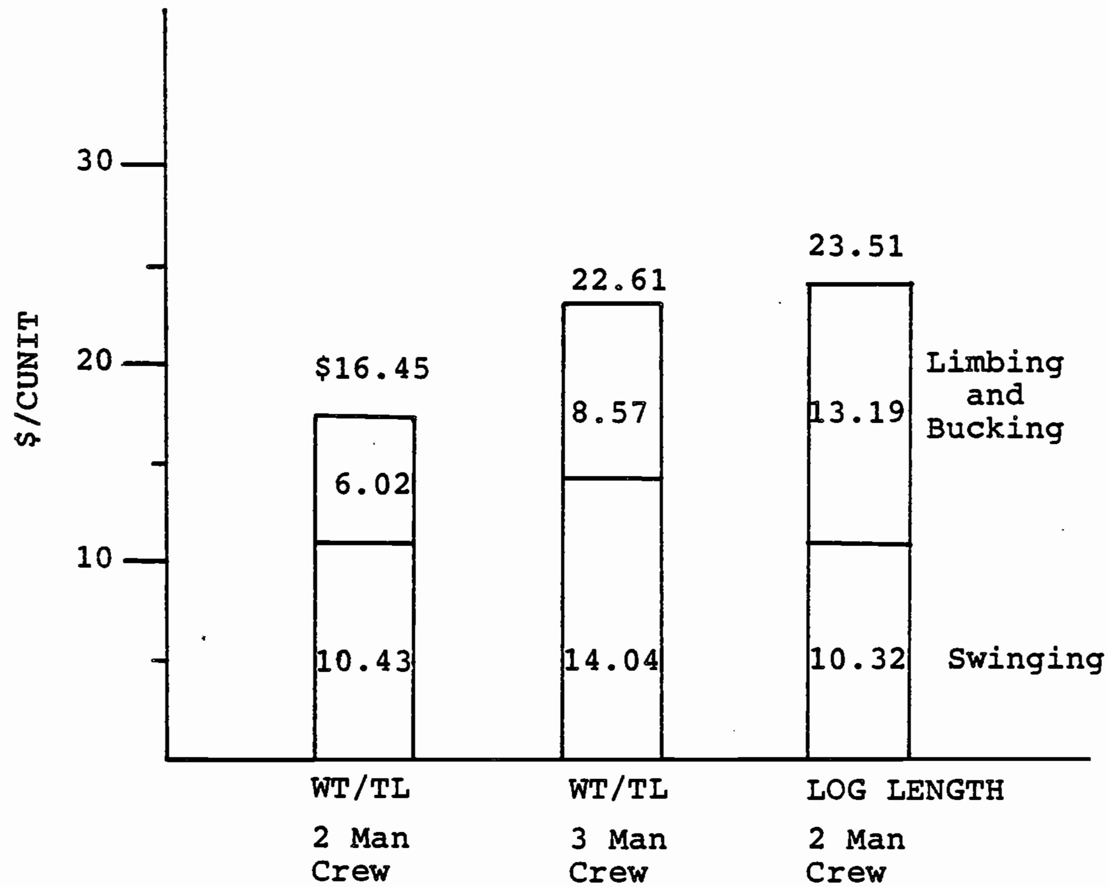


Figure 11. Skidder Swinging and Processing Costs

TABLE 5. Skidder Swinging And Processing Rates

System	Production (cunits/scheduled hour)
WT/TL - 2 Man	2.74
WT/TL - 3 Man	2.74
Log Length - 2 Man	3.41

D. Discussion

Varying crew size had no effect on production in the WT/TL system. This was verified in two ways. First, the coefficient of the "crew size" variable tested not significantly different than zero in any regression equation developed. This meant that changes in crew size did not explain variation in the amount of time it took to process a given volume of wood. Second, combined percentages of idle time for the two chasers was 93.8% or the equivalent of almost one man idle. This meant that there was enough work for only one chaser, the same as the two man WT/TL system.

Adding the extra man raised the swinging and processing cost from $16.45/cunit to $22.61/cunit and made three man crew an unattractive alternative.

Swing costs were almost identical for log length and two man WT/TL systems ($10.32/cunit and $10.43/cunit). However, high limbing and bucking costs at the stump ($13.19/cunit) made log length swinging and processing the most expensive method at $23.51/cunit. (Limbing and bucking is discussed further in Section IX).

Besides low cost, system selection can be based on balanced production rates between machines. This reduced bottlenecks and/or idle time. The production rates of the yarder and two processing methods are shown on the following page. Yarder production was calculated using a regression equation developed by Putnam (1983).

System	Production Rate
Yarder	2.10 cunits/SH
Two man WT/TL - Skidder	2.74 cunits/SH
Log Length - Skidder	3.41 cunits/SH

The yarder and two man WT/TL are most closely matched. Under the conditions of the study the yarder limited processing slightly (four percent of total time was spent waiting for pieces).

If this could be reduced, utilization for the processing system could improve up to 4%. One method of reducing unproductive time is to allow the yarder sufficient lead time to build a deck before swinging commences. For this paper, lead time is defined as the number of extra hours of operation needed by the yarder to match skidder swinging production. During this time, the swing machine could be used to skid logs near the road or straighten existing decks.

To determine lead time, breakeven analysis comparing yarder production to skidder production was used. Average production rates and conditions were assumed. Development of the solution is contained in Table B2 and Figure 12 is a graphical representation.

For the study conditions, a maximum of 4½ hours

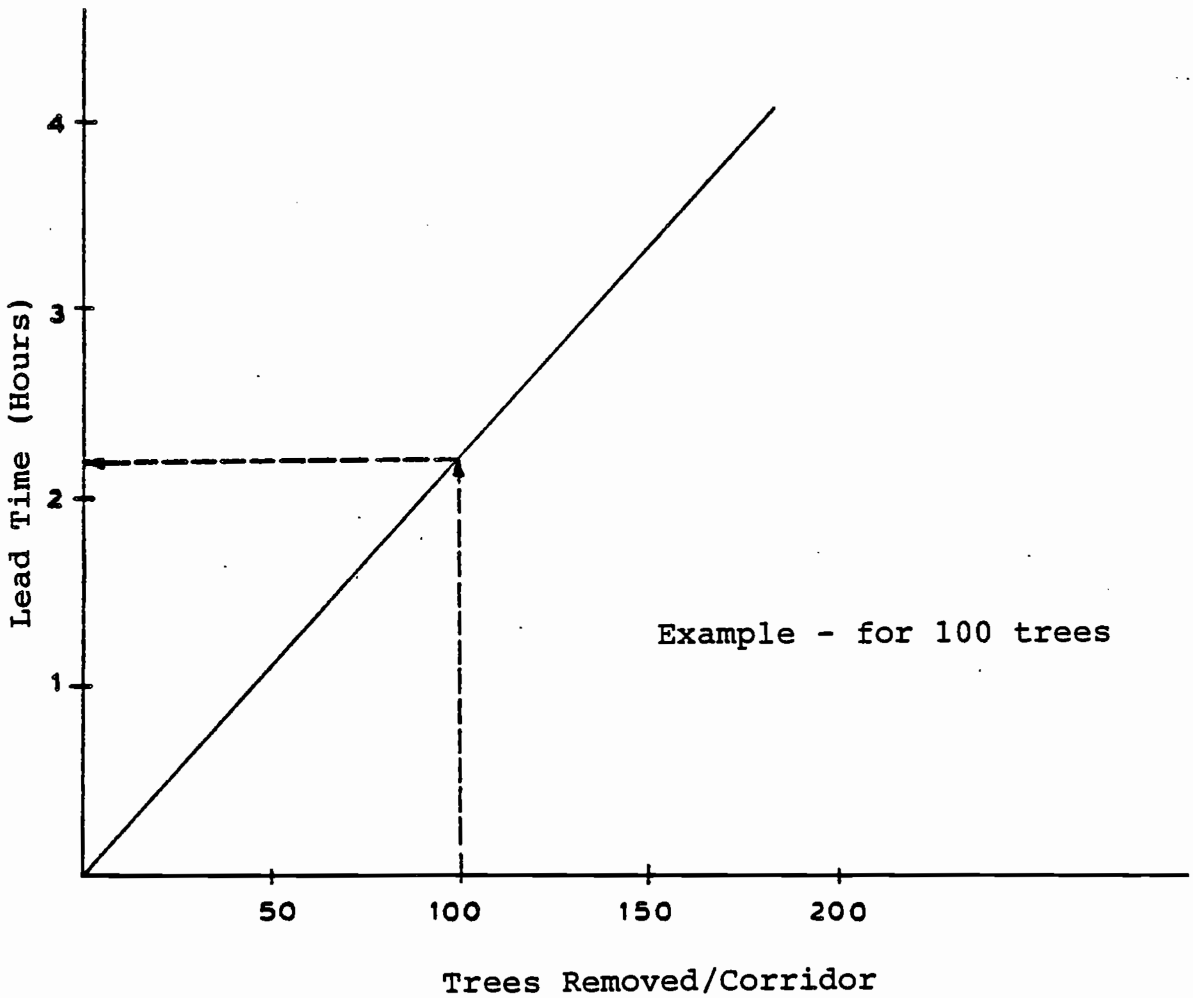


Figure 12. Yarder lead time

of lead time would be needed. To avoid building excessively large or uneven yarder decks this time could be dispersed throughout yarding of the corridor.

Assuming this technique would eliminate waiting for logs, utilization would improve 4%. Swing cost would drop to $15.50/cunit and, by using a ground based system to log part of the unit total cost may also be reduced (Aulerich (1974) found they were 2.5 times cheaper than cable systems).

Productivity could also be improved by a better mechanical maintenance program. Yarder, carriage, and line repairs took 8.1% of total time and skidder repairs 12.3%. Reduction of either of these would improve the utilization of the particular machine. However its effect on the system can not be determined. Increased production rates may cause either more bottlenecks or material shortages. Actual observation is the only way to determine this.

Finally, use of the regression equation developed in this section should be limited to operations with similar conditions. Variable size should be within the range of those stated in the paper.

VIII. Loader Production Study

Production data for the loader system was obtained using two methods: continuous time study and work sampling. The continuous time study, similar in format to the skidder study, was undertaken to determine time spent in each element of the work cycle, to develop a regression equation predicting delay free time for swinging and processing, and to analyze delays associated with the loader. Work sampling was used to generate information on the interaction of men and machines on the landing.

A. Continuous Time Study Procedure

Data was collected by the same person throughout the study. The work cycle was separated into four elements, swing, deck, limb and buck, and residue. Values for independent and dependent variables and delays were measured and recorded on field data sheets (Figure A3).

1. Dependent Variables

The following variables were timed and recorded. Residue, limb and buck, and deck did not occur on every cycle.

Swing - The time required to move trees from the yarder deck to the processing deck. The element included swinging empty, sorting and selecting stems, and swinging loaded. The element began when the operator moved the empty grapple to the yarder deck and ended when he released the tree on the processing deck.

Deck - The time taken to pile trees or cut logs. This procedure occurred at either deck. The element began when the boom moved to pick up a piece and ended when the piece was decked and the grapple released it.

Residue - The time taken to remove limbs and tops from the work area. The element began when the grapple moved to pick up slash and ended when the grapple released the slash.

Limb and Buck - The time taken to process trees into logs. The element included measuring, limbing and bucking, and getting clear of the loader when done. The element began when the chaser stepped onto the processing deck to limb and buck and ended when he got off the deck.

2. Independent Variables

Effective, safe observation of the swing cycle limited the number of independent variables that could be collected. Two collected were considered most important.

Volume - The gross cubic foot volume of the pieces swung by the loader. Volume was determined using the same methods as the skidder study.

Stems - Number of pieces swung per cycle.

3. Delays

Delay definitions developed in the skidder study were used for the loader.

One new delay was added.

Wait For Chaser - Delay of loader caused by chaser working on either deck.

B. Work Sampling Procedure

Five one hour samples of landing activity were taken by the same observer. At fixed intervals of 30 seconds the activities of the yarder operator, loader operator, and chaser/bucker were instantaneously observed and recorded on a data sheet (Figure A2). Six hundred total observations were made on each of the crew members.

1. Work Sampling Activity Categories

Six categories used in the skidder study, yard, unhook carriage, travel, limb and buck, idle and other dealy, were used in the swing loader study. The descriptions developed in the skidder section apply in this study. Three new categories, swing logs, slash removal and interference are unique to the loader study and are described below.

Swing Logs - Sorted, swung and decked trees cut logs.

Slash Removal - Cleared slash from work area with loader.

Interference - Another component impeded ability to do productive activity.

C. Results

Descriptive statistics for independent and dependent variables and delays are summarized in Tables C1-C3. The mean delay free time (a weighted average based on percent occurrence of each element) per cycle was 3.73 minutes. Elements other than swing occurred when enough material had accumulated to justify their performance. This explained why limb and buck occurred in 75%, deck in 74%, and residue handling in 63% of the turns. Mean production per cycle was 1.88 trees or 0.2622 cunits.

All system delays were attributable to the yarder, from either interference or lack of pieces to process. The system was idle 25% of the total time because of the yarder. These delays occurred frequently. The loader waited for the yarder (clear lines, carriage, etc.) on 39% of the turns and waited for pieces on 24% of the turns.

Delay free time was regressed against logs/turn and volume/turn. The best model developed could only explain 1.5% of the variation in delay free time. Both independent variables had narrow ranges in this study.

It was apparent that delay free time was not influenced by small variations in either value.

Work sampling was used to generate percentage time disbributions for the yarder operator, loader operator, and chaser/bucker (Figures 13-15). Relative accuracy (E) of work sampling data for the crew is shown below.

Yarder Engineer	± 14%
Chaser/Bucker	± 7%
Loader Operator	± 9%

From this data four statements on crew interaction can be made:

1. The yarder operator spent 4.8% of his total scheduled time unhooking turns. This occurred when the chaser processed trees. About one-third of the turns observed were unhooked by the yarder operator (Olsen, 1982).
2. Interference between components caused the yarder to be unproductive 0.4% of total time, the loader 7.1%, and the chaser/bucker 9.9%.
3. The chaser limbed and bucked during 24% of his total time.
4. Idle time occupied significant portions of each person's work day. The yarder operator was idle 11.4%, the loader operator 30.1%, and the chaser 37.5% of total time.

A second use of the work sampling data was to produce utilization rates for the components of the swing

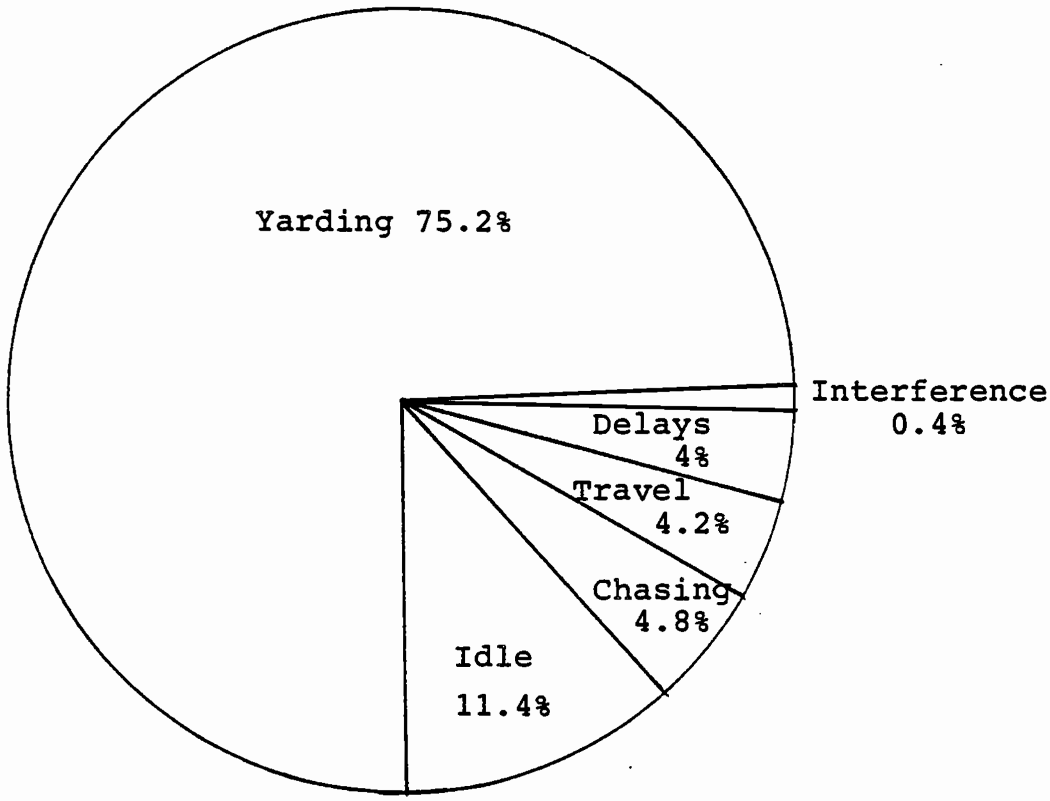


Figure 13. Yarder Operator (Loader Swing)

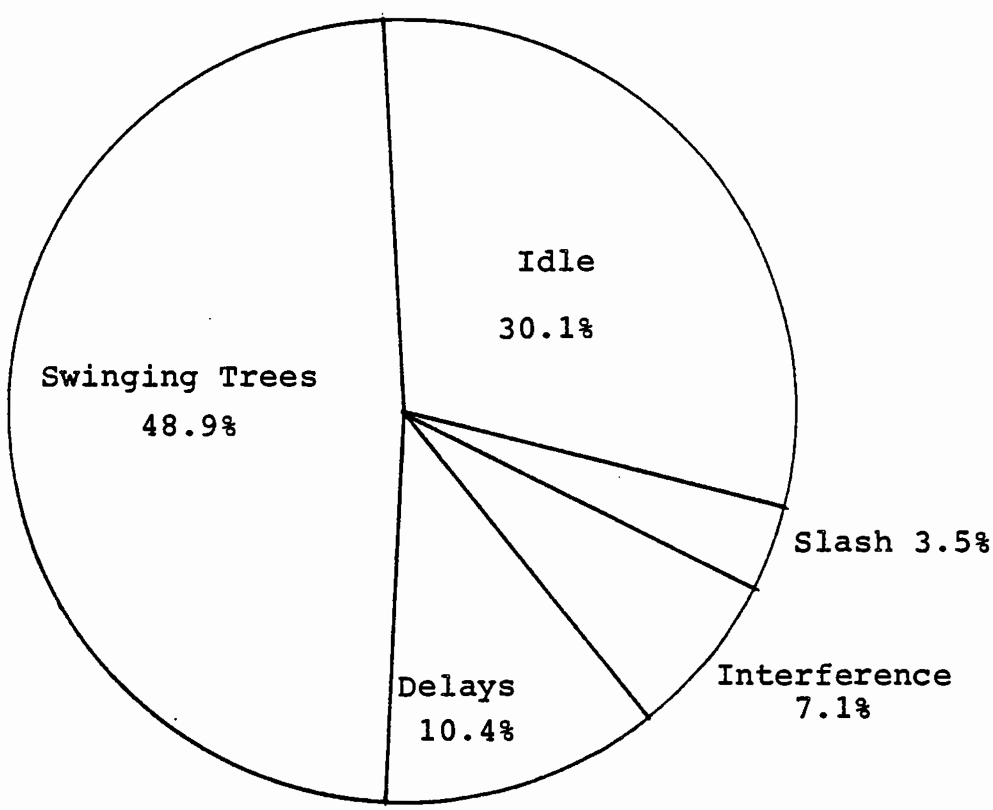


Figure 14. Loader Operator

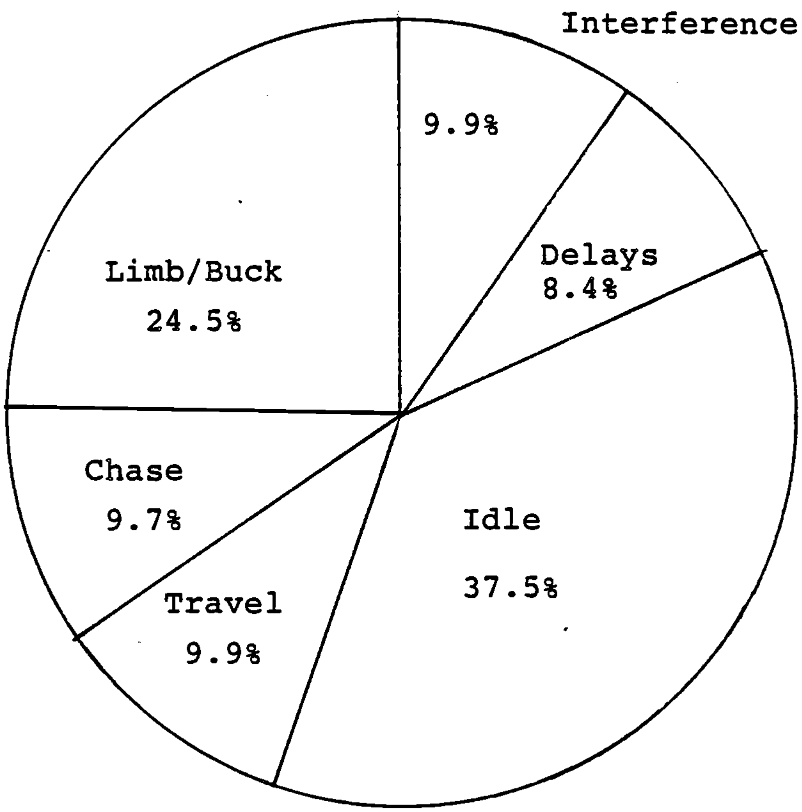


Figure 15. Chaser (Loader Swing)

system. From detailed time study data, the swing system (loader and chaser) had a utilization of .76. This meant that one or both of the components were involved in productive activity during 76% of scheduled time. However, work sampling revealed much lower rates for each of the components (Table 6).

TABLE 6. Utilization Rates For Loader Swinging and Processing

Component	Utilization
System	.76
Loader	.54
Chaser	.44

There are three reasons the components had such low utilization rates:

1. The loader was inactive during processing (22% of total scheduled time). Much of the time was spent holding the tree being limbed and bucked. This idle time was a function of safety. It was very dangerous for the chaser to work on the same deck as the loader. Several close calls were observed when both worked on the same deck.

2. Both swing components had much higher theoretical production rates than the yarder. Under the assumptions of no interference and unlimited tree supply, the loader was about 2½ times as fast as the yarder and the chaser 5 times as fast (Table 7).

TABLE 7. Nonlimited Production Rates

Component	Cunits/Scheduled Hour
Yarder	2.0
Loader[1]	5.32
Chaser/Bucker	10.88

[1]The loader's production rate was determined using the average turn size for the study. This load would weigh about 1000 lbs. However, loaders of this size class have lift capabilities of at least 3000 lbs at full extension. This implies even greater production rates could be possible for the loader.

As a result, both components spent significant portions of the work day waiting for pieces to process.

3. Interference resulted from the limited work area. The loader's work area is determined by the length of the boom (25 feet). All activities must take place in a 50 foot diameter circle. As discussed earlier, significant delay time resulted.

Cost and production data for loader swinging and processing mixed whole tree and tree length pieces are shown in Table 8 and developed in Table C5. These rates are based on the loader charged full time and the chaser on a prorated basis to the swing system.

TABLE 8. Loader Swinging and Processing Rates

Utilization	.76
Production (cunits/scheduled hour)	3.21
(cunits/productive hour)	4.22
System Cost ($/scheduled Hr)	$51.85
System Cost ($/cunit)	$16.15

D. Discussion

Two strategies are available to reduce the loader system processing cost:

1. Increase the supply of pieces to the processing

system. Conway (1982) discussed the use of medium sized yarders (Madill 044) in smallwood operations. With these machines, he stated, it was possible to use six chokers. Assuming a minimum of 5.16 cunits/scheduled hour could be yarded (a rate approaching the non-limited swing rate of the loader) the processing cost could decrease to $10.13/cunit (Table C5). In other words, doubling the small yarder production rate (5.16 cunits vs. 2.0 cunits) could decrease processing costs 37%. If the primary objective is to decrease processing costs, then pairing the loader with a medium sized yarder may be an attractive strategy. Disadvantages to this method include possible increased residual stand damage from yarding larger turns, plugged landings unless trucks are loaded out frequently, and reduced profits because of the higher operating cost of the medium sized yarder.

2. Load trailers when idle. Work sampling data indicates the loader is idle 30% of its scheduled time or 2½ hours in an 8 hour day. Studies by McIntire (1981) determined that it takes 74 minutes for a self-loading truck to load itself. Assuming a conventional truck takes the same time, two could be loaded per day by the loader. If 36.5% of the loader's rate is charged to truck loading, (based on a percent of total productive time prorated charge), the processing cost would decrease

to $11.21/cunit (Appendix C5).

This method could be effective if a trailer simiiliar to the General Short Logger was left on the landing to be loaded when time and logs were available. Otherwise, excessive truck idle time would result because loader idle time occurs irregularly throughout the day. A larger landing area would also be needed if this method was used.

The reader is reminded that neither of these strategies has been tested and actual results may be significantly different.

IX. COMPARISON OF LIMB AND BUCK

A. Study Design

A detailed time study of felling in Douglas-fir thinnings was undertaken concurrent with the swing study. Two fallers with less than five years of experience were studied. The limb and buck element of the felling cycle was defined to contain the same operations (measure, limb, back, top) as the limb and buck function on the landing. Whole tree, tree length, and log length felling were studied. For the comparison, log length limbing and bucking at the stump was compared to limbing and bucking whole tree pieces on the landing.

B. Results

A paired t-test of unequal sample sizes with unequal standard deviations was used to determine if the mean delay free time per tree at the stump to limb and buck was greater than the mean delay free time at the landing.

For limbing and bucking on the landing the time recorded was for the turn. This time was divided by the logs per turn to give a single log processing time. The means were summed and the standard error determined.

The results are shown in Table 9.

TABLE 9. T-test For Difference in Mean Delay Free Limb and Buck Time

μ_S: mean delay free time to limb and buck at the stump
μ_L: mean delay free time to limb and back at the landing

Ho: $\mu_S = \mu_L$

HA: $\mu s > \mu L$

Treatment	Stump	Landing
Mean	3.888	1.365
Standard Deviation	2.256	0.181
Degrees of Freedom	120	56
t' Calculated		12.11
t' (.05,73)		1.668

Conclusion: Reject Ho, Conclude that longer times at the stump are significant.

The times at the stump were longer for three reasons. First, from observation most limbing and bucking was done while balancing on a small log that provided unsure footing. Second, two men, one of the chasers and the skidder operator, were working on the landing, compared to one at the stump. Third, the man at the stump removed an average of 30.27 limbs per tree while the landing crew removed only 5.23 limbs. The other limbs were removed by yarding and swinging.

Production rates and costs are developed in Table

D and summarized in Table 10.

TABLE 10. Cost And Production Rates For Limbing And Bucking

Method	Production Rate (Cunits/SH)	Cost ($/cunit)
Landing - 2 man	6.54	$6.02
Landing - 3 man	6.54	$8.57
Stump - 1 man	1.82	$13.19

X. SLASH

Slash accumulation was judged not a problem during the study for three reasons:

1. Only 40% of the trees were harvested.

2. Slash was dispersed over a wide area. The skidder pushed slash into several small piles between the yarder deck and processing decks.

3. Yarding and swinging removed most of the limbs leaving only the top to be disposed of.

Slash volume was determined by yarding, swinging and processing 62 whole trees. The slash from these trees was loaded in a dump truck and moderately compacted by a swing boom loader. The trees produced 307 $ft.^3$ of slash or 4.95 $ft.^3$/tree. This was the volume occupied by wood, branches, and air and was not a solid wood estimate.

Slash handling occurred on 22% of the skidder turns and accounted for 2% of total time. The loader handled slash on 63% of its turns for 13% of total time.

XI. BREAKAGE

During the swing cycle breakage was insignificant. Eleven trees were broken constituting 1.25% of the total pieces. Volume lost was 0.2%. All breakage occurred on skidder swings where deck-road angles were acute. (See Figure 3)

XII. CONCLUSIONS

Production rates and costs for swinging and processing whole tree, tree length, and log length pieces from a Douglas-fir thinning were developed.

Statistical testing of the skidder processing methods indicated that there was no significant difference between whole tree and tree length mean turn time. A significant difference, however, existed between log length and longwood (a turn made up of any combination of whole tree and tree length pieces) treatments. There appears to be "fixed" times associated with both longwood methods that explain the similar mean turn times.

The least expensive skidder method was whole tree/ tree length with one chaser helping. Addition of another chaser raised the cost from $16.45/cunit to $22.61/cunit with no increase in production. Log length swinging with limbing and bucking at the stump was the most expensive method at $23.51/cunit.

Although, this method was the most productive, (3.41 cunits/scheduled hour versus 2.74 cunits/scheduled hour) limb and buck costs at the stump were more than double those on the landing.

Higher limbing and bucking productivity on the landing was due to three reasons:

1. Fewer limbs were removed per tree (5.23/tree

on the landing versus 30.27/tree at the stump). Yarding and swinging removed the difference.

2. Two men limbed and bucked at the landing. One at the stump.

3. Footing was more stable on the landing.

Loader whole tree/tree length processing (chaser helping part time) had a nearly identical cost to the least expensive skidder method ($16.15/cunit). Large amounts of idle time and interference reduced the productivity of the system.

Besides cost, safety, production balance, site impact, and yarder landing size were also considered important in selecting a swing system.

Table 11 summarizes each category for the most economical skidder and loader systems. Based on study information, the skidder balanced better with smallwood yarders, was safer, and could be used on smaller landings. However, its impact on truck roads may be severe in wet weather. The loader appeared to have the potential to be more productive (this remains to be proved) and should not deteriorate truck roads.

Breakage occurred only on skidder swings. Eleven trees were broken constituting 1.25% of the pieces and 0.2% of the total gross volume.

Slash accumulation was judged not a problem. A harvest of 40% of the total stems and removal of limbs during yarding and swinging contributed to low volumes of slash.

TABLE 11. A Comparison Of Loader And Skidder Swinging And Processing

System	Cost/Cunit	Production Balance[2]	Safety	Site Impact	Yarder Landing
Skidder-2 man WT/TL	$16.45/ cunit	2.74 cunits/SH Idle[1] 2.4% Interference[1] Skidder 2.4% Chaser 0.0%	Limb and Buck on Ground. No overhead logs. No close calls observed. Work area large.	On wet roads impact may be severe. Slash dispersed along road.	Can be used on small yarder landings to move logs.
Loader-2 man WT/TL	$16.15/ cunit	3.21/cunits/SH Idle[1] 9.0% Interference[1] Loader 7.1% Chaser 9.9%	Limb and buck on log deck. Potential for logs passing over employees, (Violation of 437-80-360(5), Oregon Logging Safety Code) Several close calls observed. All work occurs in 50 foot diameter circle.	Minimal, loader does not move. Slash concentrated at loader.	Needs area within 25 Feet of yarder to deck logs.

[1]Percent of total time.
[2]Yarder - 2.10 cunits/SH.

Finally, if swinging is deemed necessary in small-wood thinnings, this study determined that whole tree or tree length swinging and processing with a rubber tired skidder (chaser helping part time) was the preferred method based on cost, production balance, safety, site impact, and yarder landing size.

XIII. FURTHER RESEARCH RECOMMENDATIONS

Swinging and processing longwood young growth thinnings has been lightly researched. There are several aspects that require further examination.

First, the delimbing process should be studied in more detail. Two techniques that are widely used in other parts of the country are the delimbing gate and the skidder blade. These methods are simple to implement and may be effective in reducing limbing and bucking time, the longest work element. Other species such as western hemlock, sitka spruce, and the true firs should also be processed to determine their delimbing requirements. These species are important components of young growth forests where increased thinning is being undertaken. Whether they will delimb as effectively during yarding and swinging as Douglas-fir is undocumented.

Second, other swing machines should be tested. The grapple skidder is very effective when working with prebunched wood, so it seems logical that it would be productive as a swing machine. This has not been documented.

Finally, determination of balanced systems should be undertaken. Production rates of loaders and skidders appear to match different sized yarders. An examination of various combinations of yarders, swing machines, and limbing and bucking techniques would help to determine the most economical method of longwood processing in young growth thinnings.

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APPENDICES

APPENDIX A

FIELD DATA SHEETS

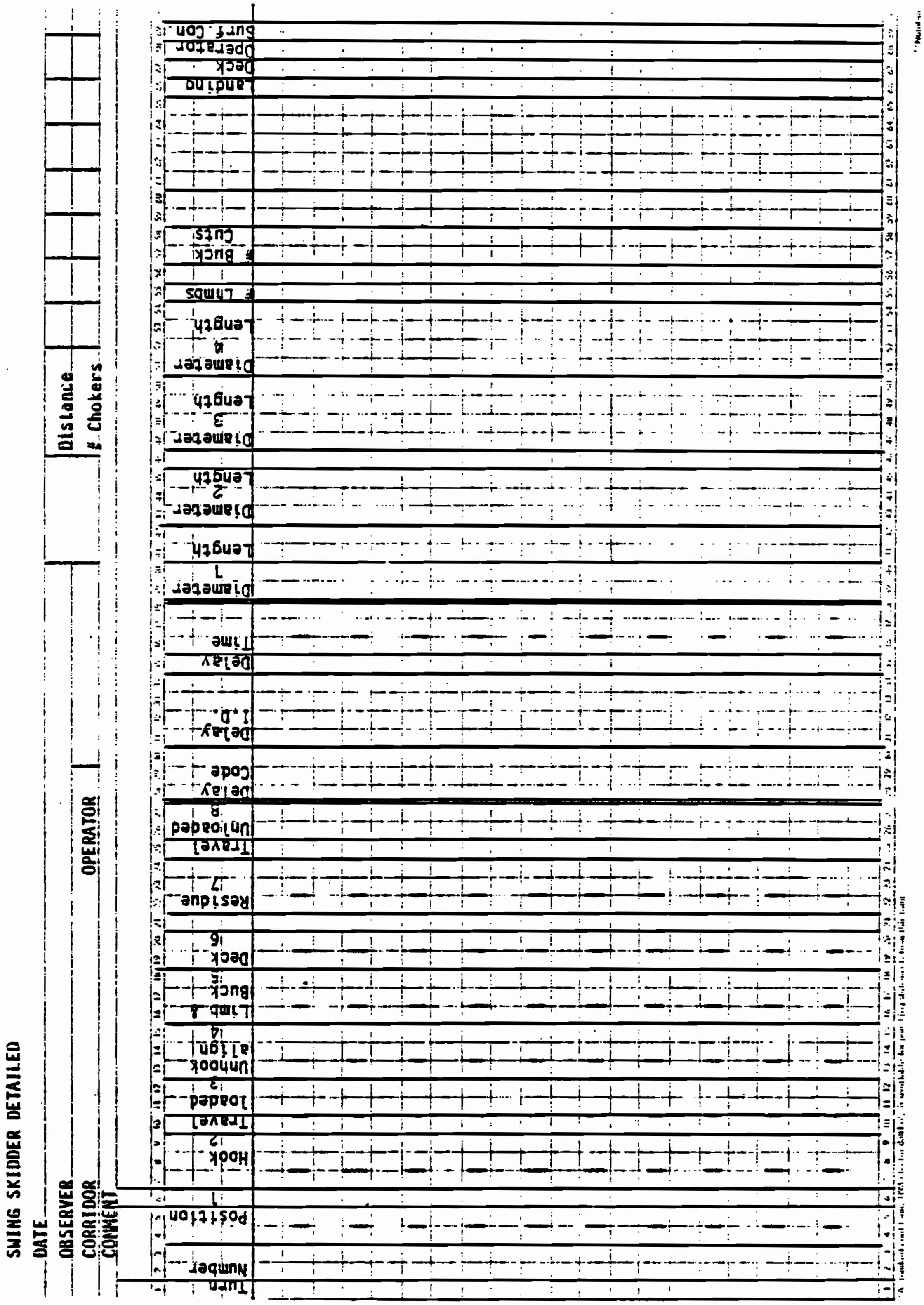

Figure A1. Skidder Detailed Time Study Sheet

ACTIVITY SAMPLING LANDING

Date: Corridor: Observer: Interval in seconds:	Comments/Description
System:	

Number of Pieces in Turn	Start time: Stop time: Elapses time:	Start slope distance: Stop slope distance:

Job / Activity	Skidder Operator	Yarder Operator	Chaser Landing Deck	Hook Tender		Total
1. Yarding						
7. Unhook skyline						
8. Hook skidder						
6. Swing/travel						
9. Unhook skidder						
2. Limb/buck						
3. Idle (no work, rest)						
4. landing Interference deck						
5. Delay brush						
10. Other (specify) Out-of-sight						
Delays landing						
TOTAL						

Figure A2. Work Sampling Sheet

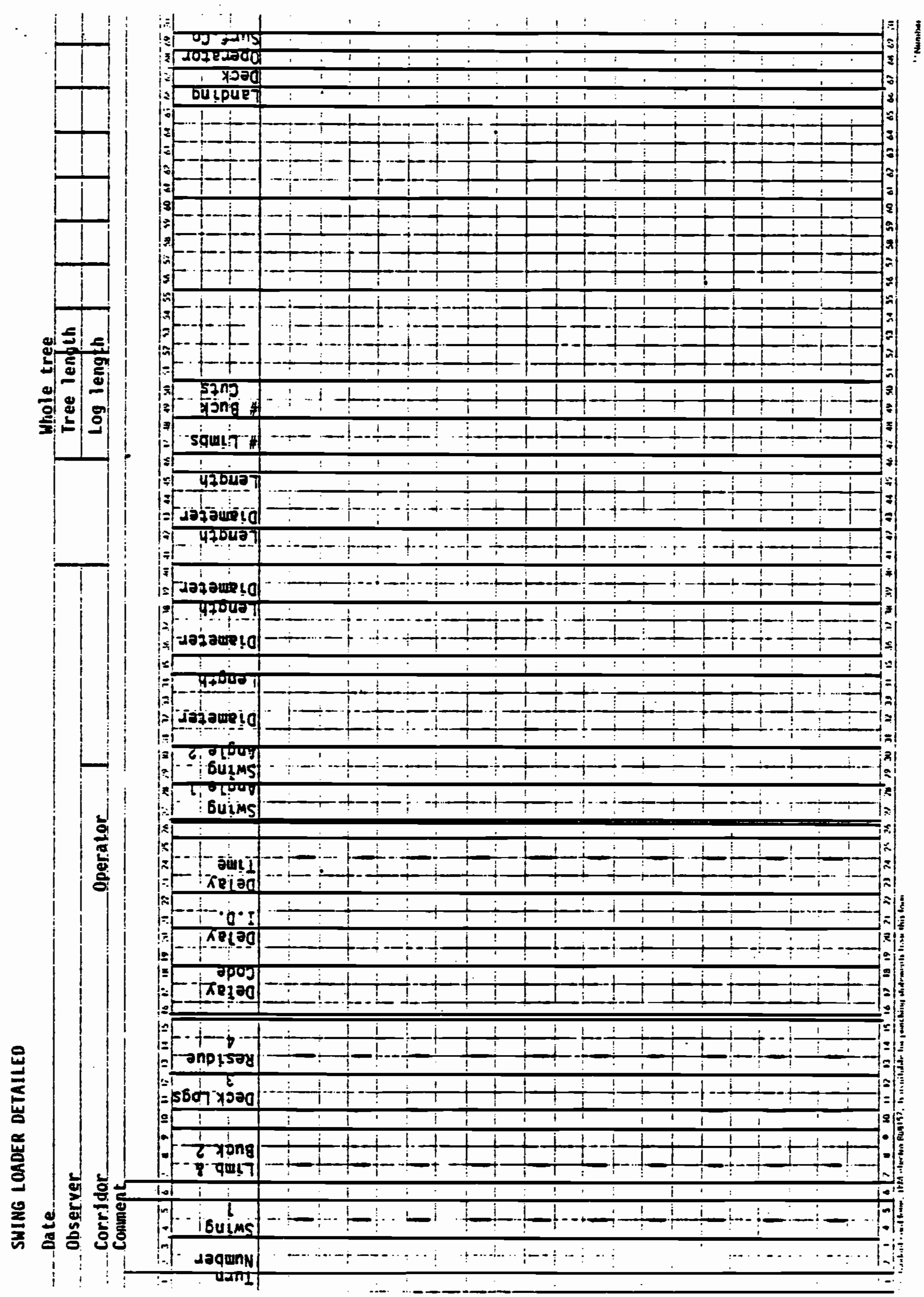

Figure A3. Loader Detailed Time Study Sheet

APPENDIX B

SKIDDER DATA

TABLE B.1 Summary Of Skidder Swing Dependent Variables (Decimal Minutes)

		Whole Tree n=105	Tree Length n=22	Log Length n=11	Mixed n=76
Hook	n	98	21	10	70
	mean	2.55	2.52	3.11	3.36
	min	0.53	0.93	0.96	1.49
	max	9.99	5.51	5.32	9.10
	s	1.35	1.11	1.36	1.52
Travel Loaded					
	n	102	21	11	72
	mean	0.94	0.81	0.76	1.15
	min	0.36	0.18	0.38	0.37
	max	2.33	2.22	1.45	4.76
	s	0.36	0.53	0.33	0.81
Unhook	n	90	19	11	73
	mean	1.12	1.01	0.89	1.49
	min	0.25	0.21	0.10	0.11
	max	4.07	2.45	1.57	6.89
	s	0.69	0.53	0.49	1.20
Limb and Buck					
	n	57	16	3	65
	mean	4.36	2.49	2.13	4.15
	min	.91	0.99	1.07	1.16
	max	9.99	4.56	3.13	9.99
	s	2.12	1.04	1.03	1.87
Deck	n	100	22	10	75
	mean	2.01	1.89	2.82	2.52
	min	0.30	.50	0.75	0.41
	max	8.22	4.92	6.27	8.24
	s	1.46	1.27	1.93	1.66

TABLE B.1 - Continued

		Whole Tree n=105	Tree Length n=22	Log Length n=11	Mixed n=76
Pile Slash					
	n	22	7	2	17
	mean	1.93	2.17	0.58	1.47
	min	0.11	0.76	0.40	0.06
	max	5.50	4.16	0.76	6.00
	s	1.48	1.23	0.25	1.42
Travel Unloaded					
	n	94	19	10	72
	mean	.48	0.48	0.49	0.59
	min	0.10	0.18	0.24	0.11
	max	1.85	0.91	0.92	1.53
	s	0.29	0.22	0.23	0.35
Total Delay Free Time	n	78	18	9	65
	mean	9.67	9.05	8.14	12.88
	min	2.25	3.71	2.88	5.03
	max	22.48	17.17	12.86	27.36
	s	4.50	3.31	3.39	4.44

TABLE B2. Skidder Dependent Variable Occurrence By Percent Of Total Turns

		Hook	Travel Loaded	Unhook	Limb & Buck	Deck	Pile Slash	Travel Unloaded
Whole Tree	n	105	105	105	60	100	21	102
	%	100	100	100	57	95	20	97
Tree Length	n	22	22	22	16	22	7	20
	%	100	100	100	73	100	32	91
Log Length	n	11	11	11	3	10	2	11
	%	100	100	100	27	91	9	100
Mixed	n	76	75	76	66	75	17	74
	%	100	100	100	87	99	22	97

Note - n is different from Table B1 because of incomplete information.

TABLE B3. Summary Of Skidder Swing Independent Variables

Variable		Whole Tree	Tree Length	Log Length	Mixed
Volume	n	104	21	11	74
	mean	65.41	69.74	63.44	80.71
(ft.^{3})	min	10.00	25.94	15.29	12.97
	max	159.86	143.55	224.58	215.56
	s	31.34	36.88	58.11	39.60
Pieces	n	104	21	11	74
	mean	3.88	3.95	3.18	4.77
	min	1	1	1	2
	max	8	7	6	8
	s	1.61	1.56	1.47	1.37
Buckcuts	n	50	13	2	61
	mean	4.56	3.07	2.0	4.03
	min	1	1	1	1
	max	12	6	3	9
	s	2.15	1.55	1.41	1.98
Limbs Removed	n	35	7	2	33
	mean	20.31	10.00	15	15.97
(Per turn)	min	1	1	3	1
	max	77	21	27	40
	s	20.06	8.56	16.97	12.16
Loss	n	1	1	-	8
	mean	20	20	-	16.25
(% of vol)	min	-	-	-	10
	max	-	-	-	30
	s	-	-	-	9.16

TABLE B3. - Continued

Variable		Whole Tree	Tree Length	Log Length	Mixed
Broken	n	1	1	-	8
(# pieces)	mean	2	1	-	1
	min	-	-	-	-
	max	-	-	-	-
	s	-	-	-	-
Road Grade	n	105	22	11	76
(%)	mean	5.54	7.00	9.81	8.01
	min	-8	-1	6	-1
	max	12	12	12	12
	s	6.07	4.98	3.03	3.75
Deck-Road Angle	n	105	22	11	76
	mean	103.06	98.23	79.18	88.68
(degrees)	min	66	66	66	66
	max	180	157	109	180
	s	32.36	34.82	17.40	27.13
Chute Width	n	105	22	11	76
(ft.)	mean	31.61	33.77	34.27	31.89
	min	10	21	20	20
	max	54	54	54	54
	s	12.56	9.57	11.48	10.82
D. Fir Deck Length	n	105	22	11	76
(ft.)	mean	71.77	72.14	67.00	74.03
	min	42	54	54	42
	max	99	99	99	99
	s	14.13	17.23	20.91	20.46

TABLE B3. - Continued

Variable		Whole Tree	Tree Length	Log Length	Mixed
D. Fir Deck Width	n	105	22	11	76
(ft.)	mean	27.63	32.86	39.45	37.93
	min	10	21	20	20
	max	50	50	50	50
	s	13.13	11.90	9.76	11.99
G. Fir Deck Length	n	40	7	7	27
(ft.)	mean	66.7	75.71	78.85	76.29
	min	60	60	60	60
	max	82	82	82	82
	s	7.05	10.73	8.31	9.82
G. Fir Deck Width	n	40	7	7	27
(ft.)	mean	13.25	18.57	19.29	18.70
	min	10.0	15	15	15
	max	20.0	20	20	20
	s	3.31	2.44	1.89	2.23
Skid Dist. To D. Fir	n	105	22	11	76
(ft.)	mean	168.01	173.41	151.91	160.75
	min	99	112	99	99
	max	273	255	186	273
	s	58.02	53.13	39.457	54.34
Skid Dist. To G. Fir	n	40	7	7	27
(ft.)	mean	258.3	276.85	291.43	279.55
	min	204	204	204	204
	max	306	306	306	306
	s	49.76	49.77	38.55	45.55

TABLE B3. - Continued

Variable		Whole Tree	Tree Length	Log Length	Mixed
Wt Pieces (pieces)	n	104	-	-	74
	mean	3.88	-	-	1.72
	min	1	-	-	0
	max	8	-	-	6
	s	1.61	-	-	1.65
TL Pieces (pieces)	n	-	21	-	74
	mean	-	3.95	-	1.73
	min	-	1	-	0
	max	-	7	-	7
	s	-	1.56	-	1.74

TABLE B4. Skidder Delays By Percent of Total Time

	Whole Tree	Tree Length	Log	Mixed	Total
Personal					
n	7	2	-	10	19
total minutes (tm)	10.22	1.86	-	25.68	37.76
% total time (%tt)	0.6	0.7	-	2.1	1.1
Consultation					
n	9	3	1	3	16
tm	13.24	2.74	0.67	3.33	19.98
%tt	0.8	1.1	0.3	0.3	0.6
Wait For Turn					
n	15	-	-	5	20
tm	81.57	-	-	49.26	130.83
%tt	5.0	-	-	4.0	3.9
Turn Stuck In Deck					
n	5	1	-	5	11
tm	13.84	6.33	-	7.50	27.67
%tt	0.8	2.5	-	0.6	0.8
Saw Delays					
n	3	-	2	3	8
tm	19.19	-	27.61	13.39	60.19
%tt	1.2	-	12.1	1.1	1.8
Lost Chokers					
n	4	-	-	2	6
tm	6.04	-	-	2.22	8.26
%tt	0.3	-	-	0.2	0.2

TABLE B4. - Continued

	Whole Tree	Tree Length	Log	Mixed	Total
Lost Log					
n	3	-	-	1	4
tm	2.60	-	-	1.37	3.97
%tt	0.2	-	-	0.1	0.1
Chasing					
n	1	-	-	1	2
tm	1.75	-	-	1.88	3.63
%tt	0.1	-	-	0.2	0.1
Skidder Stuck					
n	3	-	1	-	4
tm	11.79	-	0.49	-	12.28
%tm	0.7	-	-	-	0.4
Yarder Delays					
n	21	4	-	11	36
tm	57.44	8.43	-	14.83	80.70
%tt	3.5	3.4	-	1.2	2.4
Sort Chokers					
n	1	-	-	1	2
tm	1.41	-	-	3.61	5.02
%tt	0.1	-	-	0.3	0.1
Yarder Repairs					
n	11	2	2	2	17
tm	180.16	33.09	8.71	49.92	271.88
%tt	11.0	13.3	3.8	4.0	8.1

TABLE B4. - Continued

	Whole Tree	Tree Length	Log	Mixed	Total
Skidder Repairs					
n	11	1	2	10	24
tm	205.89	3.23	101.06	102.53	412.71
%tt	12.6	1.3	44.2	8.3	12.3
Fuel					
n	2	-	-	2	4
tm	44.36	-	-	8.71	53.07
%tt	2.7	-	-	0.7	1.6
Total Delay					
n	96	13	8	56	173
tm	649.50	55.68	138.54	284.23	1127.95
%tt	39.8	22.4	60.6	23.0	33.7
Total Time					
	1631.67	248.67	228.44	1237.22	3346
%	100	100	100	100	100

TABLE B5. Production Rates For Skidder Swinging And Processing

ABBREVIATIONS USED

SH = Scheduled Hours

I. Whole Tree/Tree Length System

A. Mean Delay Free Turn Time = 9.55 Min
B. Volume/Turn = .6613 Cunits
C. Utilization = .66

D. Cunits/SH = $\dfrac{.6613 \text{ cunits/turn}}{9.55 \text{ min/turn} \times \dfrac{1 \text{ Hr}}{60 \text{ Min}}} \times .66$

= 2.74 Cunits/SH

II. Log Length System

A. Mean Delay Free Turn Time = 8.14 Min
B. Volume/Turn = .6344 Cunits
C. Utilization (Assume No Limb and Buck) = .73

D. Cunits/SH = $\dfrac{.6344 \text{ Cunits/Turn}}{8.14 \text{ Min/Turn} \times \dfrac{1 \text{ Hr}}{60 \text{ Min}}} \times .73$ = 3.41 Cunits/SH

TABLE B6. Costs For Skidder Swinging And Processing

ABBREVIATIONS USED

SH - Scheduled Hour
PH - Productive Hour
PPT - Processing Productive Time
TPT - Total Productive Time
TT - Travel Time
DT - Delay Time

I. Whole Tree/Tree 2 Man Crew

A. Skidder and Operator (Table E1)

B. Chaser With Saw = $35.18/SH
Base Rate = $18.69/SH
Percent Charged To Swing System
(Assume Idle Time Charged To Yarder)
% = PPT + (PPT/TPT)(TT+DT)
= .276 + (.276/.334)(.126+.182)

Chaser's Prorated Cost
.53 x $18.69 = $ 9.90/SH

C. Total System Cost/SH = $45.08/SH

D. Total System Cost/Cunit
$45.08/SH ÷ 2.74 Cunits/SH = $16.45/Cunit

II. Whole Tree/Log Length 3 Man Crew

A. Skidder and Operator = $35.18/SH

B. Chaser I
(Assume Idle charged to yarder)
18.69/SH x (.336+(.336/.354)(.154+.076))
= $10.36/SH

C. Chaser II
(Assume Idle charged to swing system)
$18.00/SH x (.214+(.214/.270)(.172+.052)+.52)
= $16.41/SH

D. Total System Cost/SH = $61.95/SH

E. Total System Cost/Cunit
$61.95/SH ÷ 2.74 Cunits/SH = $22.61/Cunit

TABLE B6. - Continued

III.	Log Length 2 Man Crew		
	A.	Swing Cost/Cunit	
		Skidder and Operator	= $35.18/SH
		$35.18/SH ÷ 3.41 Cunits/SH	= $10.32/Cunit
	B.	Processing Cost	
		Limb and Buck at Stump (TABLE D1)	= $13.19/Cunit
	C.	Total System Cost/Cunit	= $23.51/Cunit

TABLE B7. Lead Time Calculations

1. Yarder Turn Time Putnam (1983)

Slope Distance (SD) = 286 ft.
Logs/Turn (L) = 1.8
Turn Volume (V) = 30.60 $ft.^3$
Lateral Yarding Distance (LD) = 33 ft.

Delay Free Time = 1.3036
+ .00546944 (SD)
+ .289567 (L)
+ .0136102 (V)
+ .0169307 (LD)

= 4.18 Minutes
+ 2.61 Delays
+ 1.94 Road Change Time
8.73 Minutes

2. Yarder Production

$$\frac{.306 \text{ Cunits/Turn}}{8.73 \text{ Min/Turn} \times 60 \text{ Min/Hr}} = 2.10 \text{ Cunits/SH}$$

3. Skidder Production

(Assuming Utilization Improves By 3.9% By Not Having To Wait For Turns)

4.15 Cunits/PH (.66+.039) = 2.90 Cunits/SH

4. Breakeven Equation

(Cunits/Corridor) ÷ (Skidder Cunits/SH) = (Cunits/Corridor) ÷ (Yarder Cunits/SH) + (Lead Time)

(.17 Cunits/Tree x Trees Removed/Corridor) ÷ 2.90 Cunits/SH =

(.17 Cunits/Tree x Trees Removed/Corridor) ÷ 2.1 Cunits/SH) + Lead Time

APPENDIX C

LOADER DATA

TABLE C1. Summary of Loader Dependent Variables

Element	Time In Decimal Minutes	% of Total Time	% of Total Turns
Swing n = 72	min = .26 max = 2.78 mean = .97	20	100
Limb And Buck n = 54	min = .17 max = 3.56 mean = 1.42	22	75
Deck n = 53	min = .21 max = 4.01 mean = 1.43	21	74
Residue n = 45	min = .15 max = 3.67 mean = 1.00	13	63
Total Delay-Free Time	267.59	76	-

TABLE C2. Summary of Loader Independent Variables

Logs/Cycle	min	1
n = 72 (turns)	max	4
	mean	1.88
Volume/Cycle (ft.^{3})		
n = 72	min	5.72
	max	84.96
	mean	26.22

TABLE C3. Summary of Loader Delays

Element	Time In Decimal Minutes	% of Total Time	% of Total Turns
Wait for Yarder n = 28	min = .22 max = 17.82 mean = 1.81	15	39
Wait For Logs n = 17	min = .43 max = 8.97 mean = 1.87	9	24
Total Delay Time	82.53	24	-
Total Time	350.12	100	-

TABLE C4. Production Rates For Loader Swinging And Processing

I. Loader - Nonlimited Rate

A. Mean Delay Free Time to Swing, Deck, and Move Slash (Based on Percent Occurrence) = 2.66 min

B. Volume/Cycle = .2622 cunits

C. Utilization (Assume No Idle Time or Interference. Routine Delays Included) = .90

D. Production/Scheduled Hour

$$\frac{.2622 \text{ Cunits}}{2.66 \text{ Min} \times \frac{1 \text{ Hr}}{60 \text{ Min}}} \times .90 = 5.32 \frac{\text{cunits}}{\text{SH}}$$

II. Chaser-Nonlimited Rate

A. Mean Delay-Free Time To Limb and Buck (Prorated) = 1.07 Min

B. Volume/Cycle = .2622 cunits

C. Utilization (Assume No Interference Or Idle Time, Routine Delays, Travel and Chasing Occur) =.72%

D. Production/Schedule Hr

$$\frac{.2622}{1.07 \text{ Min} \times \frac{1 \text{ Hr}}{60 \text{ Min}}} \times .719 = 10.57 \frac{\text{cunits}}{\text{SH}}$$

III. Loader System Limited By Yarder Production

A. Yarder Production/SH (From Appendix B7. Reduced 4.8% for Production Lost When Yarder Engineer Must Unhook Logs) $= 2.0 \frac{\text{cunits}}{\text{SH}}$

IV. Loader Whole Tree/Tree Length System

A. Mean Delay Free Turn Time = 3.73 min
B. Volume/Turn = .2622 Cunit
C. Utilization = .76
D. Cunits/Scheduled Hour(SH)

$$\frac{.2622 \text{ Cunits/Cycle}}{3.73 \text{ min/cycle} \times 1 \text{ Hr/60 Min}} \times .76 = 3.21 \text{ cunits/SH}$$

TABLE C5. Costs For Loader Swinging And Processing

Abbreviations Used

TPT = Total Productive Time
PPT = Processing Productive Time
TT = Travel Time
D = Delays
I = Interference Delays
SH = Scheduled Hour

I. Loader Charged Full Time To Swing Operation

A. Loader and Operator (Appendix E2) = $43.44/SH

B. Chaser with Saw
Base Rate = $18.64/SH
Percent Charged to Swing System
(Assume Idle Time Charged To Yarder)

% = PPT + PPT/TPT (D+TT+I)
= .245 + (.245/.342)(.084+.099+.099)
= .45

Chaser's Prorated Cost $18.69/SH x .45 = $ 8.41/SH

C. Total System Cost = $51.85/SH

D. Total Cost/Cunit
$51.85/SH ÷ 3.21 Cunits/SH = $16.15/Cunit

E. Total Cost/Cunit if Supply is 5.21 cunits/SH
$51.85/SH ÷ 5.12 cunits/SH = $10.13/Cunit

II. Loader Charged Partially To Swing System
(Loads Out Two Trucks/Day)

A. Loader Cost
Base Rate = $43.44/SH

Percent Charged To Swing System
% = PPT + PPT/TPP(D+I)
= .524 + (.524/.825)(.071+.104)
= .635

Loader Prorated Cost
$43.44/SH x .635 = $27.58/SH

B. Chaser's Cost (Unchanged) = 8.41/SH
$36.00/SH

C. Total Cost/Cunit
$36.00/cunit ÷ 3.21 cunits/SH = $11.21/Cunit

APPENDIX D

LIMB AND BUCK DATA

TABLE D1. Production Rates And Costs For Limbing And Bucking

I. Limbing And Bucking On The Landing

A. Utilization (U)

1. % of Total Productive Time Spent in LB

$$\% = \frac{564.5}{2218.05} \times 100 = 25.45\%$$

2. Prorated Delays To Limb and Buck

Personal	37.76
Consultation	19.98
	57.34 Minutes

57.34 x .2545 = 14.6

3.	LB Delays	+ 60.2
3A	Total Delay Time	74.8 Minutes

4. Determination of U

$$U = \frac{\text{Productive Time}}{\text{Total Time}} = \frac{564.5}{639.3} = .88$$

B. Production Rate

$$= \frac{65.41 \text{ Ft}^3/\text{Turn}}{3.88 \text{ Wt Pieces/Turn}} \times \frac{1 \text{ Cunit}}{100 \text{ Ft}^3} \times \frac{1 \text{ Wt Piece}}{1.36 \text{ Min}} \times \frac{60 \text{ Min}}{\text{Hr}} \times .88$$

= 6.54 Cunits/Scheduled Hr

C. Total Cost/SH Two Man Crew

\$/SH = (Fixed Cost of Skidder Idle) + (Chaser Labor) + (Skidder Operator Labor) + (Saw)

= 8.55/SH + \$9.90/SH + \$20.21/SH + \$0.69/SH

= \$ 39.35/SH

D. Total Cost/Cunit Two Man Crew

\$/Cunit = \$ 39.35/SH ÷ 6.54/Cunits/SH

= \$6.02/Cunit

E. Total Cost/SH Three Man Crew

\$/SH = 8.55/SH + \$10.36/SH + \$16.21/SH + \$20.2/SH + \$0.69/SH

= \$ 56.02/SH

F. Total Cost/Cunit Three Man Crew

\$/Cunit = \$56.02/SH ÷ 6.54 Cunits/SH

= \$8. 57/Cunit

TABLE D1. - Continued

II. Limbing and Bucking At The Stump

A. Utilization (U)

1. % of Total Productive Time Spent in Limb and Buck (LB)

$$\% = \frac{472.76 \text{ min}}{940.326 \text{ min}} \times 100 = 50.28\%$$

2. Prorated Delays Attributable To Limb and Buck

Total Saw Delays	773.513
Delays Not Attributable To LB (Inspect Area, Slashing Unmerch. Trees)	-160.535
	612.978 Min.
612.978 x .5028	= 308.20 Min.

3. Determination of Utilization (U)

$$U = \frac{\text{Total Prod. Time}}{\text{Total Time}} = \frac{472.76}{472.76+308.20} = .61$$

B. Production Rate

$$.164 \text{ cunits/tree} \times \frac{1 \text{ Tree}}{3.3 \text{ Min}} \times \frac{60 \text{ Min}}{\text{Hr}} \times .61 =$$

1.82 Cunits/SH

C. Total Cost/SH

Cutter (Includes Social Costs)

1.8 x 12.95/SH	= $23.31/SH
Saw (TABLE E3)	$ 0.69/SH
	$24.00/SH

D. Total Cost/Cunit

$24.00/SH ÷ 1.82 Cunits/SH = $13.19/cunit

APPENDIX E

MACHINE RATES

TABLE E1. Skidder Machine Rate

I. Description

Type: JD 440-C Cable Skidder

Purchase Cost	$50,000		
Less: Tire Cost 4x$1200	4,800		
Initial Investment (P)			$ 45,200
Salvage Value (S)	.2 x 45,200		$ 9,040
Estimated Life (n)	5	YRS	
Scheduled Hrs/Yr (SH)	1600	HRS	
Utilization (U)	.67		
Productive Hrs/Yr (PH)	1056	HRS	
Ave. Value of Investment	$\frac{(P-S)(n+1)}{2n} + S$		$ 30,736

II. Fixed Costs

Depreciation (D)	$\frac{P-S}{n}$		$ 7,232/YR
Interest	15 %	IIT	
Insurance	3 %		
Taxes	3 %		
Total	21 % x AVI	$30,736	$ 6,455/YR
Fixed Cost/SH	D+IIT/SH		$ 8.55/SH
Fixed Cost/PH	D+IIT/PH		$ 12.96/PH

III. Variable Cost

Maintenance & Repair	$.50 \times \frac{P-S}{n(PH)}$	$ 3.37/PH
Fuel	70 HP x .037 x $1.20	$ 3.10/PH
Oil & Lubrication	(.33 x Fuel)	$ 1.02/PH
Other Tires	$\frac{1.15 \times \$4800}{3000 \text{ HRS}}$	$ 1.84/PH
IV. Labor	11.32 Rate x 1.8 (Social Costs)	$ 20.38/SH
Total Cost/PH		$ 52.51/PH
Total Cost/SH		$ 35.18/SH

TABLE E2. Loader Machine Rate

I. Description

Type: Barko 160 With 6 x 4 Live Tandem Truck Carrier

Purchase Cost	\$71,105		
Less: Tire Cost 10x\$150	\$ 1,500		
Initial Investment (P)			\$ 69,605
Salvage Value (S)	.2 x 69,605		\$ 13,921
Estimated Life (n)	5	YRS	
Scheduled Hrs/Yr (SH)	1600	HRS	
Utilization (U)	.76		
Productive Hrs/Yr (PH)	1,216	HRS	
Ave. Value of Investment	$\frac{(P-S)(n+1)}{2n} + S$		\$ 47,331

II. Fixed Costs

Depreciation (D)	$\frac{P-S}{n}$		\$ 11,197/YR
Interest	15 %		
Insurance	3 %	IIT	
Taxes	3 %		
Total	21 % x AVI \$47,331		\$ 9,940/YR
Fixed Cost/SH	D+ITT/SH		\$ 13.21/SH
Fixed Cost/PH	D+IIT/PH		\$ 17.38/PH

III. Variable Cost

Maintenance & Repair	$.50 \times \frac{P-S}{n(PH)}$	\$ 6.48/PH
Fuel	72 HP x .037 x \$1.20	\$ 3.20/PH
Oil & Lubrication	(.33 x Fuel)	\$ 1.05/PH
Other Tires	$\frac{1.15 \times \$1,500}{8000 \text{ HRS}}$	\$ .21/PH
IV. Labor	12.18 rate x 1.8 (Social Costs)	\$ 21.92/SH
Total Cost/PH		\$ 57.16/PH
Total Cost/SH		\$ 43.44/SH

TABLE E3. Chainsaw Machine Rate

I. Description

Type: Stihl 041 Chain Saw

Purchase Cost	$475.00		
Less: Tire Cost			
Initial Investment (P)			$475.00
Salvage Value (S)	.2 x 475		$ 95.00
Estimated Life (n)	2	YRS	
Scheduled Hrs/Yr (SH)	1600	HRS	
Utilization (U)	.50		
Productive Hrs/Yr (PH)	800	HRS	
Ave. Value of Investment	$\frac{(P-S)(n+1)}{2n} + S$		$285.00

II. Fixed Costs

Depreciation (D)	$\frac{P-S}{n}$		$190.00/YR
Interest	15 %		
Insurance	3 %	IIT	
Taxes	3 %		
Total	21 %	x AVI $285.00	$ 60.00/YR
Fixed Cost/SH	D+ITT/SH		$ .16/SH
Fixed Cost/PH	D+IIT/PH		$ .32/PH

III. Variable Cost

Maintenance & Repair	1.00 x $\frac{P-S}{n(PH)}$ .653	$ .66 /PH
Fuel	.125 GAL x $1.40/GAL	$ .18 /PH
Oil & Lubrication	(.33 x Fuel)	$ .05 /PH
Other - Chain	$\frac{\$40.00}{140 \text{ Hrs}}$	$ .16 /PH
IV. Labor	___---___ Rate x 1.8 (Social Costs)	$ --- /SH
Total Cost/PH		$ 1.37 /PH
Total Cost/SH		$ .69 /SH