Operational Prebunching: A Logger's Application to Reduce Skyline Thinning Costs

A PAPER

submitted to

Forest Engineering Department

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Forestry

Completed May 5, 1980

Commencement June 1980

APPROVED:

Dr Eldon D. Olsen

Professor of Forest Engineering in charge of major

Henry A. Froehlich (Acting)

Head of Department of Forest Engineering

Date paper is presented 5/5/80

Typed by Judith A. Campbell for Cary R. Zielinsky

Cary Russell Zielinsky

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

LIST OF ILLUSTRATIONS

OPERATIONAL PREBUNCHING: A LOGGER'S APPLICATION TO REDUCE SKYLINE THINNING COSTS

INTRODUCTION

In the Pacific Northwest, loggers are faced with the problems of changing from logging old growth to second growth. This is due to the shrinking old growth timber supply and increased entry into the second growth stands. Beuter (1980) indicated that in western Oregon 70.2 percent by volume of the softwood timber presently being less than 12.9 inches (53.09 centimeters)[1] dbh, with 37 percent being less than 12.9 inches (32.77 centimeters) dbh. Tedder (1979) states that by the year 2075 the average diameter for all western Oregon owner groups will fall from 23 inches (58.42 centimeters) to 14 inches (35.56 centimeters). The trend to harvesting smaller timber will require development of harvesting techniques that can handle small wood more efficiently. Small wood is defined (Aulerich 1975) as a tree under 20 inches (50.8 centimeters) dbh or logs averaging less than 100 board feet (0.71 cubic meters) in volume.

In small wood harvesting, commercial thinnings pose special problems. Thinnings are used as a silvicultural treatment to enhance the growth of the residual stand. In skyline thinnings, yarding logs laterally into the corridors is a time consuming activity, especially pulling slack during lateral outhaul and finding enough logs within reach of the chokers to build an optimum turn (near maximum payload). Aulerich (1974) found lateral yarding accounted for 46 percent of the total yarding time.

1. Conversion factors are given in Appendix A.

Sparse log density and small log size make building an optimum turn difficult.

Yarding logs laterally through standing timber is also a problem. There are frequent, time-consuming hangups requiring resetting the chokers or dropping off part of the turn. Reset time can be expensive, because the yarder stands idle and its hourly operating costs are high.

In previous research at Oregon State University, prebunching and swinging has been suggested as a means for reducing yarding costs in skyline thinning operations. Prebunching and swinging differs from full-cycle (conventional) yarding in that in prebunching and swinging, logs are moved from the unit to the landing in two yarding cycles. The first cycle is the prebunching cycle, where the logs are laterally yarded to decks along the skyline corridor. The second yarding cycle is the swinging cycle, where the logs are yarded from the prebunched decks to the landing. In full-cycle yarding logs are yarded in one cycle which includes the lateral yarding and swinging. By prebunching with a low investment yarder, it may be possible to increase the utilization of an expensive yarder and thereby reduce total yarding costs.

PREVIOUS STUDIES

Prebunching and swinging in small wood thinnings has been studied at Oregon State University by Kellogg (1976) and Keller (1979). Both previous projects were experimentally designed studies, where researchers had control over the unit layout, treatments, and harvesting techniques. The two studies utilized different techniques to perform the prebunching operation. The prebunching in Kellogg's 1976 study utilized a small, portable Volkswagen-powered, single-drum winch, mounted on a metal sled. The winch was equipped with a remote-controlled radio, requiring only one person for prebunching. Kellogg's study was conducted in Oregon State University's McDonald Forest. The stand characteristics are summarized in Table 1.

The sled was winched down the corridors and set up at the different prebunching spars (Figure 1). The winch line was placed in a block hung in the prebunch spar, amd the logs were yarded into the corridor. The prebunched decks were later yarded to the landing by a Schield Bantam T-350 yarder using a live skyline system with a Maki carriage.

The results from Kellogg's prebunching and swinging study were compared to predicted production rates from a study by Aulerich (1975) for the Schield-Bantam thinning under similar conditions without prebunching. Kellogg concluded that prebunching logs can reduce total yarding costs by 24 percent in skyline thinnings compared to conventional yarding.

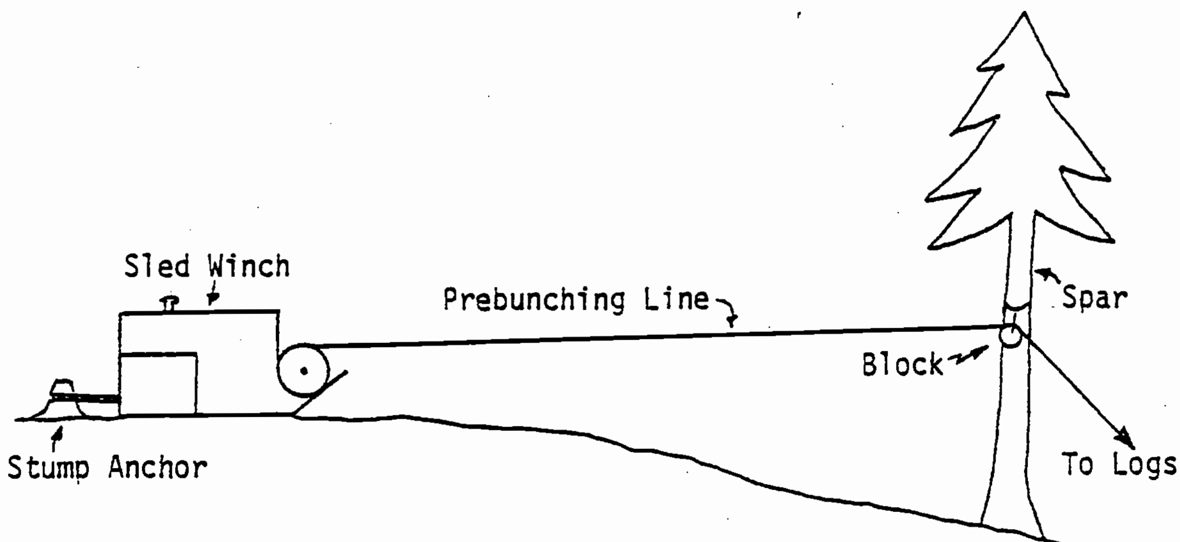
Keller's 1979 study on prebunching utilized a different lateral yarding technique. The prebunching yarder was located on the landing as opposed to in the corridor as in Kellogg's study. The prebunching was accomplished with an Igland-Jones Trailer Alp skyline yarder powered by a John Deere 2640 farm tractor. The yarder was located on the landing and a carriage, fixed in various positions on the skyline, was used to laterally yard logs into the skyline corridor. After prebunching, the logs were swung to the landings with a West Coast Madill yarder and a Koller carriage. The prebunching operation required three per-

Table 1. SUMMARY OF CHARACTERISTICS FOR PREBUNCHING STUDIES

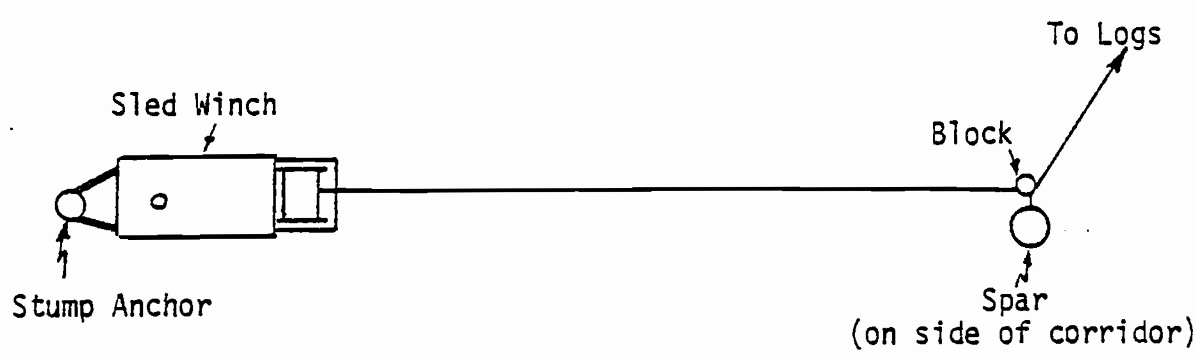
	KELLOGG (1976)	KELLER (1979)	ZIELINSKY (1980)
Study Type	Experimental	Experimental	Observational
Machine	Sled Mounter Winch	Igland-Jones Trailer Alp	Used Skagit GU-10 Mounted in a Dumptruck
Configuration	Corridor Based Sled Winch	Landing Based Skyline Yarder	Landing Based Drum Set
Cost of Pre-bunching Machine	$12,000 (1976)	$61,988 (1979)	$7,000 (1980)
Crew (persons)	1	3	3
Stand Age (years)	35 to 40	27 to 53	60 to 90
Species	Douglas-fir	Douglas-fir west. hemlock	Douglas-fir
Average dbh (inches)	12	16.7 [1/] 12 [2/]	17
Volume per Acre (cunits)	60.35	23.96 [1/] 39.10 [2/]	93.75
Volume Removed per Acre (percent)	36	18	37
Trees per Acre (pieces)	221	207	70

1. Douglas-fir

2. western hemlock



SIDE VIEW



TOP VIEW

FIGURE 1. YARDING CONFIGURATION FOR KELLOGG's PREBUNCHING SYSTEM

sons; one yarder operator and two chokersetters. The study was conducted in Oregon State University's Blodgett tract in Columbia County. The stand characteristics are summarized in Table 1. The prebunching and swinging in Keller's study was compared to full-cycle yarding with the West Coast yarder and carriage in the same area with the same crew. Keller concluded that this prebunching and swinging technique cost about twice as much as the full-cycle yarding.

JUSTIFICATION

The results from the two previous studies are contradictory; Kellogg's study showed that prebunching and swinging could save money, while in Keller's prebunching and swinging doubled the yarding cost. This project analyzes the results of a field study conducted during the summer of 1979 between August 9 and September 30 on a system of prebunching designed by an industry logger. The logs were prebunched using a two-speed Skagit GU-10 drum set (Figure 2) and later yarded or swung using a Madill 071 yarder (Figure 3). This study provided an opportunity to evaluate a third prebunching technique in an industry operation. Results were compared to previous results obtained using experimental techniques at Oregon State University. Table 1 summarizes the basic differences between the three studies.

OBJECTIVES

The objectives of this study are:

1. To compare the yarding costs and production rate of prebunching with a low investment, landing based drum set and

Figure 2. Skagit GU-10 Mounted in a Dumptruck

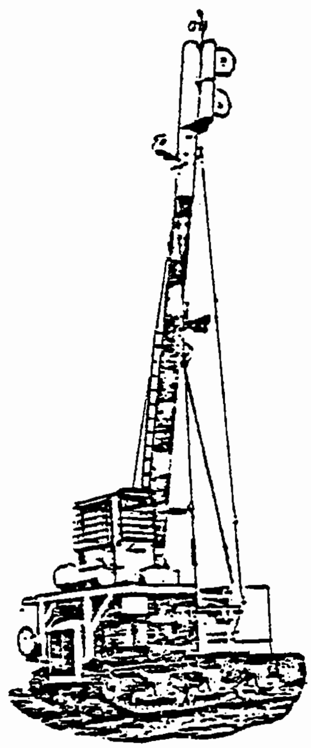


Figure 3. Madill 071 Used for Swinging

swinging to full-cycle yarding in a skyline thinning.

2. To develop regression equations which can be used to predict bunching cycle times.
3. To determine and compare factors that influence prebunching cycle times.
4. Compare with field observations previous prebunching and swinging data collected under experimental conditions.
5. To identify future research needs on prebunching.

SCOPE

The analysis of prebunching includes a comparison of two crews; one crew with the owner/operator as a chokersetter and one crew without the owner/operator as a chokersetter. Production data was obtained during a three-month summer period in one stand.

The performance of the prebunching and swinging technique used in the study was compared to previous studies and to the owner/operator's estimate of production using full-cycle yarding under similar conditions. A direct comparison between prebunching and swinging and full-cycle yarding was not possible because the owner/operator chose to prebunch all feasible areas within the sale; no study areas were left for full-cycle thinning.

Production equations were developed for the prebunching cycle in order to predict the yarding production for the system.

GENERAL APPROACH

The analysis of the prebunching and swinging data was performed in several steps. The first step was to summarize the production and operating costs for prebunching and swinging. Next, production equations were determined by a detailed regression analysis of the prebunching cycle elements. A less detailed analysis was performed on the swinging cycle because of limited data. The data for the yarding cycles was randomly split into two groups. One group with 80 percent of the observed turns was used to build the regression models; the remaining 20 percent was used to validate the regression models using a paired t-test. The regression analysis identified the variables that influence prebunching cycle times. They were compared to the variables found significant in previous studies.

A hypothesis as to which variables might influence the dependent variable was formed for the yarding cycles and cycle elements. The variables were entered into a model of the form:

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

These models were then tested by various criteria to determine which models were best.

After the prebunching and swinging costs had been determined, comparisons of yarding costs were made between prebunching and swinging and full-cycle yarding. The comparisons were based on yarding production equations developed by Keller for the West Coast Madill yarder and the owner/operator's estimate of production for full-cycle yarding under similar conditions.

STUDY AREA AND UNIT LAYOUT

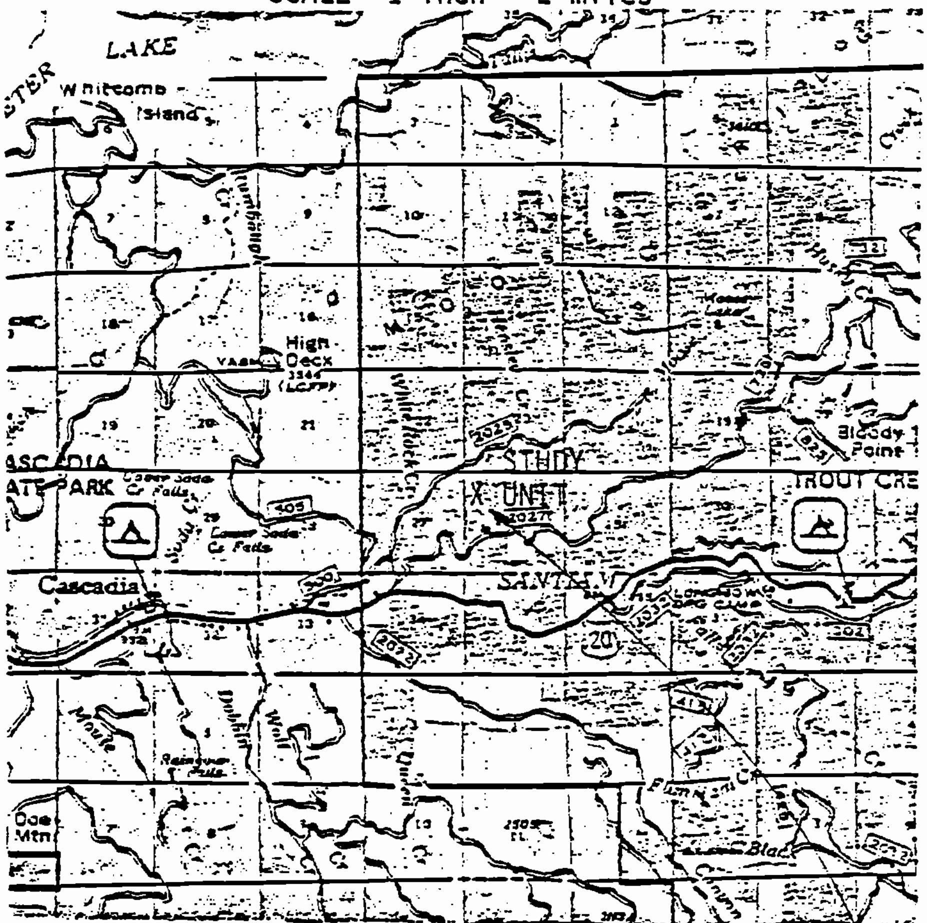
AREA AND STAND DESCRIPTION

The study area is a portion of the United States Forest Service Powder 4 timber sale, E. ½, Sec. 27, and W. ½, Sec. 26, T. 13 S., R. 3 E, Willamette Meridian, Linn County, Oregon (Figure 4). This area was designated for individual tree marking with skyline yarding specified. According to cruise data obtained from the U.S.F.S., the volume averaged about 93.75 cunits per acre (648.15 cubic meters per hectare) with 6.25 cunits per acre (43.21 cubic meters per hectare) marked for thinning exluding spar and corridor trees. The average dbh for the stand was 17 inches (43.18 centimeters) with about 70 stems per acre. The stand was mostly second growth trees ranging from 60 to 90 years old. The main merchantable species was Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) with western hemlock (*Tsuga heterophylla* (Raf.) sarg.) accounting for only 0.4 percent by volume. The understory was mostly of vine maple (*Acer circinatum* (Pursh) with a few scattered Pacific yew (*Taxus brevifolia* (Nutt).

Two study areas were outlined within two adjacent units. Both had northeast to northwest aspects with similar stand characteristics (Figure 5). The southern boundary of unit 1 and has north facing slopes in excess of 70 percent was marked by the ridge top spur road (number 2034264). The western boundary of unit 1 was the 2034262 road which is an upper midslope road terminating at landing 2 on a cross slope ridge. In both units, the skyline corridor profiles are characterized

WILLIAMETTE NATIONAL FOREST

SCALE 1 inch = 2 miles



Research Location E. ½, Sec. 27, and W. ½, Sec. 26, T. 13 S., R. 3 E., W.M.

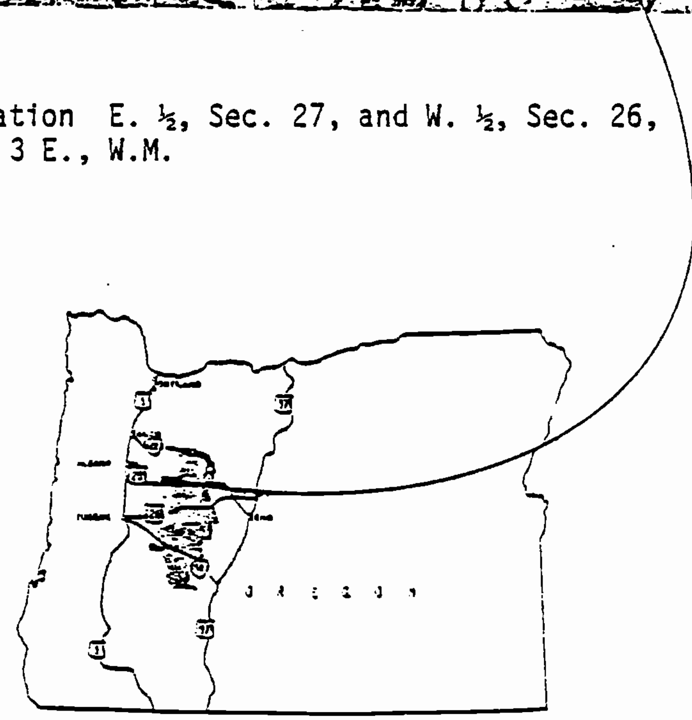


FIGURE 4. STUDY UNIT LOCATION.

PREBUNCH AND SWING RESEARCH AREA

WILLIAMETTE NATIONAL FOREST, LYNN CO. OREGON

E. ½, Sec. 27, and W. ½, Sec. 26, T. 13 S., R. 3 E., W.M.

AREA: 26.6 Acres

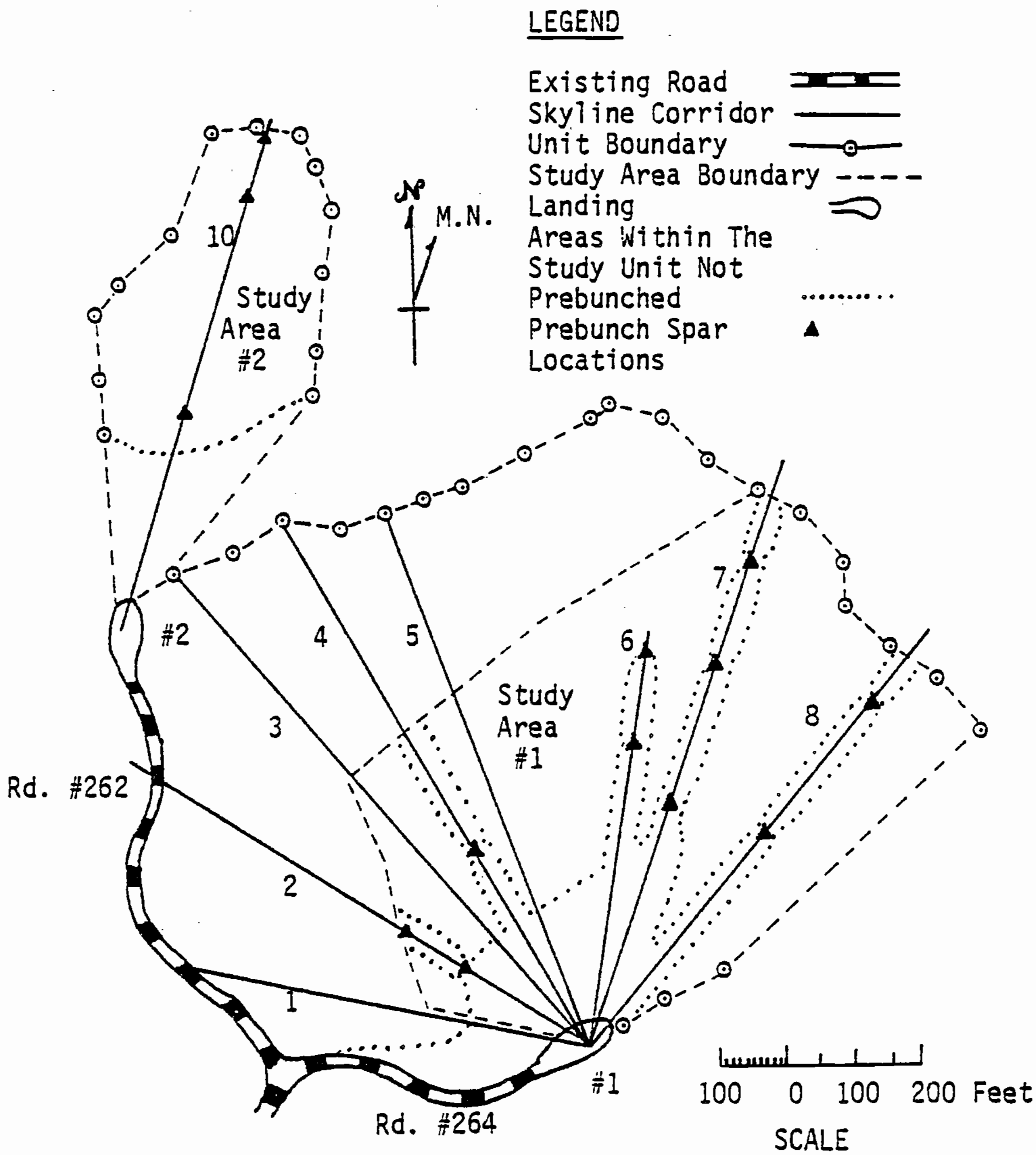


FIGURE 5. STUDY AREA AND UNIT LAYOUT.

by steep slopes in excess of 60 percent immediately below the landings, flattening out to less than 25 percent about one third of the way down the slope (Appendix B). The soil type for this area is classified by the United States Geological Survey as Holocomb silty clay loam.

UNIT LAYOUT

Eight corridors were located in the study areas by the owner/operator. The study area boundaries differ from the unit boundaries because the areas outside the study boundaries were prebunched before the study began (Figure 5). The average horizontal corridor length was 802 feet (244.61 meters) with the shortest measuring 620 feet (189.10 meters) and the longest 930 feet (283.65 meters). The average slope yarding distance was 561 feet (171.11 meters) and the average lateral slope yarding distance was 93 feet (28.37 meters). A total of 26.6 timbered acres (10.8 hectares) were surveyed for the study.

POST THINNING ASSESSMENT

After the thinning operation, a 10 percent cruise using fifth acre plots was taken to determine the changes in stand volume and number of stems per acre. The cruise indicated that 26.2 stems per acre (64.69 stems per hectare), or 37.4 percent of the stems were removed. There was an average of 1818 cunits per acre (125.69 cubic meters per hectare) removed during the thinning (about 19 percent by volume). The removed volume per unit area is 278 percent higher than the 654 units per acre (45.21 cubic meters per hectare) originally specified by the sale contract. The increase is due to the additional volume removed in the prebunch spars, corridor trees and wind-thrown trees.

METHODS

FELLING AND BUCKING

The fallers did not use any directional felling techniques with respect to the corridors, because the corridors were not located until the timber was cut. On the steeper ground, timber was felled along the contours when possible to reduce breakage and sliding. On the flatter slopes, the timber was felled either into openings to reduce hangups or away from broken ground to reduce breakage. A random felling pattern was created over both units. The trees were primarily bucked into 35 foot (10.68 meter) and 41 foot (12.51 meter) logs.

PREBUNCHING TECHNIQUE

The prebunching yarder was a small two-speed Skagit GU-10 drum-set powered by a 350 cubic inch (5.74 liter) displacement Chevrolet V-8. The entire unit was mounted in the back of a dump truck (Figure 6). The prebunching operation required the use of only one of the two drums. The drum used for prebunching held 1,100 feet (335.5 meters) of 7/16 inch (1.11 centimeter) line. The maximum line pull and line speed at mid-drum for low gear are 23,800 pounds (10,805 kilograms) and 245 feet per minute (74.73 meters per minute) respectively. For high gear the maximum line pull and line speed are 11,750 pounds (5,535 kilograms) and 500 feet per minute (152.5 meters per minute) respectively. The drum frictions and brakes are mechanically actuated. The Chevrolet V-8 is capable of delivering 175 horsepower (131 kilowatt) and 280 foot-pounds (378 joule) of torque to the drum set. Talkie Tooters were used for radio communication between the chokersetters and the yarder operator. They were used for both sending whistle signals and for one-way verbal communication from the chokersetters to the yarder operator.

The prebunching operation required three persons; one yarder operator and two chokersetters. The two chokersetters worked as a team, both pulling line during outhaul. They would usually alternate between setting chokers, and chasing the turn. If the distance was short, both would set chokers and one would chase the turn. During the study, two different chokersetting crews were observed. One crew consisted of the owner and a chokersetter with two years of woods experience. This crew will hearafter be referred to as "The crew with the owner/operator as a chokersetter". The other crew consisted of the chokersetter with the two years of experience and a chokersetter with six months of rigging experience. This crew will hereafter be referred to as "The crew without the owner/operator as a chokersetter".

The prebunching yarder was positioned on the landing in the approximate location where the swinging yarder was to be located. The prebunching line was then strung down the corridor and through a block that was attached to a choker or strap hung in the prebunching spar (Figures 6 and 7). The line was manually pulled out and attached to a turn of logs using two chokers, one attached to a slider. After the chokers were set, the turn was yarded into a deck at the prebunching spar. This process was repeated until all logs that were to be bunched to the spar were yarded. The rigging was then moved down the corridor to successive spars. A 17-foot (5.19 meter) aluminum ladder was used to rig the block and strap in the prebunching spar.

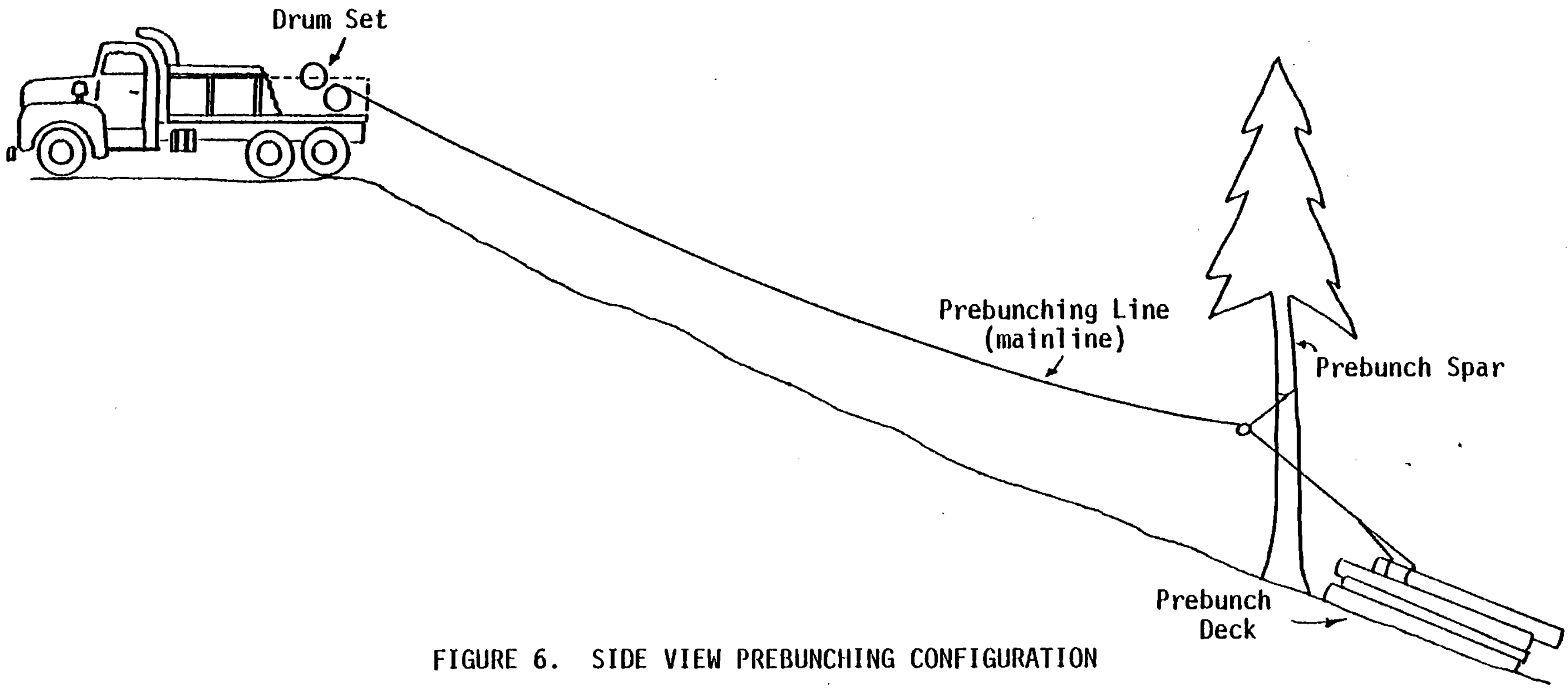


FIGURE 6. SIDE VIEW PREBUNCHING CONFIGURATION

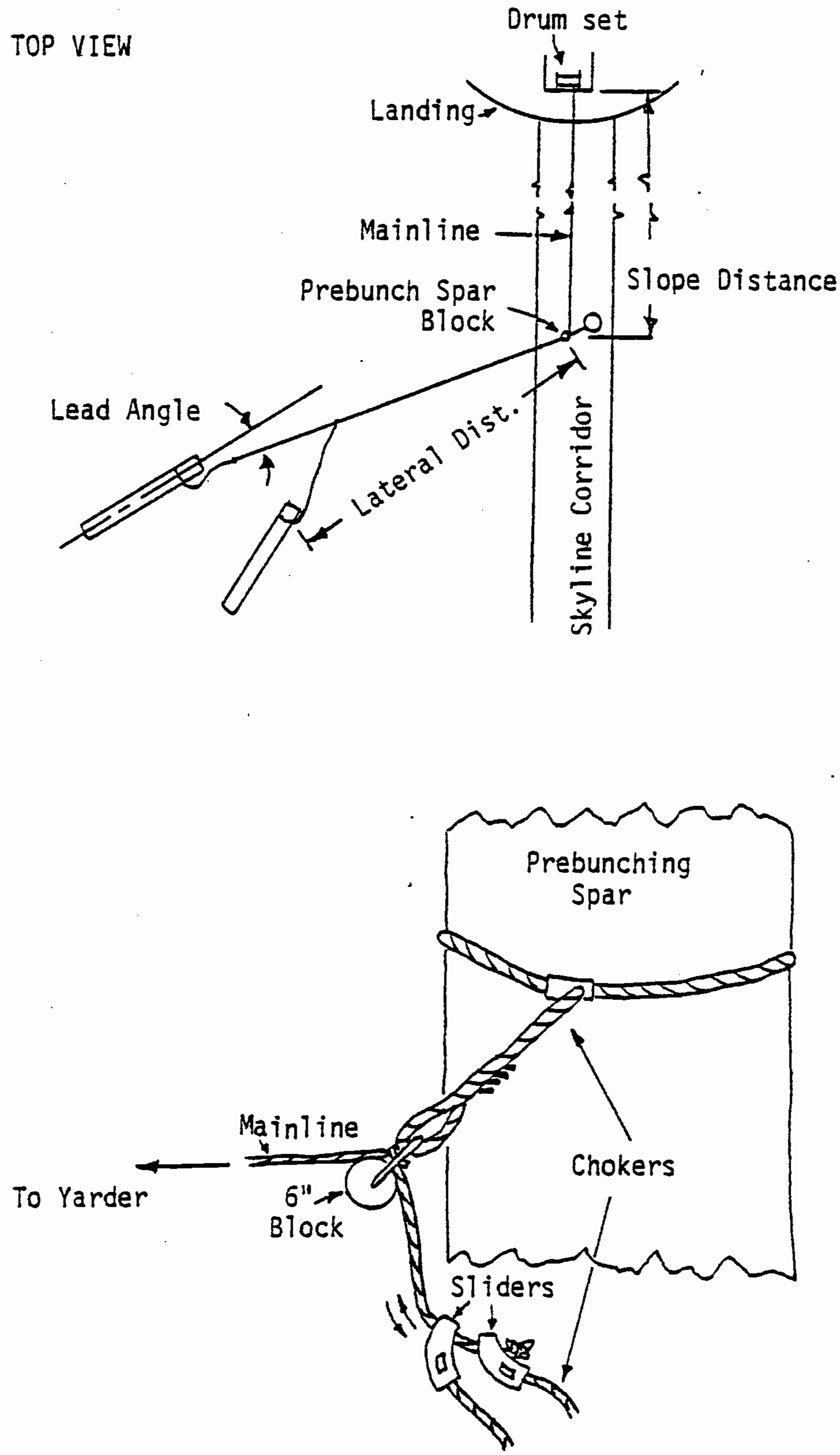


FIGURE 7. PREBUNCHING CONFIGURATION AND SPAR RIGGING

All of the logs on a prebunched corridor were not prebunched. At the chokersetters discretion, logs were not prebunched in the steep areas close to the landings or where the logs were already laying in the corridors (see Figure 5). The areas next to the landings were not prebunched because the slope was too steep to keep bunched logs from sliding off the decks. Also, because the settings were fan shaped there was a high density of corridors next to the landings.

SWINGING WITH THE MADILL 071

The swinging was accomplished using a Madill 071 crawler-mounted, mobile skyline yarder equipped with a Danebo S-40 mechanical slackpulling carriage. The decking and loading was accomplished using a Bantam C-366 loader with a Danebo heel boom. Specifications for the Madill 071 are given in Appendix C.

The Danebo S-40 is a mechanical slackpulling carriage that consists of three drums on a single axle (Figure 8). The main line and skidding line are over-wound while the slackpulling line is under-wound. While the haulback holds the carriage in position, the slackpulling line pays out the skidding line. The S-40 holds a capacity of 225 feet (67 meters) of 7/8 inch (2.22 centimeters) line.

The swinging operation used an eight person crew (standard crew for More Logs, Inc.), consisting of a yarder operator, loader operator, chaser, hooktender, second hook, rigging slinger and two chokersetters. A standard industry crew does not include a second hook. Four chokers were used during swinging, three of which were attached to sliders.
The swinging operation included the yarding of non-prebunched logs just

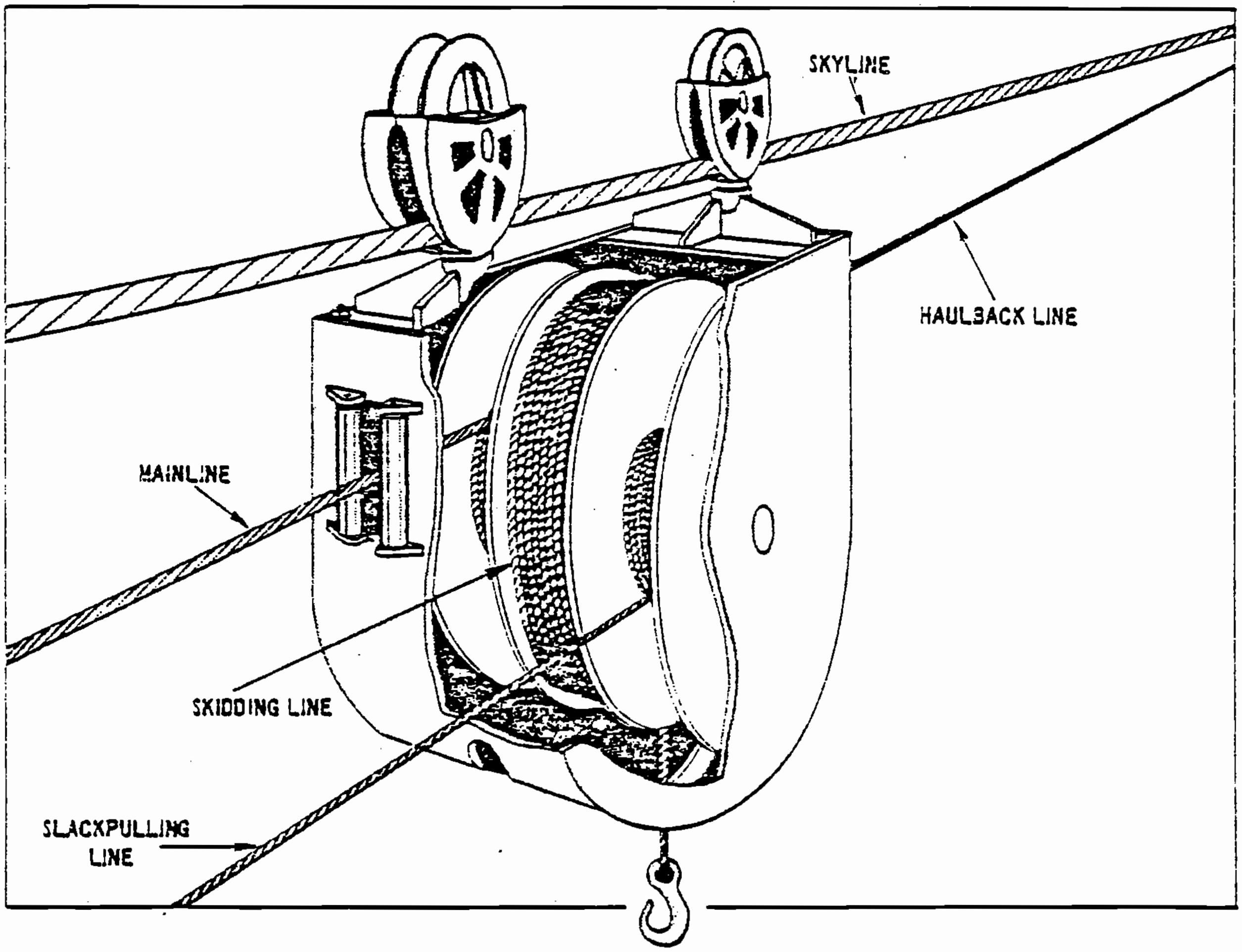


FIGURE 8. CARRIAGE WITH SAME CONCEPT AS DANEBO S-40.

off the landing, the yarding of logs left between the prebunched decks and swinging the prebunched logs. Seventeen percent of the turns swung were not prebunched.

Both of the landings in this study were of adequate size to allow for the sorting and loading of logs without interrupting the swinging cycle. The areas of landing number one and landing number two were 0.1 acres (0.04 hectares) and 0.08 acres (0.03 hectares) respectively.

STUDY DESIGN AND DATA COLLECTION

The study plan originally required a comparison between prebunching and swinging and conventional yarding. Data was to be gathered on both prebunching and swinging and conventional yarding in similar areas. However, the owner/operator prebunched every feasible area within the sale, leaving no area where a comparison could be made. Comparisons between the two yarding systems will be limited to the owner/operators estimation of conventional yarding production in similar timber and comparisons with conventional yarding production in previous studies.

A detailed time study was performed on the prebunching cycle to break out the individual yarding element times and to develop a production equation for predicting cycle times. A less detailed time study was performed on the swinging cycle due to personnel limitations.

TIME STUDY

Production data was collected daily for both the prebunching cycle and the swinging cycle during the study. For prebunching, measurements were taken of the time required to complete a sequence of activities which form a turn or yarding cycle. Measurements were also taken for independent variables thought to influence turn times. For swinging, only the total turn time was measured. No elemental times were recorded and only delays that could be observed from the landing were separated. Some of the independent variables which were thought to influence swing time were measured.

PREBUNCHING CYCLE ELEMENTS

OUTHAUL is the time required to pull the rigging from the prebunching spar to the closest log in the turn. The activity begins when the chokersetter takes hold of the prebunching line to pull it to the next turn. The activity ends when the chokersetter reaches the first log in the next turn.

HOOK is the time required to attach the chokers to the logs in the turn and for the chokersetters to move to a safe position. The activity begins when the chokersetter reached the first log in the turn and ends when the prebunching line moves for inhaul.

INHAUL is the time required to yard the turn of logs to the prebunch spar and position them on the deck. The activity begins when the prebunching line begins moving and ends when the turn reaches the corridor and the line slacks.

UNHOOK is the time required to remove the chokers from the logs. The activity begins when the turn reaches the corridor and the line slacks, and ends when the chokersetter takes hold of the chokers to pull them to the next turn.

DELAYS - Delay times were recorded for any interruption in the basic yarding cycle. Delays were classified as either operating or nonoperating. Operating delays are those delays directly related to the completion of the yarding cycle for a given yarding system, such as resetting a hang-up or repositioning a turn on the deck. Nonoperating delays are delays which interrupt the basic yarding cycle and divert the crew's attention away from the yarding cycle, such as broken lines or mechanical failures.

Operating delays for prebunching were classified into the following two categories.

RESET is the time required to free a hung-up turn. RESET occurs anytime a choker must be reset or adjusted to avoid obstructions, or when a log must be dropped from the turn. Time begins when turn stops because of an obstruction and ends when the prebunching line moves for inhaul.

REPOSITION - Delay occurs when the yarder operator must reposition the yarder to facilitate line spooling. Time begins when the dump truck is started and ends when the yarder is started. Only that portion of the reposition time that affects turn time was recorded.

SPAR CHANGE - The prebunching operation required that periodically the rigging be moved to a new spar location on the same corridor. The time required to rig down, move and rig up as well as the distance moved were recorded.

CORRIDOR CHANGE - The time required to rig down, change corridors and rig up as well as distances moved were recorded.

All other delays that occurred during the prebunching operation were not specifically classified. Their times were recorded in the delay column and identified by a brief description in the comment column.

YARDING CYCLE - The basic yarding cycle is defined by the sequence of the outhaul, hook, inhaul and unhook activities (Figure 9a).

INDEPENDENT VARIABLES

Previous work on defining variables and their respective influence on production and cost for prebunching has been done by Kellogg (1978) and Keller (1979). Kellogg identified four key variables that influenced production: slope distance; lead angle of the logs to the winch line; turn volume; and number of chokers. Keller found that prebunching production varied as a function of lateral distance and volume per acre removed.

The following are the designated independent variables that were used to explain the variation in time required for each activity and for predicting prebunching production.

LATSD is the lateral slope distance from the prebunching spar to the first log in the turn. Prior to yarding the unit slope distances were layed out on a 50-foot by 50-foot grid. The time keeper estimated the position of the log to the nearest five feet.

SDIST is the slope distance down the corridor to the prebunching spar from the yarder. Markers on a 50-foot spacing were layed prior to yarding. Since SDIST was a constant for a given prebunching spar, the distance from the nearest marker was measured with a bucking tape to the nearest foot.

BLKHT is the block height measured as the vertical distance from

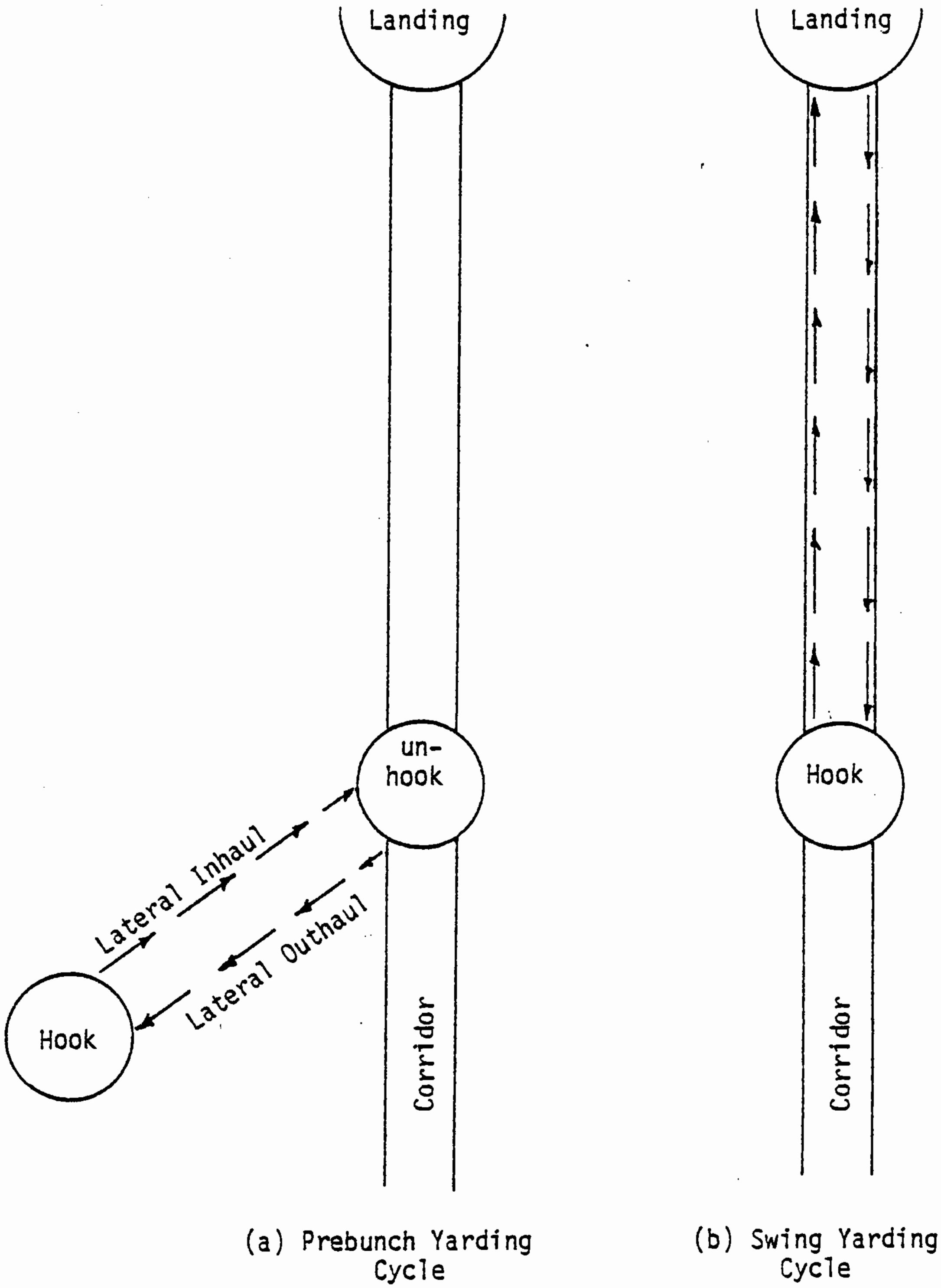


FIGURE 9. PREBUNCHING AND SWINGING CYCLES.

the ground to the block hung in the prebunching spar measured in feet.

LEADA is the lead angle, measured as the angle between a line formed by the prolongation of a line through the axis of the log and the lead of the line, measured to the nearest 5 degrees in the horizontal plane. A special protractor device was used for measuring LEADA (Figure 10).

NOCHOK is the number of chokers used to set the turn of logs.

NOLOGS is the number of logs that reached the prebunch deck.

TOTVOL is the total cubic foot volume of all of the logs yarded in the turn. Prior to yarding the length, small end diameter, and large end diameter of all the logs were measured and recorded. Tags were stapled to each end of the logs so that during yarding the log numbers could be recorded. The cubic foot volume for each log was calculated using the Columbia River Log Scaling and Grading Bureau volume formula.

AVELV is the average log volume for the turn in cubic feet and is equal to the TOTVOL divided by NOLOGS.

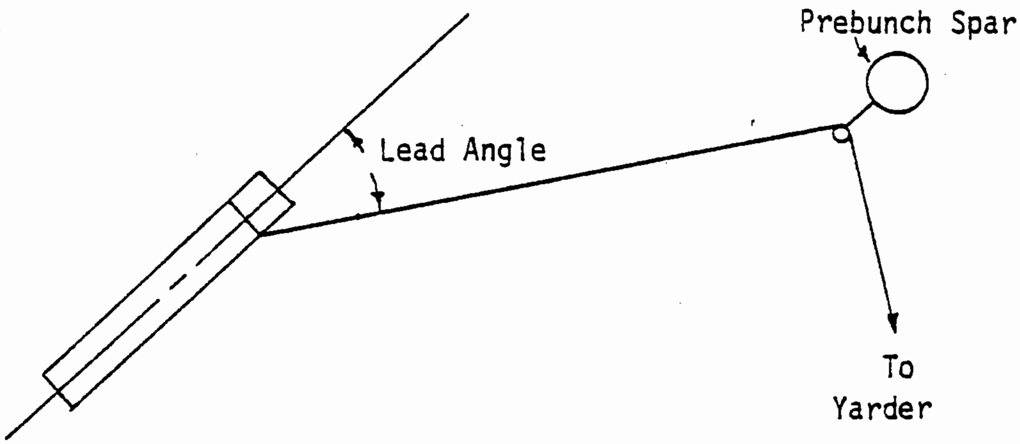
DKHT is the estimated height of the prebunch deck in feet.

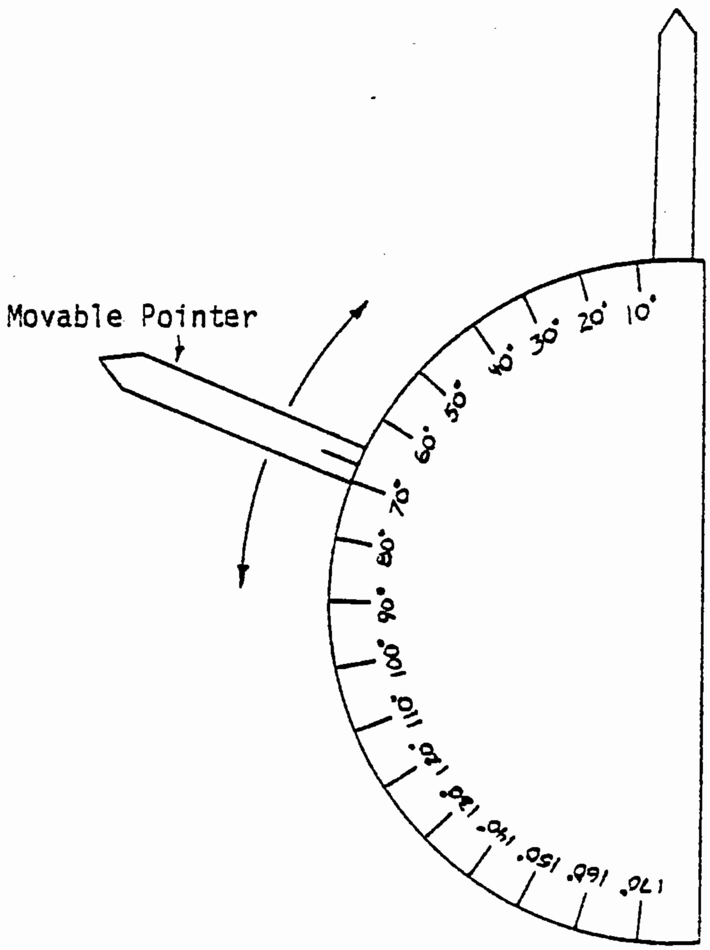
CREW is a zero-one dummy variable, zero when owner/operator was a chokersetter and one when he was not.

SWING CYCLE

The swing cycle was studied in less detail than was the prebunch cycle due to personnel limitations. The swing yarding cycle was not divided up, but timed as a whole .

SWING TIME is defined as the time required to swing a turn of logs from a prebunched corridor to the landing. The activity begins





Protractor Device

FIGURE 10. METHOD FOR MEASURING LEAD ANGLE.

and ends when the choker sliders hit the carriage plate (Figure 9).

DELAYS - Only those delays that could be observed from the landing were timed. The delay time was recorded in the delay column and a brief description of the delay was written in the comment column.

ROAD CHANGE - The time to change roads, and if necessary reposition the yarder and guylines, was recorded. The road change activity began when the skyline was slacked and ended when the skyline was raised into the yarding position.

INDEPENDENT VARIABLES

CREWNO is the number of rigging men. NOLOGS, NOCHOK, TOTVOL and SDIST are defined the same as in prebunching.

DATA COLLECTION METHODS

Two persons were used for time study data collection during the prebunching cycle. One person carried a stop watch and data collection sheet. He was responsible for measurement and recording of the element times and the recording of the independent variables. The second person carried a bucking tape and the protractor device. He was responsible for measuring and reporting the independent variables.

For the swing cycle only one person was available. He gathered cycle times, delays, and independent variables from the landing.

Cycle and element times were measured to the nearest 1/100 of a minute using a digital stopwatch and the continuous timing technique. Element and cycle time were determined by subtracting element stop and start times. The field data was recorded on rain proof data sheets carried on a clipboard. Appendix D shows data sheets for both prebunching and swinging.

STATISTICAL METHODS

Descriptive statistics were computed using the Statistical Interactive Programming System (SIPS)[2] for both the dependent and independent variables in the prebunching and swinging cycles so that production and operating costs could be summarized.

The data for the yarding cycles was randomly split into two groups. One group, containing 80 percent of the observed turns, was used to build the regression models and the remaining 20 percent was used to validate the regression models.

Using SIPS multiple regression analysis, a model of the form:

$$Y = \beta_o + \beta_1 X_{i1} + \beta X_{i2} \cdots \beta_{p-1} X_{i,\ p-1} + \varepsilon_i$$

was built for the yarding cycle elements. A "forward stepwise" selection procedure was used to add independent variables into the model, one at a time, until all of the variables thought to influence element times were in the model. Once all of the independent variables were in the model a "backward stepwise" selection procedure was used to drop variables, one at a time, until no variables were left in the model. Forward stepwise uses the highest coefficient of determination (R^2) as the criteria for which variable enters the model and backward stepwise used the lowest R^2 as the criteria for determining which variable leaves the model. The results of the two selection procedures were compared to find the combination of independent vari-

---

2. Rowe, K. and J. A. Barnes. 1978.

ables which best describe the variation in the dependent variable.

The selection of the variables for the best equation was based on three different criteria. The first was the significance level of the coefficients given the other variables in the model. The coefficients were each tested under the hypothesis:

$$H_o : \beta_i = 0 \quad VS \quad H_a : \beta_i \neq 0$$

using the Student's t-test. Variables that were not found significant at the 95 percent confidence level were dropped from the model. The second criterion was that the entering variable must add at least one percent to the coefficient of determination (R^2) or it was dropped from the model. The third criterion was the Cp criterion (Neter and Wasserman 1974), which minimizes the total squared error. This test was used to determine which combination of independent variables that had earlier passed the first two tests was best.

When the final equation was found, its statistical significance was determined based on its R^2 and the F-Test of the hypothesis:

$$H_o : \beta_1 = \beta_2 = \cdots \beta_{p-1} = 0 \quad VS \quad H_a : \beta_1 \neq \beta_2 \neq \cdots \beta_{p-1} \neq 0$$

Any equation that did not explain at least 10 percent of the variation of the dependent variable or have an F-value significant at the 95 percent confidence level was dropped. In this case, the mean value of the dependent variable was considered the best estimate.

In addition to the previous tests, a t-test was performed to determine if the R^2 was significant for those elements with significant regression equations. Confidence intervals were computed for each element at the mean of the independent variables, half-way between the highest values and the means of the independent variables, and half-way between the lowest values and the means of the independent variables.

The regression models were validated using a paired t-test to test the difference between element times estimated using the regression equations and actual element times. The hypothesis tested was of the form:

$$H_o : \mu_{difference} = 0 \quad VS \quad H_a : \mu_{difference} \neq 0$$

For those elements in which no significant regression models were developed, the significance of the mean value of the element was tested using a paired t-test.

A comparison of the mean turn time without delays was made between prebunching with the owner/operator as a chokersetter and prebunching without the owner/operator as a chokersetter by using a paired t-test. The hypothesis:

$$H_o : \mu_{with\ owner/operator} = \mu_{without\ owner/operator} \quad VS$$

$$H_a : \mu_{with\ owner/operator} \neq \mu_{without\ owner/operator}$$

was tested to determine if there was a significant difference between the mean production of the two crews.

DATA ANALYSIS

PRODUCTION AND COST SUMMARIES

The data collected in this study was first reduced to a simple estimate of production for each system. The data set for the time study totaled 416 complete observations of individual yarding cycles (191 prebunching cycles and 225 swinging cycles). Basic yarding cycles were subdivided into individual elements, delay elements, and independent variables affecting each cycle. Prebunching production was also divided into two catagories by crew. One crew had the owner/operator as a chokersetter and one crew had another crew member as a chokersetter.

For both prebunching and swinging, the production estimates were determined by summing the observed times for all yarding cycles and dividing by the total volume produced for each operation. These production estimates are presented as a relationship between the volume of wood yarded and the time required to yard it. Three levels of production were examined in this analysis: delay-free production, production with operating delays included, and production with all delays included.

Delay-free production was determined by adding the basic yarding cycle elements, excluding delays. This level of production shows what we would expect if no delays occurred.

Production with operating delays includes all delays that occurred as a direct result of the yarding activity. Included in operating delays are spar and corridor change for prebunching and road change for swinging. These were classified as operating delays because they are necessary operations.

The production with all delays depicts the actual expected production. This is the most realistic estimate of production, accouting for all of the delays, both operating and non-operating, that occur during actual yarding activities.

The three levels of production provide for analysis of the production of each system in stages. In the first stage, the production is measured without including delays. By operating and nonoperating delays, the way each type of delay affects production of the yarding system is determined.

In order to make comparisons between prebunching and swinging and conventional yarding, the operating costs of the system as well as the production must be considered. The cost per unit volume was determined by dividing the system cost per hour by the volume produced per hour. A comparison was made between prebunching and swinging and conventional yarding on the basis of unit cost.

PRODUCTION SUMMARY

Table 2 summarizes the yarding phase of prebunching at the three levels of production for both crews and for the combination of the two crews. The data in table 2 shows that delays reduce production rates by 47 percent compared to delay-free time. Also, the difference in production rates between the two crews is noticeable.

Table 3 summarizes the observed time per unit volume required for prebunching spar changes and corridor changes.

Table 4 summarizes the production rates for the swing cycle. Observed delays for the swinging cycle account for a reduction of 19 per-

TABLE 2. SUMMARY OF VOLUME PRODUCTION FOR PREBUNCHING

Crew	Delay-free Production Cunits/hr	Production With Operating Delays Cunits/hr	Production With All Delays Cunits/hr
With Owner/operator as a Chokersetter	9.50	5.75	5.19
Without Owner/operator as a Chokersetter	6.56	4.27	3.37
Combination	8.15	5.09	4.32

TABLE 3. SUMMARY OF OBSERVED TIME PER UNIT VOLUME REQUIRED FOR PREBUNCHING SPAR CHANGES AND CORRIDOR CHANGES

Crew	Delay-free Time min./cunit	Time With Operating Delays min./cunit	Time With all Delays min./cunit
With Owner/operator as a Chokersetter	0.12	0.20	0.22
Without Owner/operator as a Chokersetter	0.18	0.28	0.36
Combination	0.14	0.23	0.27

TABLE 4. SWING CYCLE PRODUCTION SUMMARY

Delay-free Production Cunits/hr	Production With Operating Delays Cunits/hr	Production With All Delays[1] Cunits/hr
16.23	14.4	13.22

1. Only those delays that could be observed from the landing are included.

cent in the total production.

The conventional yarding production was first estimated using Keller's total turn time regression equation and the average independent variable values from this study. The owner/operator's estimate provided a second estimate. The West Coast Madill yarder used in Keller's study is very similar to the Madill 071 used in this study. The main difference between the two yarders is the engines; the West Coast Madill had a 239 horsepower (178 kilowatt) 6-71 and the Madill 071 had a 284 horsepower (212 kilowatt) 8-71. The crew used for the full-cycle thinning operation in Keller's study consisted of four persons; an operator, a chaser, a rigging slinger and one chokersetter. Table 5 shows the estimated conventional yarding production. The computations are given in Appendix E.

Table 6 shows the overall handling time for prebunching, swinging and conventional yarding. By comparing overall handling time for prebunching and swinging to conventional yarding, it can be seen that prebunching and swinging involves more handling time than does conventional yarding in all cases.

YARDING COST SUMMARY

A comparison between prebunching and swinging and conventional yarding on the basis of production or handling time is misleading because of the difference in hourly costs between the systems. The most equitable comparison is made using estimated hourly operating costs. Table 7 summarizes the hourly operating costs for each system. Profit and risk is not included in the cost analysis.

TABLE 5. ESTIMATED CONVENTIONAL YARDING PRODUCTION

Estimate Source[1]	Production With Operating Delays Cunits/hr	Production With All Delays Cunits/hr
Keller	7.0	4.7
Owner/operator	N/A[2]	4.5

The total hourly operating costs for each system can be determined by dividing the hourly costs by the unit volume per time for both thinning techniques. Table 8 summarizes the cost per unit volume for both thinning techniques. One should note that the hourly cost for both swinging and conventional yarding includes the hourly cost of the loader. It is evident in all cases that prebunching and swinging costs less money than conventional yarding.

COST COMPARISONS

The total yarding costs presented in Table 8, for prebunching and swinging were analyzed to see if there was a significant difference between crews. The analysis was based on the difference in production for the two crews, which is related to the cost per unit by a constant (hourly cost). A paired t-test was used to test the hypothesis:

H_o : $\mu_{\text{with owner/operator}} = \mu_{\text{without owner/operator}}$ VS

H_a : $\mu_{\text{with owner/operator}} \neq \mu_{\text{without owner/operator}}$

1. Production was estimated using Keller's production equation and by using the owner/operator's estimate.

2. Not available.

TABLE 6. COMPARISON OF OVERALL HANDLING TIME FOR PREBUNCHING AND SWINGING AND CONVENTIONAL YARDING

Crew[3]	Prebunching Production min./cunit	Swinging Production min./cunit	Prebunch and Swing Production min./cunit	Conventional Production (Keller)[1] min./cunit	Conventional Production (owner/operator)[2] min./cunit
With Owner/operator	11.55	4.54	16.09	—	—
Without Owner/operator	17.78	4.54	22.32	—	—
Combination	13.89	4.54	18.43	12.77	13.40

1. Estimate based on Keller's regression equation.

2. Owner/operators estimate.

3. Crew applies only to prebunching production and prebunch and swing production.

TABLE 7. ESTIMATED HOURLY COSTS FOR THE YARDING OPERATIONS [1/]

Cost Item	Skagit GU-10 and Dumptruck	Madill 071 Yarder	Bantam C-366 Loader
Depreciation	$6.26	$27.67	$10.90
Maintenance and Repair	1.38	9.60	5.14
Fuel and Lubricants	3.00	5.78	7.53
Labor	38.14	79.83	14.08
Insurance, Intrest, Taxes	0.75	18.00	11.86
TOTAL	$49.53	$140.88	$49.51

The difference in crew production was significant at the ($P < .005$) level; therefore, there is a significant difference in unit cost between the two crews. Due to the nature of this study it is impossible to attach statistical significance to the difference in cost between prebunching and swinging and conventional yarding. A break even analysis was performed to determine the conventional yarding production necessary for conventional yarding to be more economical than prebunching and swinging. The calculated breakeven production is at 7.36 cunits (20.6 cubic meters) per hour. Appendix G shows the calculations for the breakeven analysis.

YARDING CYCLE ANALYSIS

The yarding cycle elements for prebunching were analyzed in detail using multiple regression analysis. The swing yarding cycle was not divided into cycle elements; regression analysis could only be run on total

1. A complete itemization of costs for each yarding system is presented in Appendix H.

TABLE 8. YARDING COSTS FOR EACH UNIT SUMMARIZED BY INDIVIDUAL CYCLES

Crew[1/]	Activity	Production Costs ($/cunit) Delay-free	Operating Delays	All Delays
With Owner/ operator	Prebunch	5.21	8.62	9.54
	Swing	11.73	13.22	14.40
	Total	16.94	21.84	23.94
Without Owner/ operator	Prebunch	7.65	11.61	14.84
	Swing	11.73	13.22	14.40
	Total	19.29	24.83	29.24
Combination	Prebunch	6.08	9.72	11.46
	Swing	11.73	13.22	14.40
	Total	17.81	22.94	25.86
(Keller)[12]	Conventional Yarding	N/A[13]	27.08	40.51
(owner/operator)	Conventional Yarding	N/A	N/A	42.50

1. Crew applies only to prebunch and swing activities.

2. (Keller) and (owner/operator) refer to the basis used for estimating conventional yarding production.

3. Not available.

turn time. Equations were developed for the yarding cycle elements that explain the relationship between the cycle elements and the independent variables. These equations could also be used to predict how the system would perform on another area.

PREBUNCHING YARDING CYCLE

Multiple regression was used to analyze the following basic elements of the prebunching cycle: OUTHAUL, HOOK, INHAUL and UNHOOK. In addition to the basic elements, RESET, an operational delay, and delay free turn time (DFTIME) were also analyzed. Other delays were not analyzed due to their random occurrence.

The independent variables which were included in the regression analysis were: LATSD, SDIST, BLKHT, LEADA, NOLOGS, TOTVOL, AVELV, DKHT and CREW as defined earlier. Table 9 gives a summary of cycle times for prebunching. Table 10 gives a summary of independent variables for prebunching.

A 0.95 confidence level was used as the minimum level of significance of variables allowed in the regression models. Many variables were also significant at the 0.001 probability level.[3/]

The following hypothesis were developed as to which variables might influence element times:

H_0 : OUTHAUL = f (LATSD, BLKHT, SDIST, CREW)

H_0 : HOOK = f (NOLOGS, TOTVOL, AVELV, CREW)

3. In the regression equations:
*** Indicates significance of a variable at the .001 probability level.
** Indicates significance of a variable at the .01 probability level.
* Indicates significance of a variable at the .05 probabilty level.

TABLE 9. SUMMARY OF CYCLE TIMES FOR PREBUNCHING MEASURED IN MINUTES

Element			Element		
Outhaul n=191	max	2.35	Total n=191	max	7.20
	min	0.12		min	1.20
	mean	0.81		mean	3.95
Hook n=191	max	4.50	Reset	max	11.90
	min	0.23		min	0
	mean	1.25		mean	1.01
Inhaul n=191	max	2.05	Total Time With Operating Delays	max	—
	min	0.13		min	—
	mean	0.76		mean	6.32
Unhook n=191	max	3.32	Total Time With All Delays n=191	max	—
	min	0.15		min	—
	mean	1.13		mean	7.45

TABLE 10. SUMMARY OF INDEPENDENT VARIABLES FOR PREBUNCHING

Variable			Variable		
Lateral Slope Distance (feet)	max	214.00	Number of Logs	max	5.00
	min	10.00		min	1.00
	mean	92.75		mean	2.14
Block Height (feet)	max	14.00	Total Volume (cunits)	max	1.38
	min	6.00		min	0.04
	mean	9.40		mean	0.54
Slope Distance (feet)	max	890.00	Deck Height (feet)	max	10.00
	min	190.00		min	0
	mean	575.86		mean	0.57
Lead Angle (degrees)	max	140.00	Average Log Volume (cunits)	max	1.25
	min	0		min	0.04
	mean	55.68		mean	0.26

H_o : INHAUL = $_f$ (LATSO, BLKHT, SDIST, LEADA, NOLOGS, TOTVOL, AVELV, CREW)

H_o : UNHOOK = $_f$ (NOLOGS, TOTVOL, DKHT, AVELV, CREW)

H_o : RESET = $_f$ (LATSD, BLKHT, SDIST, LEADA, NOLOGS, TOTVOL, DKHT, AVELV, CREW)

H_o : DFTIME = $_f$ (LATSD, BLKHT, SDIST, LEADA, NOLOGS, TOTVOL, DKHT, AVELV, CREW)

Table 11 presente the results of regression analysis for the pre-bunching elements. Only those variables which satisfied the criteria previously stated for selection have coefficients presented.

OUTHAUL

The following model was developed for the prediction of outhaul time.

OUTHAUL = $_f$ (LATSD, CREW)

OUTHAUL = 0.4157
+ 0.0035 (LATSD)***
+ 0.0729 (CREW) **

R^2 = 0.1599

n = 151

The 95 percent confidence limits for the mean outhaul time was determined for both crews at: the mean lateral slope distances (mean); mid-way between the longest lateral slope distances and the mean lateral slope distances (mid-way longest); and mid-way between the shortest lateral slope distances and the mean lateral slope distances (mid-way shortest). The mean outhaul times and the 95 percent confidence limits for mean outhaul times for both crews are given in Appendix I, Figure 19.

A t-test of the coefficient or correlation (R^2) indicates that R^2 is statistically significant at ($P<.001$).

The paired t-test, which was used to validate the regression equa-

TABLE 11. REGRESSION EQUATIONS DEVELOPED FOR PREBUNCHING YARDING CYCLE

Cycle element variable	Regression coefficients for: Lateral Outhaul	Hook	Lateral inhaul	Total (delay-free)	Unhook	Reset
Constant	+.4157	+1.0289	+.2842	+1.2142	+1.13	+1.09
LATSD (ft.)	+.0035	N/A[1/]	+.0050	+.0154	N/A	N/S[2/]
BLKHT (ft.)	N/S	N/S	N/S	N/S	N/S	N/S
SDIST (ft.)	N/S	N/S	N/S	+.0016	N/A	N/A
LEADA (deg.)	N/A	N/S	N/S	N/S	N/A	N/S
NOLOGS (pieces)	N/A	N/S	N/S	N/S	N/S	N/S
TOTVOL (ft^3)	N/A	N/S	N/S	N/S	N/S	N/S
DKHT (ft.)	N/A	N/A	N/A	N/S	N/S	N/S
AVELV (ft^3)	N/A	N/S	N/S	N/S	N/S	N/S
CREW (0-1)	+.1729	+.6078	N/S	+.9976	N/S	N/S

1. Not available
2. Not significant

tion developed for outhaul, shows that there is no signficant difference between observed values and the expected values at the ($P<.001$) significance level. Table 12 shows the paired t-test used to validate the regression equation for outhaul.

In previous research studies on prebunching, Kellogg found that outhaul time was a function of lateral slope distance. Keller found that outhaul time was a function of lateral slope distance, slope distance, slope distance squared and slope direction. This analysis found lateral slope distance and CREW to be the only statistically significant variables.

HOOK

The following model was used for the prediction of hook time:

$$HOOK = f\ (CREW)$$

$$HOOK = 1.0289 + 0.6078\ (CREW)\ ^{***}$$

$$R^2 = 0.1965 \qquad n = 151$$

The 95 percent confidence limits for the mean hook time was determined for when CREW = 0 (owner/operator was a chokersetter) and for when CREW = 1 (owner/operator was not a chokersetter). The mean hook times and the 95 percent confidence limits for mean hook times are given in Appendix I, Figure 20.

A t-test of the coefficient of correlation (R^2) indicates that R^2 is significant at ($P<.001$). The paired t-test which was used to validate the regression equation for hook time, shows that there is no significant difference between observed values and expected values at the

TABLE 12. PAIRED t-TEST FOR VALIDATING OUTHAUL REGRESSION EQUATION

Observed value Y_i (minutes)	Predicted value $\hat{Y}_i$ (minutes)	Difference (D) $Y_i - \hat{Y}_i$
1.38	1.06	0.32
0.88	0.87	0.01
0.28	0.76	-0.48
1.30	1.10	0.20
1.17	0.63	0.54
0.63	0.94	-0.31
0.43	0.63	-0.20
0.26	0.55	-0.31
1.02	0.98	0.04
0.52	0.82	-0.30
0.45	0.79	-0.34
0.68	1.04	-0.36
0.55	0.84	-0.28
0.83	0.71	0.12
0.57	0.71	-0.14
0.57	0.89	-0.32
1.17	0.94	0.23
0.93	0.70	0.23
0.55	0.56	-0.01
0.45	0.75	-0.30
0.97	0.71	0.26
1.95	0.95	1.00
2.15	1.01	1.14
0.73	0.79	-0.06
1.42	1.26	0.16
0.93	0.91	0.02
0.83	0.88	-0.05
0.90	0.80	0.10
0.87	0.61	0.26
0.68	0.70	-0.02
0.55	0.52	0.03
0.38	0.61	-0.23
0.48	0.67	-0.19
0.58	0.84	-0.26
1.78	0.67	1.11
0.67	0.63	0.04
0.17	0.57	-0.40
0.40	0.61	-0.21
0.25	0.52	-0.27
0.17	0.76	-0.59

(cont'd next page)

TABLE 12
(continued)

$H_o: \mu_D = 0$ VS $H_a: \mu_D \neq 0$

$\bar{x}_D = \Sigma(Y_i - \hat{Y}_i)/n = 0.0041$ $s = 0.3974$

$$t = \frac{\bar{x}_D}{s/(n)^{1/2}} = \frac{0.0041}{0.3974/(40)^{1/2}} = .07$$

Do not reject H_o since $t_{calc.} = 0.07 < t_{.05/2,\ 38} = 1.96$

(P<.001) significance level. The paired t-value was calculated in the same manner as was shown in Figure 11.

Dykstra (1975) stated that hooking is influenced by the efficiency of the person hooking the logs as well as by the many characteristics of the logging unit, some of which may be difficult to objectively measure, such as brush density. In this study, the only variable found significant in influencing hook time was CREW, which indicates that there is a significant difference in efficiency between crews. In previous research on prebunching, Kellogg found that hook time was a function of volume and number of chokers, Keller found no significant variables.

INHAUL

The following model was used for the prediction of inhaul time:

INHAUL = f (LATSD)

INHAUL = 0.2842
+ 0.0050 (LATSD) * * * $R^2 = 0.2781$
$n = 151$

The 95 percent confidence limits for the mean inhaul time was determined at: the mean lateral slope distance (mean); mid-way between the longest lateral slope distance and the mean lateral slope distance (mid-way longest); and mid-way between the shortest lateral slope distance and the mean lateral slope distance (mid-way shortest). The mean inhaul times and the 95 percent confidence limits for the mean inhaul times are given in Appendix I, Figure 21.

A t-test of the coefficient of correlation (R^2) indicates that R^2 is significant at ($P<.001$). The paired t-test which was used to validate the regression equation for inhaul time, shows that there is no significant difference between observed values and expected values at the ($P<.001$) significance level. The paired t-value was calculated in the same manner as was shown in Figure 11.

Past studies of cable operations have shown that inhaul time increases as the slope yarding distance increases (Dykstra, 1975). Although the statement was made with regards to conventional yarding, it also applies to prebunching. In this study, the LATSD explained 28 percent of the variation in inhaul time. In previous research on prebunching, Kellogg found that inhaul time was a function of the lateral slope distance, lead angle, and number of chokers. Keller found that inhaul time was a function of lateral slope distance squared and slope distance.

DFTIME = f (LATSD, SDIST, CREW)

DFTIME = 1.2.42
+ 0.0154 (LATSD) * * *
+ 0.00157 (SDIST) * * *
+ 0.9976 (CREW) * * *

$R^2 = 0.4332$
n = 151

The 95 percent confidence limits for the mean relay-free time was determined for both crews at: the mean lateral slope distance and the mean slope distance (mean); mid-way between the longest lateral slope and slope distances and the mean lateral slope and slope distances (mid-way longest); and mid-way between the shortest lateral slope and slope distances and the mean lateral and slope distances (mid-way shortest). The mean delay-free outhaul times and the 95 percent confidence limits for mean delay-free times for both crews are given in Appendix I, Figure 22.

A t-test of the coefficient of correlation (R^2) indicates that R^2 is significant at ($P<.001$). The paired t-test used to validate the regression equation for delay-free time shows no significant difference between the observed values and expected values at the ($P<.001$) signficance level. The paired t-value was calculated in the same manner as was shown in Figure 12.

The regression equation shows that estimated delay-free turn time increases as lateral slope distance and slope distance increase. The delay-free time also depends on the crew; it is higher when the owner/operator was not a chokersetter than when he was. Fourty three percent of the variation in delay-free turn time is explained by these three variables. In previous research on prebunching, Kellogg found that total turn time was a function of lateral slope distance, lead angle, volume and number of chokers. Keller found that delay-free time was a function of lateral slope distance, lateral slope distance squared, slope distance squared, average log volume and carriage height.

SWINGING YARDING CYCLE

Multiple regression was used to analyze delay-free swinging time.

The independent variables included in the regression analysis were: NOLOGS, NOCHOK, TURNVOL and SDIST. The following hypothesis was developed for those variables thought to influence swinging time:

H_0 : DFTIME = $_f$ (NOLOGS, NOCHOK, TURNVOL, SDIST)

For the swinging cycle, no significant regression equation could be developed to explain the relationships between the independent variables measured and cycle times. Table 13 summarizes both the delay-free turn times and the independent variables for the swinging cycle.

Because a significant regression equation could not be developed, the mean value of delay-free time was considered the best estimate. The paired t-test, used to validate the mean delay-free time, showed no significant difference between the split data means.

In previous research on swinging, Kellogg found that slope distance, average lead angle of the turn and the log volume per turn were significant in explaining the variation in turn times. Keller found that for swinging the significant variables were: the number of logs, slope distance and number of chokers.

DELAY ANALYSIS

The analysis of delays in total cycle time shows that the relative impact of delays differs markedly between prebunching and swinging. Table 14 summarizes the percentages of total yarding time occupied by delays. The difference in percentages of delays was due to the inherent differences between the two yarding systems. The prebunching cycle was entirely devoted to the lateral yarding of logs through standing timber, thus frequent hangups required resetting the turn. The prebunching op-

TABLE 13. SUMMARY OF SWINGING CYCLE TIMES AND INDEPENDENT VARIABLES

Elements	(minutes)		Variables		
Total Turn Time Without Delays n=225	max min mean	14.82 1.68 5.41	NOLOGS (pieces) n=224	max min mean	10.00 1 4.55
Total Turn Time With Operating Delays[1] n=225	mean	6.10	NOCHOK n=225	max min mean	4 3 3.97
Total Turn Time With All Delays n=225	mean	6.64	TURNVOL ($ft.^3$) n=91	max min mean	298.60 33.20 146.36
			SDIST (ft.) n=114	max min mean	890 306 561.31

eration also used a 7/16 inch (1.11 centimeter) line with a breaking strength that was less than the maximum line pull of the GU-10, causing the line to break occasionally. The swinging cycle primarily yarded logs up the corridors where there was less potential for hangups. Also, the swinging yarder was equipped with lines capable of handling the maximum tensions created during the swinging cycle.

Table 15 presents a summary of the prebunching delays. Total delay time, accounted for about 47 percent of total yarding time. Delays were divided into two catagories; operating delays account for 32 percent of total yarding time and non-operating delays represented 15 percent of the total yarding time. The main contributor to non-operating delay time was the re-rigging time associated with breaking the prebunching line.

1. Includes only those delays that could be observed from the landing.

TABLE 14. PERCENTAGE OF TOTAL YARDING TIME OCCUPIED BY DELAYS

System		Total Productive Time	Operating Delays	Non-operating Delays	Total Delay Time	Total Recorded Time
Prebunch Owner/operator	Time (min.)	405.53	265.71	72.42	338.13	743.66
	Percent	54.50	35.70	9.70	45.50	100.00
Prebunch Without Owner/operator	Time	349.49	186.60	143.02	329.62	679.11
	Percent	51.50	27.50	21.10	48.50	100.00
Prebunch Combined	Time	755.02	451.90	215.44	667.34	1422.36
	Percent	53.10	31.80	15.10	46.90	100.00
Swing	Time	1217.78	154.24	122.77	277.01	1494.79
	Percent	81.50	10.32	8.21	18.53	100.00

TABLE 15. SUMMARY OF PREBUNCHING DELAYS

Non-operating Delays	Frequency	Mean (minutes)	Total (minutes)	Percent of Delay-free Time (minutes)	Percent of Total Time (minutes)
Line Fouled on Drum	1	9.45	9.45	1.25	0.66
Yarder	4	2.52	10.06	1.33	0.71
Break Line	12	15.03	180.40	23.89	12.68
Personal	3	2.22	9.66	1.28	0.68
Radio Whistle	2	1.48	2.95	0.39	0.21
Look for Lost Slider	1	2.92	2.92	0.39	0.21
Total	23	9.37	215.44	28.53	15.15

Operating Delays	Frequency	Mean (minutes)	Total (minutes)	Percent of Delay-free Time (minutes)	Percent of Total Time (minutes)
Reposition Truck	7	1.59	11.14	1.48	0.78
Reconnaissance	5	1.00	5.00	0.66	0.35
Discussion	1	0.50	0.50	0.07	0.04
Reposition Logs	1	0.42	0.42	0.06	0.03
Untangle Rigging	3	1.12	3.37	0.45	0.24
Reset	76	2.54	193.15	25.58	13.58
Reposition Block	2	3.82	7.63	1.01	0.54
Miscellaneous	5	1.57	7.83	1.04	0.55
Block Change	8	17.23	114.97[17]	15.23	8.08
Corridor Change	3	43.12	107.89	14.29	7.59
Total	111	4.07	451.90	59.85	31.77

(continued on next page)

TABLE 15

(continued)

Delays	Frequency	Mean (minutes)	Total (minutes)	Percent of dealy-free Time (minutes)	Percent of total time (minutes)
Total time with all delays	134	4.98	667.34	88.39	46.92

1. The block and corridor change times are adjusted for the number of turns actually used in analysis of turn time.

This delay accounted for 84 percent of the non-operating delay time and 13 percent of the total yarding time. The main contributors to operating delay time were reset, block changing and corridor changing. These delays accounted for 92 percent of the operating delay time and 29 percent of the total yarding time.

Table 16 presents a summary of the prebunching delays by crews. The percent of total yarding time occupied by total delay time is almost equal for the two different crews, but the proportion of delay time spent in operating and non-operating delays differs substantially. It should be noted that although the percentages of total yarding time occupied by delays are almost equal for the two crews, the magnitude of the delay times are different. The crew with the owner/operator as a chokersetter spent about 60 percent of the non-operating delay time or about 6 percent of the total yarding time re-rigging the broken prebunching line, while the crew without the owner/operator spent about 96 percent of the non-operating delay time, or about 20 percent of the total yarding time re-rigging the broken prebunching line. The resetting of turns accounted for 43 percent of the operating delay time, or16 percent of the total yarding time for the crew with the owner/

TABLE 16. PREBUNCHING DELAYS BROKEN DOWN BY CREWS

Non-operating Delays	Total With Owner/operator (minutes)	(n)	Percent of Total Time (minutes)	Total Without Owner/operator (minutes)	(n)	Percent of Total Time (minutes)
Line Fouled on Drum	9.45	1	1.27	0	0	0
Yarder	3.86	3	0.52	6.20	1	0.91
Break Line	43.58	5	5.86	136.82	7	20.15
Personal	9.66	3	1.30	0	0	0
Radio Whistle	2.95	2	0.40	0	0	0
Look For Lost Slider	2.92	1	0.39	0	0	0
Total	72.42	15	9.74	143.02	8	21.06

Operating Delays	Total With Owner/operator (minutes)	(n)	Percent of Total Time (minutes)	Total Without Owner/operator (minutes)	(n)	Percent of Total Time (minutes)
Reposition Truck	2.34	2	0.31	8.80	5	1.30
Reconnaissance	5.00	5	0.67	0	0	0
Discussion	0.50	1	0.07	0	0	0
Reposition Logs	0.42	1	0.06	0	0	0
Untangle Rigging	2.69	2	0.36	0.68	1	0.10
Reset	115.44	48	15.52	77.71	28	11.44
Reposition Block	5.85	1	0.79	1.78	1	0.26
Miscellaneous	0	0	0	7.83	5	1.15
Corridor and Block changes	133.47		17.95	89.80		13.22
Total Operating Delays	265.71		35.73	186.60		27.48
Total Delays	338.13		45.47	329.62		48.54

operator as a chokersetter. For the crew without the owner/operator, 42 percent of the operating delay time, or about 11 percent of the total yarding time was spent resetting hangups.

The difference between the delays for the two crews may be due to the lack of experience and skill of the chokersetters. They were not always able to spot potential hangups before breaking the line. Looking at reset time and time spent re-rigging, it is possible that there is a trade-off between the time spent resetting and breaking the line. An experienced chokersetter can judge this difference.

Table 17 summarizes the delays for the swinging cycle.

Table 18 compares the availability and utilization for the yarding systems.

TABLE 17. SUMMARY OF SWINGING CYCLE DELAYS[1]

(minutes)

Non-operating Delays	Frequency	Mean	Total	Percent of Delay-free Time
Move Guyline	2	7.18	14.35	1.18
Trim Line	4	1.02	4.09	.34
Send Gear	8	4.25	33.99	2.79
Swap Ends	1	21.52	21.52	1.77
Fall Tree	2	10.00	20.00	1.64
Change Dropline	1	18.02	18.02	1.48
Miscellaneous	8	1.35	10.80	.89
Total	26	4.72	122.77	10.08

Operating Delays	Frequency	Mean	Total	Percent of Delay-free Time
Chaser	4	2.49	9.95	.82
Loader	3	3.15	9.46	.78
Road Changes	4	45.05	134.83	11.07
Total Operating Delays	11	14.02	154.24	12.70
Total Delays	37	7.49	277.01	22.75

1. Only those delays that could be observed from the landing are included.

TABLE 18. YARDING SYSTEM MECHANICAL AVAILABILITY AND UTILIZATION

Machine (crew)	Number of Shifts	TIME: Minutes per turn — Productive: Regular[1/] Cycle	Productive: Change Yarding Roads and/or Blocks	Delays: Mechanical	Delays: Other Non-Mechanical	Mechanical Availability (percent)	Utilization[2/] (percent)
GU-10 With Owner/operator	5	4.60	1.14	0	0.62	100	90
GU-10 Without Owner/operator	2	6.03	1.21	0	1.93	100	79
GU-10 Combination	7	5.15	1.17	0	1.13	100	85
Madill 071	5	5.50	0.60	0	0.55	100	92

1. Indicates operating delays other than change yarding roads and/or blocks.

2. Utilization percent = $\frac{\text{total time without delays}}{\text{total time}}$

TABLE 19. SUMMARY OF TIME AND COST PER UNIT VOLUME FOR THE YARDING CYCLES FOR PREBUNCHING AND SWINGING

Element of Yarding Cycle	Time Per Unit Volume (min./cunit)	Cost Per Unit Volume ($/cunit)	Percentage of Total Yarding Cost With All Delays Included
Outhaul (prebunch)	1.51	1.25	4.83
Hook (prebunch)	2.33	1.92	7.42
Inhaul (prebunch)	1.42	1.17	4.52
Unhook (prebunch)	2.11	1.74	6.73
Reset (prebunch)	1.88	1.55	5.99
Deck Change (prebunch)	1.12	0.92	3.56
Corridor Change (prebunch)	1.06	1.06	4.10
Other Delays (prebunch)	2.02	2.02	7.81
All Delays (swing)	0.84	2.67	10.32
Delay-free Prebunch Yarding	7.36	6.08	23.51
Delay-free Swing Yarding	3.70	11.73	45.36
Delay-free Yarding Combined	11.06	17.81	68.87
Yarding With All Delays (combined)	18.43	25.86	100.00

DISCUSSION OF RESULTS

COMPARISONS OF TOTAL COSTS

This study has shown prebunching with a low investment drumset and swinging with a Madill 071 reduced logging costs in a thinning compared to conventional yarding with a Madill 071. Using the owner/operator's estimate of yarding production with the Madill 071, the prebunching and swinging technique saves between $13 and $19 per cunit ($5 to $7 per cubic meter) or 31 to 45 percent compared to conventional yarding. Using the predicted conventional yarding production calculated from Keller's equation for full-cycle yarding, prebunching and swinging saved between $11 and $17 per cunit ($4 to $6 per cubic meter) or 28 to 41 percent compared to conventional yarding.

The breakeven point for yarding production per hour between prebunching with the low investment drum set and swinging with the Madill 071, and conventional yarding with the Madill 071 is 7.36 cunits (20.61 cubic meters) per hour. Appendix G shows the calculations for the breakeven analysis.

THE PREBUNCHING CYCLE

Table 19 presents a summary of the time and cost per unit volume for prebunching and swinging yarding cycles. For the combined production of the two crews, the prebunching cycle represents about 44 percent of the total cost for prebunching and swinging.

One of the most significant variables found to influence the prebunching cycle time was CREW. The crew with the owner/operator as a chokersetter produced an average of 1.82 cunits (5.1 cubic meters) or about 54 percent more volume per hour than the crew without the owner/operator as a chokersetter. This difference can be explained by the difference in skill and motivation between the crews.

THE SWINGING CYCLE

In this study, the swinging cycle included swinging of prebunched logs in the corridors to the landings, and yarding non-prebunched logs on the steep ground just beyond the landings and logs left in the corridors. The average turn time for the non-prebunched turns was 0.41 minutes less than the turn time for prebunched logs, due to the concentration of non-prebunched logs close to the landings. The average turn size and turn volume for the prebunched turns was 4.64 logs and 151.72 cubic feet (4.25 cubic meters), respectively. For the non-prebunched logs the average turn size and turn volume was 4.08 logs and 127.32 cubic feet (3.56 cubic meters), respectively.

The swinging operation used three persons on the chokersetting crew. By reducing the crew to two persons, the decrease in production, if any, would likely be offset by the decrease in unit cost.

COMPARISON WITH PAST STUDIES

Table 20 lists the average conditions for the three studies on prebunching and swinging. Figure 11 shows the percent differences between prebunching and swinging for the three studies.

This study indicates prebunching with the Skagit GU-10 and swinging with a Madill 071 is more economical than conventional yarding with

TABLE 20. AVERAGE STAND CONDITIONS FOR PREBUNCHING AND SWINGING STUDIES

	Kellogg	Keller	(1980) Zielinsky
Slope Yarding Distance	178 ft.	363.7 ft.	575.9 ft.
Lateral Yarding Distance	78 ft.	62.2 ft.	92.8 ft.
Volume per turn			
Prebunching	20.7 (ft^3)	19.1 (ft^3)	53.6 (ft^3)
Swinging	42.3 (ft^3)	47.4 (ft^3)	146.4 (ft^3)
Logs per turn			
Prebunching	1.3	1.5	2.1
Swinging	2.8	4.9	4.5
Volume per log	15.1 (ft^3)	13.2 (ft^3)	26.4 (ft^3)

the Madill 071. Kellogg's study (1976) also found that prebunching and swinging reduced skyline thinning costs compared to conventional yarding. Keller's study (1979), on the other hand, showed prebunching and swinging cost more than conventional yarding in a thinning. Direct cost comparisons between the three prebunching and swinging studies would be misleading due to the differences in equipment, piece sizes, yarding distances, crews and cutting techniques. Instead, the comparisons were made on the basis of percent increase or decrease in yarding costs due to prebunching and swinging. Kellogg concluded that prebunching with the single-drum sled winch and swinging with the Schield-Bantam T-350 was about 24 percent less expensive than conventional yarding with the Schield-Bantam T-350. Keller concluded that prebunching with the Igland-Jones Mini Alp and swinging with the West Coast Madill yarder was about twice as expensive as full-cycle yarding with the West Coast Madill. In this study prebunching and swinging savings were estimated to be between 22 and 39 percent compared

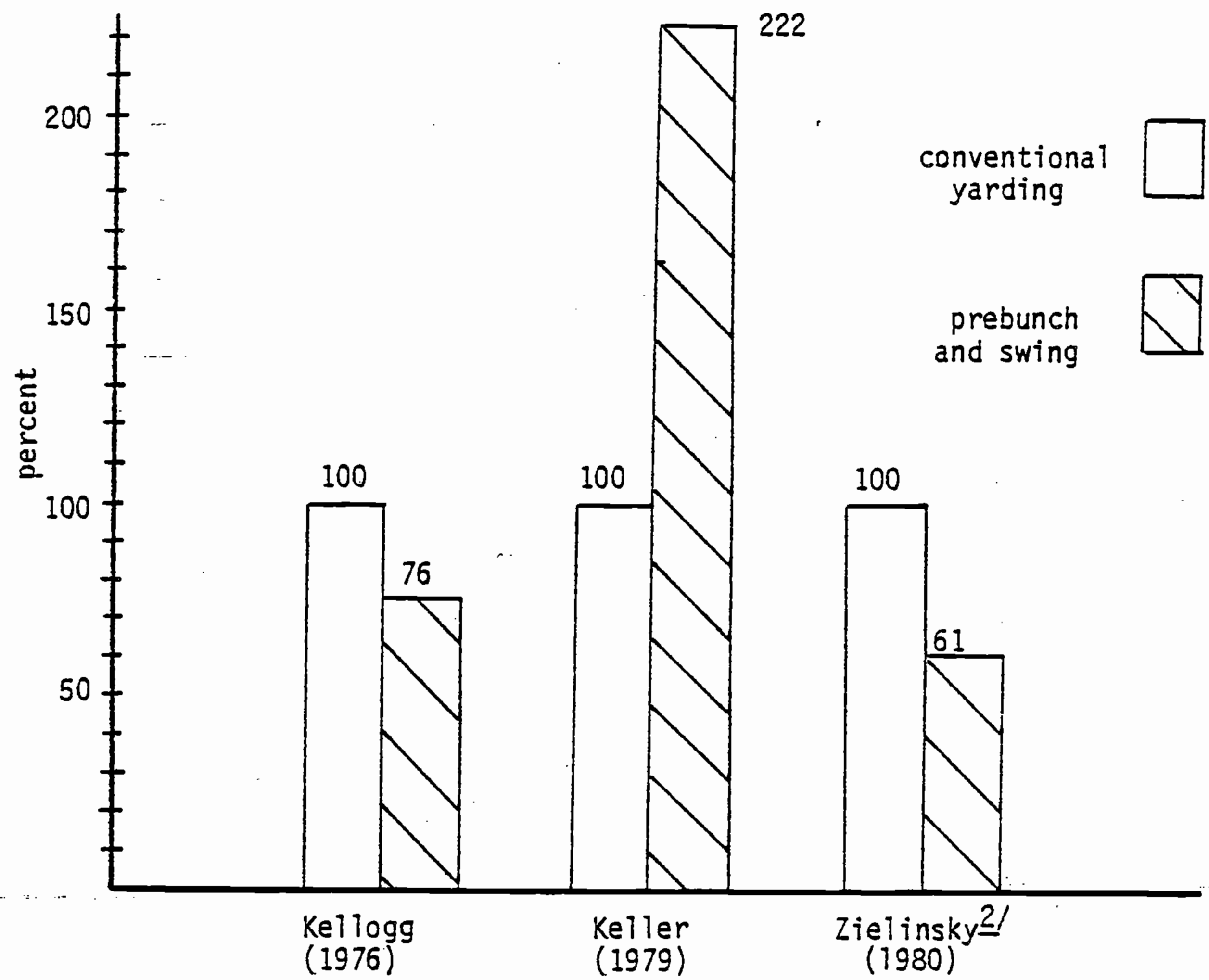


FIGURE 11. SUMMARY OF PERCENT DIFFERENCES BETWEEN PREBUNCHING AND SWINGING.[1/]

1. Conventional yarding is set at 100 percent.

2. Based on owner/operators estimate.

to conventional yarding. Keller stated in his conclusion that "Any attempt to reduce lateral yarding costs by prebunching must concentrate on reducing the operating costs of the prebunching system." The statement should be qualified with reference to production. The total operating cost of the prebunching system is only important relative to production of the system.

EXTENSIONS OF THE PREBUNCHING CONCEPT

BREAKEVEN SPAR LOCATIONS

In a situation where the unit to be prebunched is fan shaped, (corridors radiating from a common point), the lateral distance between the corridors is short near the landings and increases towards the tail hold. There is a breakeven point in corridor distance above which it is most economical to use conventional yarding techniques and below which it is most economical to prebunch and swing. The breakeven point is determined by the cost per unit volume for conventional yarding versus prebunching and swinging. This economic breakeven point is where the first prebunching spar should be located. Figure 12 outlines a methodology for determining the optimum location of the first prebunching spar. Appendix J shows the derivation of the lateral yarding distance equation and shows an example calculation of the optimum location of the first prebunching spar. In areas where the slopes next to the landing are steep, as in this study, operating feasibility, not economics, would determine the first prebunching spar location.

Once the first prebunching spar location has been determined, either by the methodology outlined in Figure 13 or by operating feasibility, the optimum prebunching spar spacing for each successive spar down the corridor can be determined. The optimum spacing is determined based on the time required to change prebunching spar locations and the prebunching yarding cycle time. Figure 13 shows a methodology developed to determine the optimum prebunching spar spacing for the minimization of total prebunching time per unit volume. Appendix K shows how the

FIGURE 12. A METHODOLOGY FOR DETERMINING THE OPTIMUM FIRST PREBUNCHING SPAR LOCATION

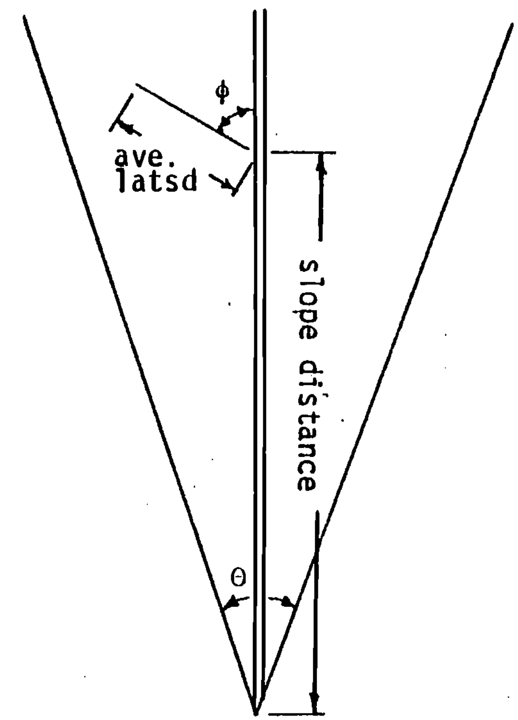
The breakeven distance can be determined by using an equation of the form:

$$P\ cost/min\left(\frac{1}{P\ vol/turn}\right)(P\ turn\ time)) + (S\ cost/min\left(\frac{1}{S\ vol/turn}\right)(S\ turn\ time)) = (C\ cost/min\left(\frac{1}{C\ vol/turn}\right)$$

$$(C\ turn\ time))$$

Where:

P = Prebunching
S = Swinging
C = Conventional
cost/min = Operating cost per minute
turn time= Estimated turn time based on predictive equation or mean
vol/turn = Estimated volume per turn



NOTE: The solution of this equation requires that the predictive equations are a function of slope distance and/or lateral slope distance.

Required information:

Θ = Angle between corridor boundaries
ϕ = Lead angle
Cost per minute for prebunching
Cost per minute for swinging
Cost per minute for conventional yarding
Volume per turn for prebunching
Volume per turn for swinging
Volume per turn for conventional yarding
Estimated turn times

(continued on next page)

FIGURE 12
(continued)

$$\text{Average lateral slope distance (ave. latsd)} = \frac{\sin(90 + \theta/2)(\text{slope dist.})(\sin \theta/2)}{2\sin(\phi - \theta/2)}$$

Breakeven equation:

$$(PC\ (1/PV)(\beta_{op} + \beta_{1p}\ (\text{ave. latsd}) + \beta_{2p}\ (\text{sdist}) + \ldots + \beta_{np}X_{np}) + (SC(1/SV)(\beta_{os} + \beta_{1s}\ (\text{ave. latsd})$$

$$+ \beta_{2s}\ (\text{sdist}) + \ldots + \beta_{ns}X_{ns}) = (CC(1/CV)(\beta_{oc} + \beta_{1c}\ (\text{ave. latsd}) + \beta_{2c}\ (\text{sdist}) + \ldots + \beta_{nc}X_{nc})$$

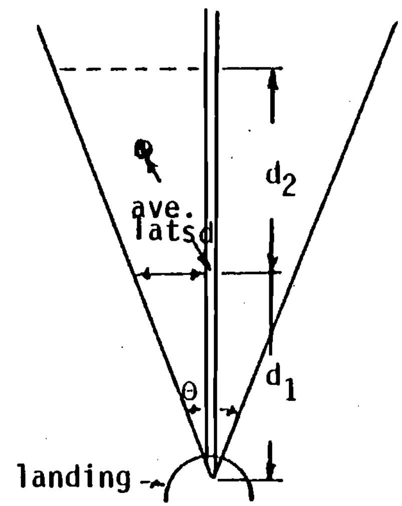
Solve equation for slope yarding distance (sdist).

Where:

- PC = Prebunching cost per minute
- PV = Prebunching volume per turn (cunits)
- β_{ip} = Prebunching regression equation parameters
  - β_{op} = constant
  - β_{1p} = Lateral slope distance coefficient
  - β_{2p} = Slope distance coefficient
  - ... β_{np} = Other coefficients
- β_{is} = Swing regression equation parameters
  - β_{os} = Constant
  - β_{1s} = Lateral slope distance coefficient
  - β_{2s} = Slope distance coefficient
  - ... β_{ns} = Other coefficients
- β_{ic} = Conventional yarding equation parameters
  - β_{oc} = Constant
  - β_{1c} = Lateral slope distance coefficient
  - β_{2c} = Slope distance coefficient
  - ... β_{nc} = Other coefficients

FIGURE 13. A METHODOLOGY FOR DETERMINING THE OPTIMUM LOCATION OF SUCCESSIVE SPARS

This methodology is based on the average prebunching spar change time and a regression equation for prebunching turn time. The optimum spacing will be determined by finding the point where the total time per unit volume is minimized. The two components of time per unit volume are; the spar change time divided by the volume to be yarded to the spar, and the total prebunching cycle time divided by the volume per turn.



Required information:

- S = Average corridor slope in percent
- d_1 = Slope distance to first spar, or last spar in feet
- θ = angle between corridor boundaries in degrees
- V = Volume per acre to be yarded (cunits)
- P = Average time to move and rig spar (minutes)
- Tv = Volume per turn (cunits)
- L = Lateral slope distance perpendicular to the skyline road at the upper spar

Regression coefficients:

- β_0 = Constant (includes delays)
- β_1 = Coefficient for lateral slope distance
- β_2 = Coefficient for slope distance
- ... β_p = Other regression coefficients

d_2 = Optimum spacing is determined by iterating for the minimum value of the equation. this is repeated for successive spars spacings.

Equation to be minimized:

$$\frac{P}{(2d_2L_1+\sin(\theta/2)d_2^2)(V)\cos(\tan^{-1}(\frac{S}{100})))/43560} + \frac{\beta_0 + \beta_1\,(\text{ave. latsd}) + \beta_2\, d_2 + \ldots \beta_p X_p}{Tv}$$

$$\text{ave.latsd} = \sqrt{\left(\frac{(\frac{L}{2})^2 d_2 + (1/6)\sin^2(\theta/2)d_2^3 + \frac{1}{2}L\,\sin(\theta/2)d_2^2}{Ld_2 + \sin(\theta/2)d_2^2/2}\right)^2 + \left(\frac{\frac{1}{2}d_2^2 L + (1/3)\sin(\theta/2)d_2^3}{Ld_2 + \sin(\theta/2)d_2^2/2}\right)^2}$$

equation was developed and an example calculation of the optimum prebunching spar spacing. These spacings may have to be modified, depending on whether or not there are prebunching spars available near the optimum locations.

Figure 14 summarizes unit cost comparisons between prebunching and swinging and conventional yarding for various prebunching yarder investment costs. Prebunching unit cost is not very sensitive to yarder investment cost. Appendix L shows the calculations for the breakeven cost for the prebunching yarder.

SAFETY CODE IMPLICATIONS

The Oregon Safety Code for Places of Employment, effective May 15, 1969 with ammendments, was the safety code in effect when this study took place. The safety code in effect March 1, 1980, is the new Oregon Occupational Safety and Health Code.[4/] Changes in the safety code that may have an impact on prebunching should be noted. In the new Oregon safety code (1980) the rigging requirements for prebunching spars are not specifically covered, but would likely be covered by rule 80-290, "TAIL AND LIFT TREES GUYING". This rule states that "Lift trees shall be supported by at least two guylines when the rigging is placed on the lift tree at a height greater than five times the tree diameter at breast height or higher than 10 feet (3.05 meters) from the highest ground point, whichever is lower." The maximum ground slope on which logs can be decked is covered in rule 80-325-5. This rule states that: "(a) If

4. Oregon Occupational Safety and Health Code (Oregon Administration Rules); Chapter 437, Division 80, Workers Compensation Dept., 1980.

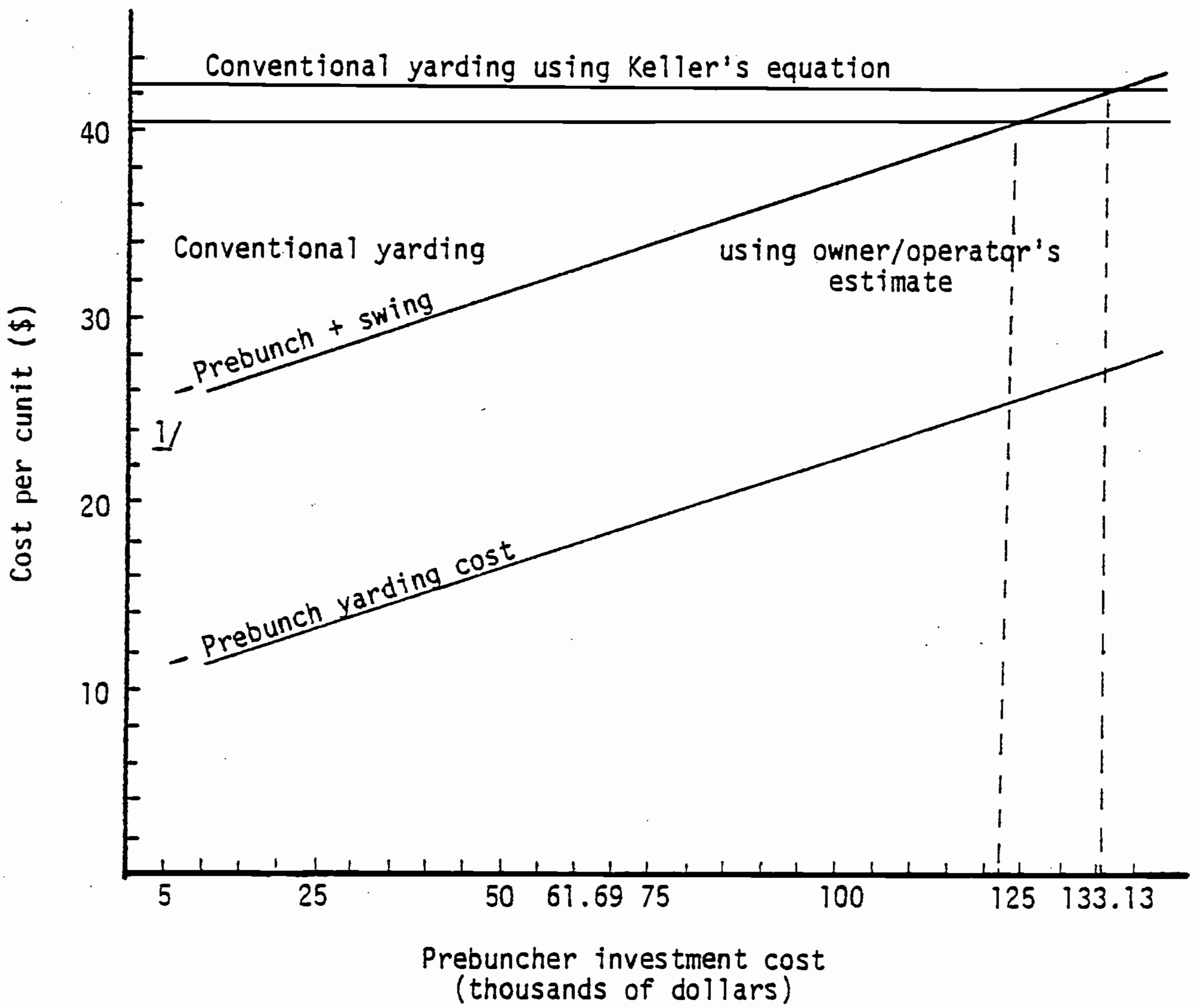


FIGURE 14. UNIT COST COMPARISONS BETWEEN PREBUNCHING AND SWINGING AND CONVENTIONAL YARDING AT DIFFERENT YARDER COSTS.

---

1. Investment costs below $10,000 were depreciated over two years and cost over $10,000 were depreciated over four years.

the landing chute slope is 20% or less, logs may be landed and decked in the chute provided the logs can be left in a stable position; (b) If the landing chute slope exceeds 20%, decking is not permitted in the chute if a chaser is required to unhook the rigging from the logs or if workers are working below the landing chute and are exposed to rolling or sliding logs." This rule could restrict the prebunching spar location to slopes less than 20%. A third rule, covered in both the old Oregon Safety Code (1969) and the new Oregon Safety Code (1980), prohibits the use of "V" lead[5/] yarding. This rule restricts the area in which logs can be bunched to a spar to the area below the spar or less than a "square" lead.[6/] Littler lateral deflection of prebunching spars was observed during inhaul when the horizontal yarding angle was less than a square lead and the spar was rigged lower than 10 feet. However, there is potential for failing the spar when yarding with a "V" lead or with the block rigged higher than 10 feet or five times the diameter of the tree.

---

5. A horizontal angle of greater than 90° formed by the projected line from the drum of the yarder to the prebunching spar and the turn of logs.

6. A horizontal angle of approximately 90° formed by the projected line from the drum of the yarder to the prebunching spar and the turn of logs.

SUGGESTIONS FOR FUTURE RESEARCH

This study was an observational study and lacked the rigid control necessary to insure that all data required for a complete statistical comparison was obtained. The following are suggestions for those wishing to conduct an observational study on an operation where the owners are not being compensated for their cooperation.

1. Make sure that there is sufficient preparation time for the field study prior to beginning operations.
2. Make sure there is a complete understanding with the operators as to what treatments will be applied, and that there will be a control for comparing treatments.
3. Be prepared to change the study if the operators change their plans.

Prebunching is not addressed specifically in the new Oregon Safety Code (1980), and a careful interpretation of the rules for prebunching must be made. Two areas relating to safety need more research:

1. There is a need for further investigation of the forces developed in an unsupported spar, and the specification of the diameters and maximum rigging heights required to safely withstand these forces. Research should also identify the yarding zones to be avoided for an unsupported spar.
2. The current safety code does not allow for the decking of logs on slopes exceeding 20%. This limit is arbitrary; the maximum slope for safely decking logs of various species on different soil types, with various moisture conditions should be determined through research.

SUMMARY

This study compared the production rates and yarding costs of prebunching with an inexpensive yarder and swinging with a Madill 071 to estimated conventional yarding costs and production rates in a thinning. The study analyzed two different chokersetting crews for the prebunching operation. One crew had the owner/operator as one of the chokersetters and the other crew did not.

Yarding cost comparisons were based on the owner/operator's estimate of conventional yarding production and on the predicted conventional yarding production calculated with Keller's equation for full-cycle yarding production. The analysis of yarding costs, using these estimates, indicates that prebunching and swinging saved 11 to 44 percent compared to conventional yarding.

The average production rate for prebunching was 5.1 cunits per hour (14.3 cubic meters per hour) or 17.2 logs per hour. The average production rate for swinging was 13.22 cunits per hour (37.02 cubic meters per hour) or 41 logs per hour. The estimated conventional yarding production was between 4.5 and 5.8 cunits per hour (12.5 and 16.2 cubic meters per hour).

Significant differences in production rates were found between the two crews. The crew with the owner/operator as a chokersetter averaged 54 percent more volume per hour than the crew without the owner/operator as a chokersetter.

Regression analysis was used to analyze the yarding cycle for prebunching. the regression equations developed relate the time required

to complete a yarding cycle or element to the independent variables that effect it. For the prebunching regression analysis only three variables were found to be significant, lateral yarding distance, slope yarding distance, and crew. For those elements in which no significant regression models were developed, the mean value was used as the best estimate.

The average delay-free prebunching cycle time was 3.95 minutes. With all delays included the average cycle time was 7.45 minutes. The average delay-free swinging cycle time was 5.41 minutes. With all delays included the average cycle time was 6.64 minutes. For prebunching, delay time accounted for about 47 percent of the total yarding time. Operating delays accounted for about 32 percent of the total yarding time, while non-operating delays accounted for about 15 percent of the total yarding time. For the swinging cycle, only those delays that could be observed from the landing were included in the delay analysis. Total delay time for swinging accounted for about 19 percent of the total yarding time. Operating delays accounted for about 13 percent to the total yarding time, while non-operating delays accounted for about 6 percent of the total yarding time.

CONCLUSION

The results of this case study show prebunching and swinging was an economical alternative to conventional yarding in thinnings. Prebunching techniques may be of most benefit to loggers that own one yarder, in the size class of the Madill 071, and who want to work in thinnings. It is likely that less expensive ways to skyline yard in a thinning are available, such as using a small specialized yarder, but if the logger is constrained to a large yarder with a high hourly cost, prebunching may help keep the cost per unit volume down. The large yarder may be used elsewhere during prebunching.

The prebunching cycle was seriously affected by delays. The operating and non-operating delays together accounted for about 47 percent of the total prebunching yarding time. The greatest room for improvement in the prebunching cycle probably lies in reducing delays. Two of the major delays, breaking the prebunching line and resetting hung-up turns which account for 26 percent of the total prebunching yarding time can be reduced. The delay resulting from breaking the prebunching line could be reduced by using clutch frictions that slip before exceeding the safe working load of the line, or by utilizing a smaller engine. These changes could eliminate line breakage and increase production by about 13 percent.

The delay time involved with resetting hangups could be reduced by more planning, directional falling techniques, and crew training. Planning of the unit layout should occur before the cutting operation begins so that the fallers know the location of the corridors and prebunching spars. By using directional falling techniques the timber could be felled to lead, thus reducing breakage and reset time.

BIBLIOGRAPHY

1. Aulerich, D. E.; K. N. Johnson; and H. A. Froehlich. Tractor or Skylines: What is Best for Thinning Young-growth Douglas-fir? Forest Industries. 101(12):42-45. 1974.

2. Aulerich. D. E. Smallwood Harvesting Research at Oregon State University. Loggers Handbook, Vol. XXXV:10-12,84-88. 1975.

3. Beuter, J. H. Personal communication of unpublished data. January 1980.

4. Columbia River Log Scaling and Grading Bureau, Official Log Scaling and Grading Rules. 1978.

5. Dykstra, D. P. Production Rates and Costs for Cable, Balloon, and Helicopter Yarding Systems in Old-growth Douglas-fir. Research Bulletin 18. For. Res. Lab., School of Forestry, Oregon State University, Corvallis. 57 p. 1975.

6. Keller, R. R. Prebunching with a Low Investment Skyline Yarder in Thinnings. Master of Science Thesis, Oregon State University, Corvallis. 138 p. 1979.

7. Kellogg, L. D. A Case Study of Prebunching and Swinging, a Thinning System for Young Forests. Master of Forestry Paper, Oregon State University, Corvallis. 88 p. 1976.

8. Neter, J.; and W. Wasserman. Applied Linear Statistical Models. Richard D. Irwin, Inc., Homewood, Illinois. 379-382 pp. 1974.

9. Oregon Occupational Safety and Health Code. (Oregon Administration Rules, Chapter 437), Division 80, Logging Workers' Compensation Department. 1980.

10. Renoud, D. Personal communication. Owner/Operator More Logs Inc. Sweet Home, Oregon. September 1979.

11. Rowe, K. and J. A. Barnes. Statistical Interactive Programming System (SIPS): Command Reference Manual. Statistical Computing Report No. 6. Department of Statistics, Oregon State University, Corvallis. 109 p, 1979.

12. Tedder, P. L. Oregon's Future Timber Harvest: The Size of Things to Come. Journal of Forestry 77(11):714-716. 1979.

APPENDICES

APPENDIX A

CONVERSION FACTORS FOR CONVERTING ENGLISH UNITS TO METRIC MEASURE

TABLE 21.

From Given Units	To Desired Units	Multiply by "C" Factor
Acres	Hectares	0.405
Feet	Meters	0.305
Inches	Centimeters	2.54
Cubic feet	Cubic Meters	0.0283
Cunits[1/]	Board Feet	480.00
Cunits	Cubic Meters	2.83
Cubic Inches	Liters	0.0164
Horsepower	Kilowatt	0.746
Foot-pound	Joule	1.35
Pound	Kilogram	0.454

1. Conversion factor for the study.

APPENDIX B

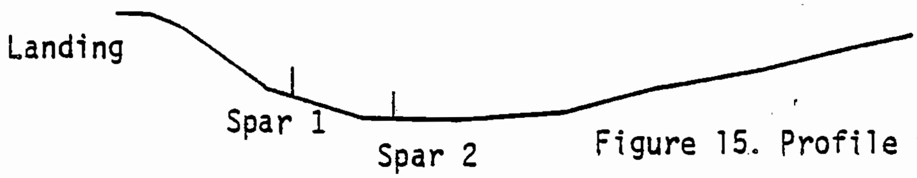


Figure 15. Profile for Corridor 2

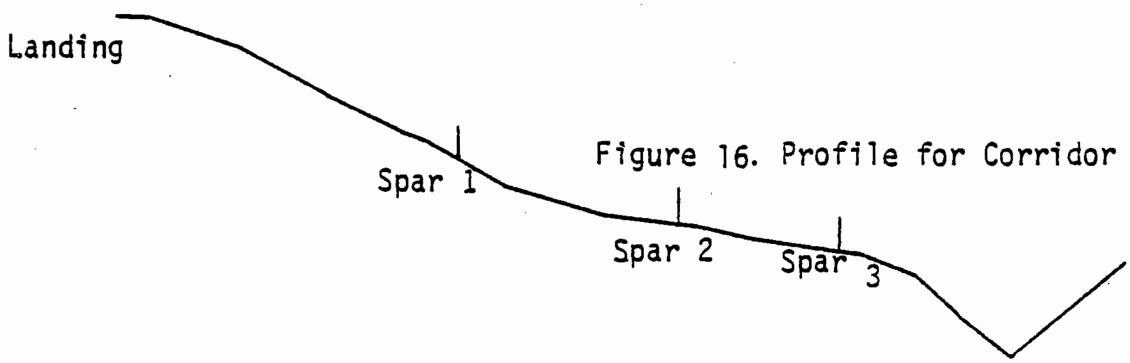


Figure 16. Profile for Corridor 7

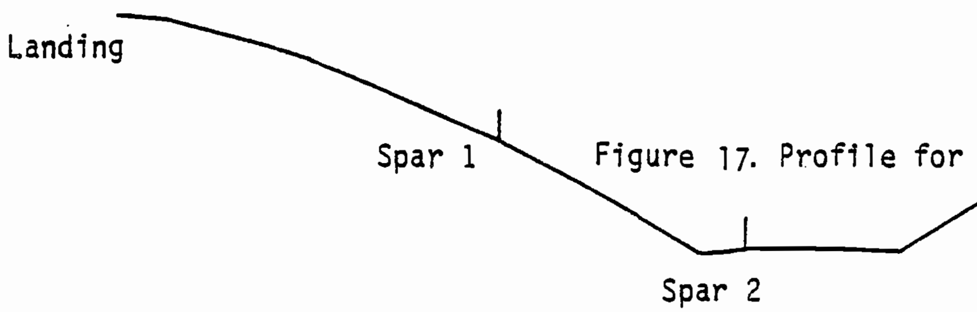


Figure 17. Profile for Corridor 8

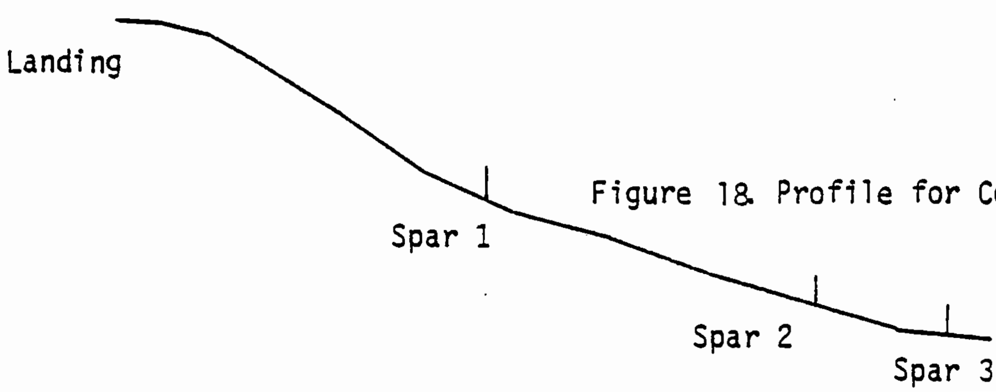


Figure 18. Profile for Corridor 10

Appendix C

MADILL 071 SPECIFICATIONS

Engine	Detriot Diesel 8-V-71-N
Rated Engine Horsepower	284 at 2100 RPM
Carrier	Crawler Type
Tower	48'5" Tube Type
Weight	73,500 pounds
Drum Capacity	
Skyline	1500 feet of 1-1/8" Dia.
Mainline	2180 feet of 3/4" Dia.
Haulback	3045 feet of 3/4" Dia.
Tagline	2450 feet of 7/16" Dia.
Strawline	3340 feet of 3/8" Dia.
Guylines	225 feet of 1-1/8" Dia.
Line Speed	1510 feet per minute (main drum, mid capacity)
Line Pull	36,206 pounds (main drum, mid capacity)
Brakes	Wichita

APPENDIX D

DATE: PREBUNCH DATA COLLECTION SHEET CREW: Pg.

START TIME: WEATHER: CORR. NO.: ASPECT:

TURN NO.	OUT-HAUL	HOOK	IN-HAUL	UN-HOOK	REPO.	DELAY	LAT. S.D.	BLKHT / S.D	LEADA	NO. CHOKS	NO. LOGS	TAG NOS.	DKHT	COMMENTS

DATE: SWING DATA COLLECTION SHEET CREW: Pg.

START TIME: WEATHER: CORR. NO.: ASPECT:

TURN NO.	TURN TIME	DELAY	ROAD Δ	NO. LOGS	NO. CHOK.	TAG NOS.	L	D_L	D_S	COMMENTS

APPENDIX E

ESTIMATED CONVENTIONAL YARDING PRODUCTION

Using Keller's equation for total time with operating delays:

Total time with operating delays =

$$
R^2 = .448 \quad
\begin{array}{l}
2.805 \\
+ .0195 \text{ (VOLUME)} \\
+ .0452 \text{ (LOG VOLUME)} \\
+ .000256 \text{ (LDIST SQ)} \\
+ .253\text{x}10^{-5} \text{ (SDIST SQ)} \\
+ .0294 \text{ (CARHT)}
\end{array}
\qquad
\begin{array}{l}
2.805 \\
+ .0195\ (99.99) \\
- .0452\ (33.3) \\
+ .000256\ (124.7)^2 \\
+ .253\text{x}10^{-5}\ (951.4)^2 \\
+ .0294\ (40) \\
= 10.70
\end{array}
$$

VOLUME = Total turn volume, estimated using my average log volume of 33.3 ft^3 and assuming a 3.0 log turn equals 99.99 ft^3.

LOG VOL + average log volume = 33.3 ft^3 for my study.

LDIST SQ = Lateral slope distance squared for my study equals (124.7 ft.)

SDIST SQ = Slope distance squared for my study the average equals $(951.4 \text{ ft.})^2$

CARHT = Carriage height, estimated to be 40 feet.

Keller's average non-operating delays equals 11.8 percent of total turn time. Total turn time = 10.70 + 1.43 = 12.13.

Average road changing time for my study = .60. Total turn time = 12.73 min/turn.

12.73 min/turn = 4.71 turns/hour

4.71 turns/hour x 1.00 cunits/turn = 4.71 cunits/hour

Owner/operator's estimate of production = 4.48 cunits/ hour.

APPENDIX G

BREAKEVEN POINT FOR PREBUNCHING AND SWINGING VERSUS CONVENTIONAL YARDING (VOLUME/HOUR)

Prebunching Production/Hour	= 4.3208 cunits/hour
Cost/Cunit	= $11.46/cunit
Swinging Production/Hour	= 13.218 cunits/hour
Cost/Cunit	= $14.40/cunit
Conventional Yarding Cost/Hour	= $190.39/hour

$$\frac{\$190.39}{x} = \frac{\$25.86}{1\ \text{cunit}} \qquad x = 7.36\ \text{cunits/hour}$$

Appendix H

HOURLY OPERATING COST FOR THE PREBUNCHING YARDER

TABLE 22.

Item	Cost/Hour
Depreciation	
GU 10 Drum set and Engine ($2000.00; no salvage; 2 years, 5 months/year).	$ 1.36
Cable ($715.00; no salvage, 5 months).	.78
Dumptruck ($5,000.00, no salvage; 4 years, 5 months/year).	1.70
Radio ($3858.00; 20%; 4 years).	.44
Crew Vehicle ($9.650.00; no salvage; 3 years).	1.83
Blocks, Ladder, Rigging ($450.00; no salvage; 4 years).	.15
Total Depreciation	$ 6.26
Maintenance and Repair	
Yarder (50% of depreciation).	$ .68
Dumptruck (25% of depreciation).	.43
Radio (60% of depreciation).	.26
Total Maintenance and Repair	$ 1.36
Fuel and Lubricants	
Yarder (1.5 gal/hour at $1.20).	$ 1.80
Crew Vehicle (5 gal/day at $6.00/day).	.75
Dumptruck (.2 gal/hour at $.90).	.18
Lubricants (10% of Fuel Cost).	.27
Total Fuel and Lubricants	$ 3.00

TABLE 22
(continued)

Item	Cost/Hour
Labor	
Yarding Operator	$ 14.08
Chokersetters	24.06
Total Labor	$ 38.14
Insurance, Interest, and Taxes (18% Average Annual Investment)	
Yarder	$ .15
Dumptruck	.32
Radio	.28
Total Overhead	$ .75
Total Hourly Cost	$ 49.53

Appendix H

HOURLY OPERATING COSTS FOR THE MADILL 071

TABLE 23.

Item	Swing Cost per hour
Depreciation	
Madill 071 ($250,000.00; 20%; 8 years).	$ 14.20
Radio ($3858.00; 20%; 4 years).	.44
Danebo S-40 Carriage ($6500.00; 20%; 4 years).	.74
Lines ($16,580.00; no salvage; 1 year).	9.42
Crew Vehicle (9,650.00; no salvage; 3 years).	1.83
Blocks and Rigging ($4803.00; no salvage; 4 years).	.68
Miscellaneous Rigging ($2500.00; no salvage; 4 years).	.36
Total Depreciation	$ 27.67
Maintenance and Repair	
Yarder (50% of Depreciation).	$ 7.10
Radio (60% of Depreciation).	.26
Carriage and Rigging (20% of Depreciation).	1.78
Crew Vehicle (25% of Depreciation).	.46
Total Maintenance and Repair	$ 9.60
Fuel and Lubricants	
Yarder (5 gal/hour at $.90).	$ 4.50
Crew Vehicle (5 gal/day at $6.00/day).	.75
Lubricants (10% of Fuel Costs).	.53
Total Fuel and Lubricants	$ 5.78

TABLE 23
(continued)

Item	Cost/Hour
Labor	
Yarder Operator	$ 14.08
Hook Tender	16.17
Rigging Slinger	13.23
Chokersetters (2)	24.06
Chaser	12.29
Total Labor	$ 79.83
Overhead	
Average Annual Investment (AAI) = New Cost + Annual Depreciation + Salvage	
Insurance = 2% of AAI per Year	
Interest = 12% ofAAI per Year	
Taxes = 4 % of AAI per Year	
Total = 18% of AAI per Year	
Yarder and Carriage	$ 17.09
Crew Vehicle	.63
Radio	.28
Total Overhead	$ 18.00
Total Hourly Cost	$140.88

Appendix H

HOURLY OPERATING COSTS FOR THE BANTAM C-366

TABLE 24.

Item	Swing cost per hour
Depreciation	
Bantam C-366 ($170,000.00; 20%; 8 years).	$ 9.66
Vehicle ($8700.00; no salvage; 4 years).	1.24
Total Depreciation	$ 10.90
Maintenance and Repair	
Yarder (50% of Depreciation).	$ 4.83
Vehicle (25% of Depreciation).	.31
Total Maintenance and Repair	$ 5.14
Fuel and Lubricants	
Loader (7 gal/hour at $.90).	$ 6.30
Vehicle (3.64 gal/hour at $4.36/day).	.55
Lubricants (10% of fuel cost).	.68
Total Fuel and Lubricants	$ 7.53
Labor	
Loader Operator	$ 14.08
Insurance, Interest, and Taxes (18% Average Annual Investment).	
Loader	$ 11.30
Vehicle	.56
Total Overhead	$ 11.86
Total Hourly Cost	$ 49.51

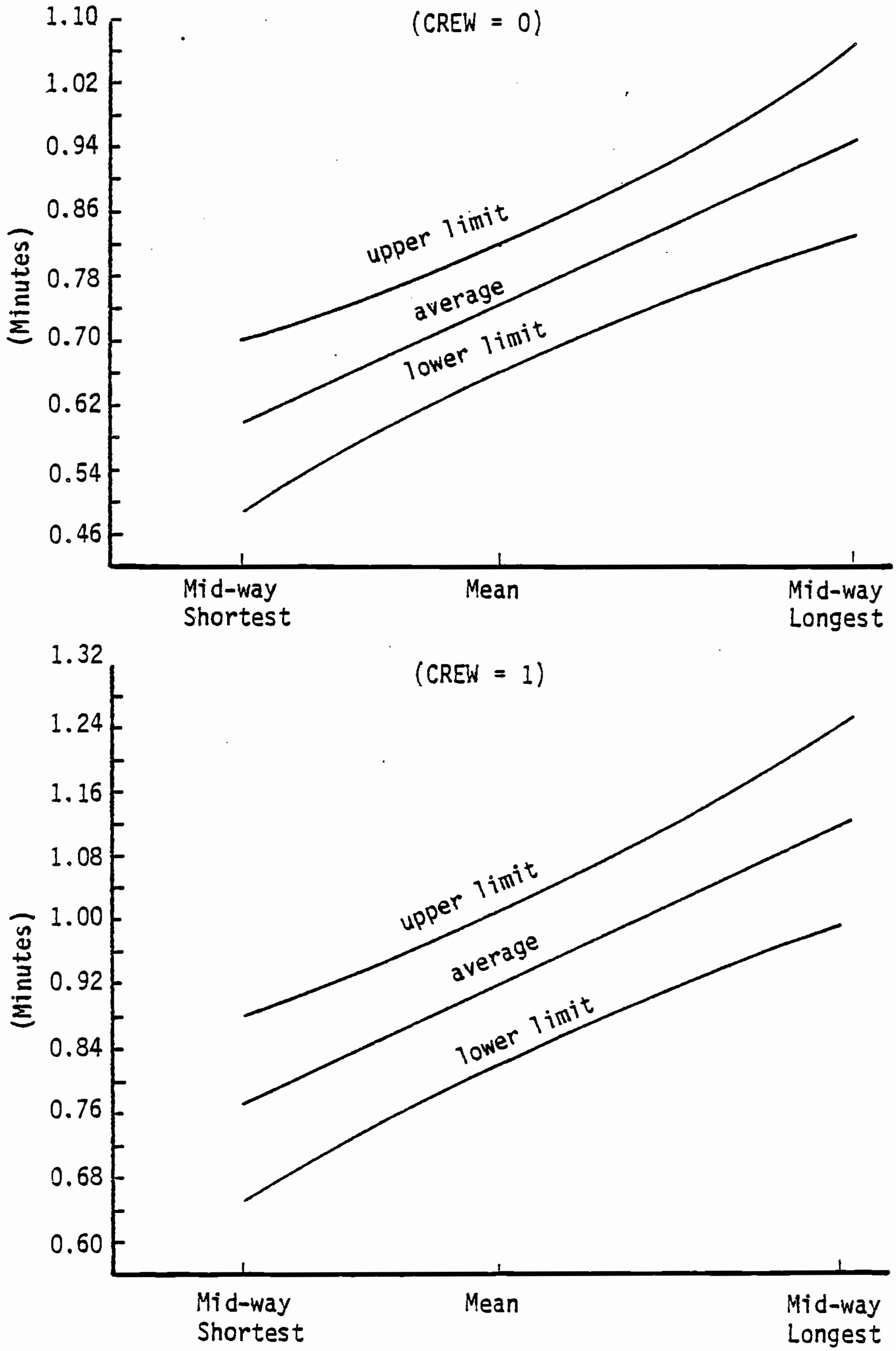


Figure 19 . 95 percent confidence intervals for outhaul time

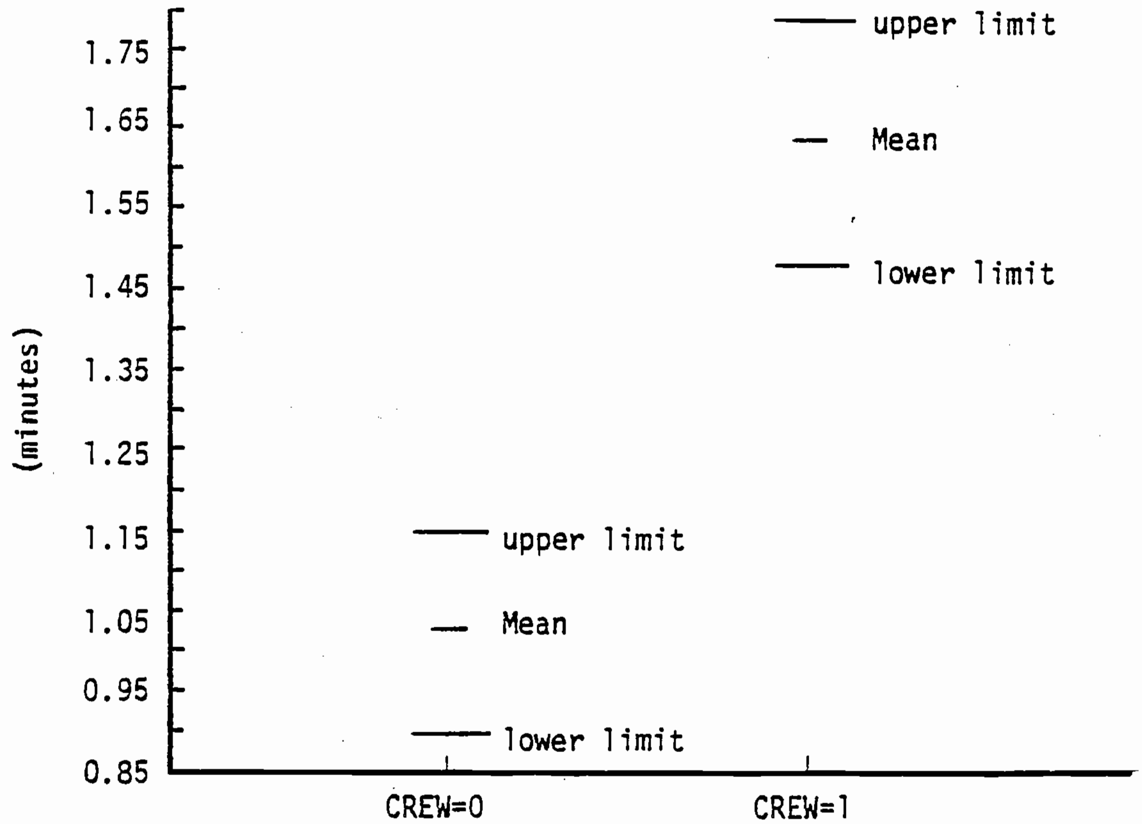


Figure 20. 95 percent confidence intervals for hook time.

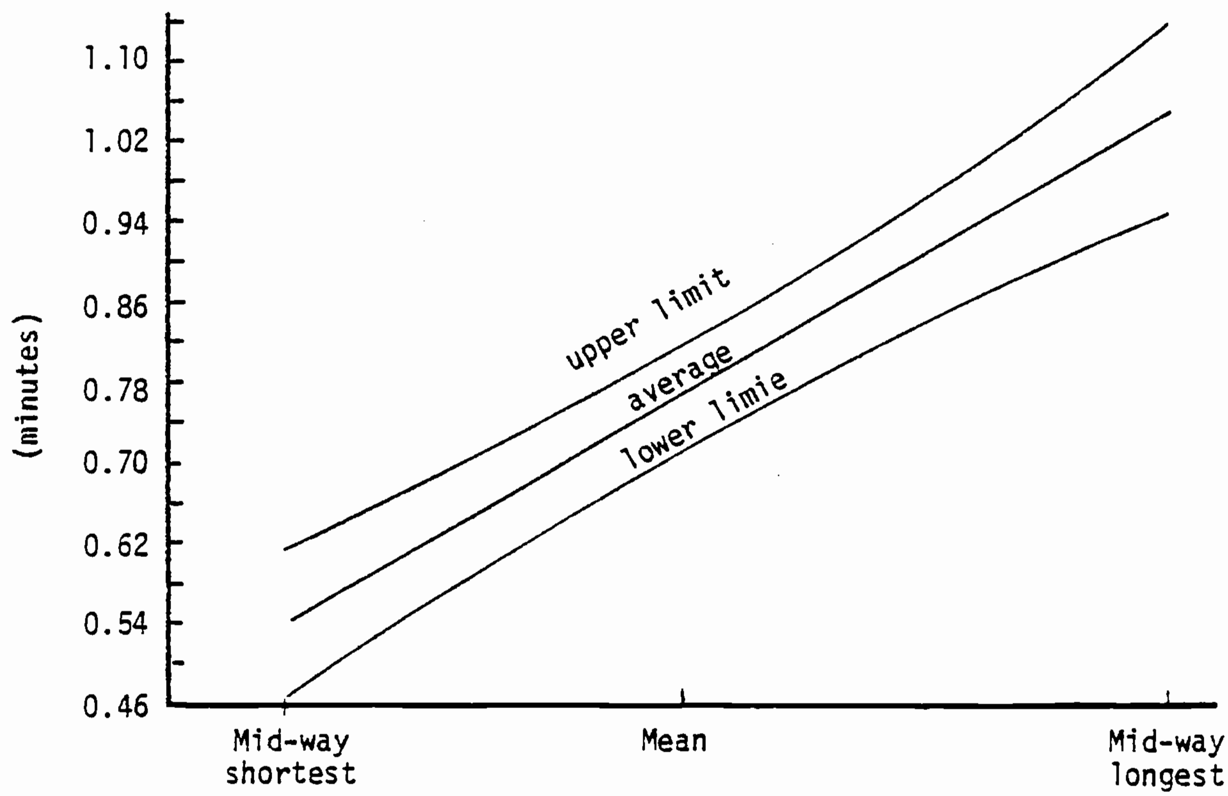
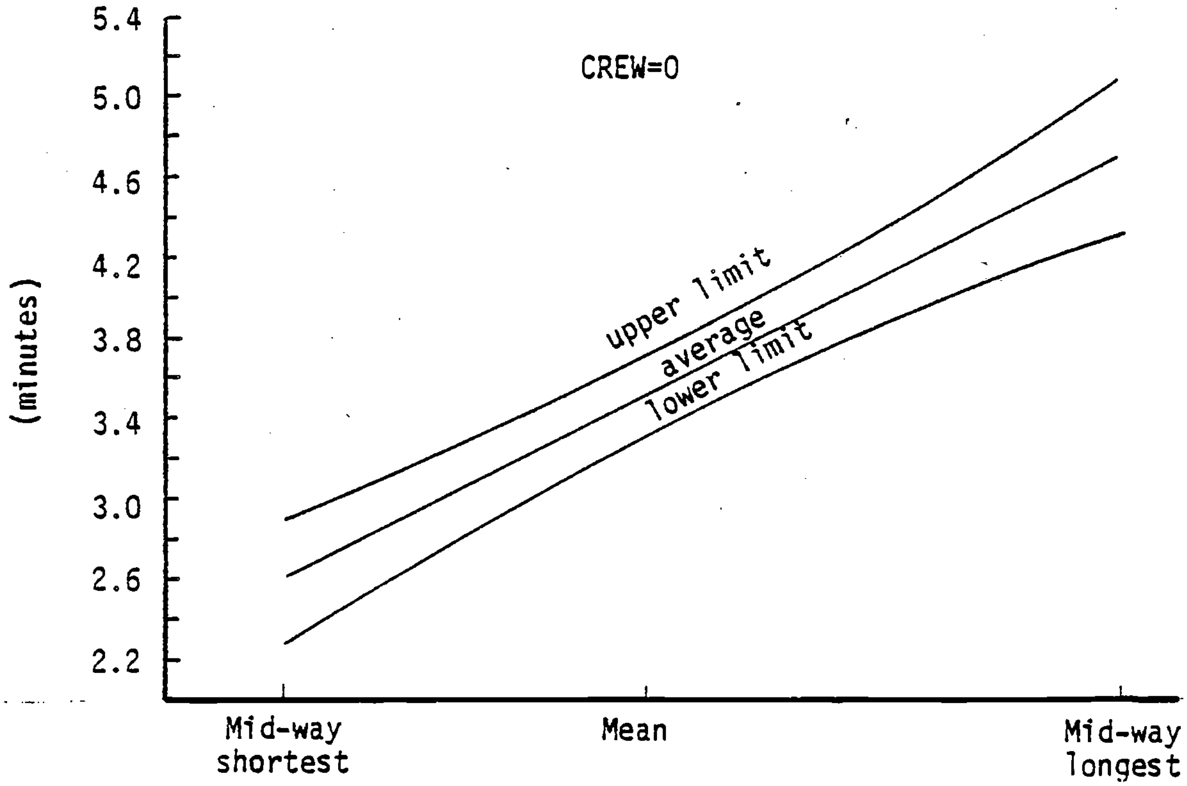


Figure 21. 95 percent confidence interval for inhaul time.

APPENDIX I continued



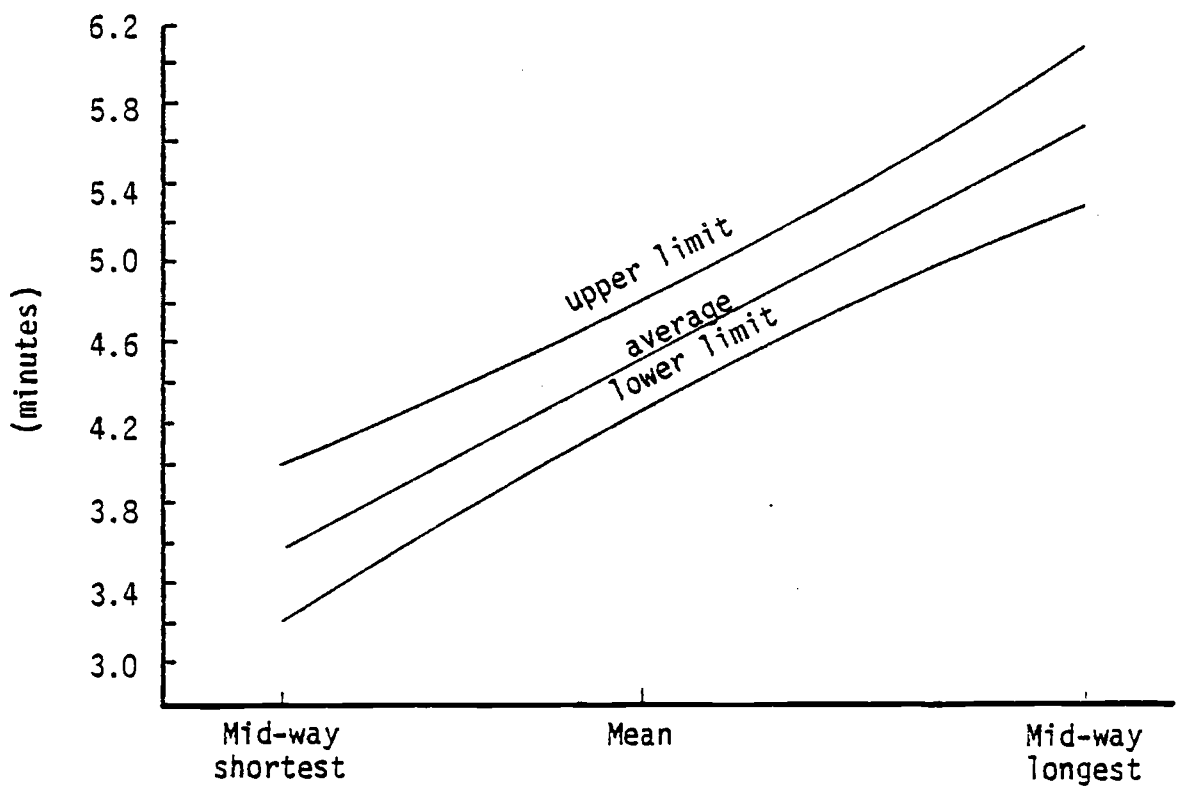


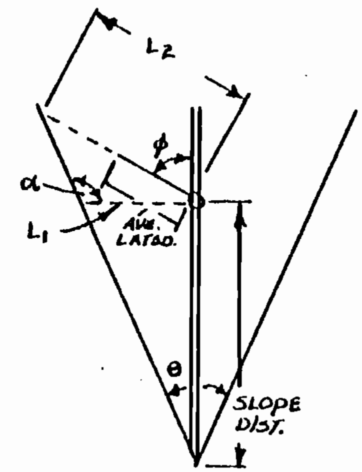
Figure 22. 95 percent confidence intervals for delay-free time.

APPENDIX J

Derivation of the lateral yarding distance equation and sample calculation of optimum first spar location

The average lateral slope distance (ave. latsd) derivation:

L_1 = Slope Dist. $(\sin \theta/2)$, $\alpha = 90^0 + \frac{1}{2}\theta$



Using law of sines, $\frac{L_2}{\sin(90^0 + \frac{1}{2}\theta)} = \frac{\text{Slope Dist. } (\sin\theta/2)}{\sin(\phi - \theta/2)}$

$$\text{SO, } L_2 = \frac{\sin(90^0 + \theta/2)\,(\text{Slope Dist.})\,(\sin \theta/2)}{\sin(\phi - \theta/2)}$$

$$\text{Ave. latsd} = \tfrac{1}{2} L_2 = \frac{\sin(90 + \theta/2)\,(\text{Slope Dist.})\,(\sin \theta/2)}{2 \sin(\phi - \theta/2)}$$

This example is based on Keller's regression equation for full cycle yarding time and the regression equation for prebunching turn time developed in this paper.

$= 20^0$

$= 60^0$

Cost per minute for prebunching (PC) = $0.83

Cost per minute for swinging (SC) = $2.35

Cost per minute for conventional (CC) = $2.35

Volume per turn for prebunching (PU) = .50 cunits

Volume per turn for swinging (SU) = 1.3 cunits

Volume per turn for conventional (CV) = .75 cunits

(continued on next page)

β_o includes delays except road change
$\beta_{op} = 3.54$
$\beta_{1p} = .0154$
$\beta_{2p} = .00157$
$\beta_{3p} = .9976$
$X_{3p} = CREW = 0$
$\beta_{os} = 6.04$ (mean is best estimate)
$\beta_{oc} = 4.35$
$\beta_{1c} = .000256$

$X_{1c} = (LATSD)^2$
$\beta_{2c} = .00000253$
$X_{2c} = (SDIST)^2$
$\beta_{3c} = 0.195$
X_{3c} = Volume (FT^3) per turn = 83.33
$\beta_{4c} = -.0452$
X_{4c} = average log volume (FT^3) = 33.33
$\beta_{5c} = .0294$
X_{sc} = carriage height = 30'

$$\$0.83\ (1/1.5)\ (3.54 + .0154\ \frac{(\sin 100)\ (\text{slope dist.})\ (\sin 10^0)}{2 \sin (50^0)}) + .00157\ (SDIST)\ + \$2.35\ (1/1.3)\ 6.04 =$$

$$\$2.35\ (1/.75)\ (3.69 + .000256\ \sin 100)\ \frac{(\text{slope dist.})(\sin 10^0)}{2 \sin (50^0)}^2 + .00000253\ (SDIST)^2 + .0195(.75.00)$$

$$-.0452\ (.25.00) + .0294(30)$$

$$0.0055\ (SDIST) + 16.79 = .00009746\ (SDIST)^2 + 15.36$$

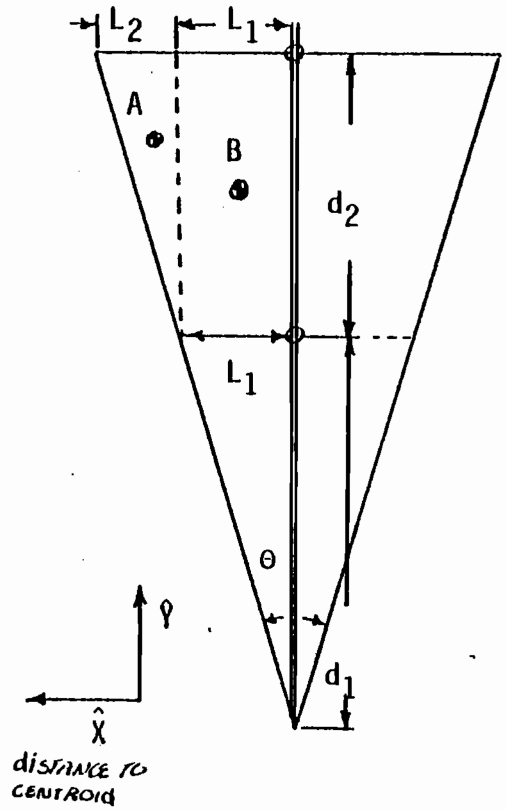
$$.00009746\ (SDIST)^2 - .0055\ (SDIST) - 1.43 = 0$$

SDIST = 152.95 feet

APPENDIX K

DEVELOPMENT AND SAMPLE CALCULATION OF THE OPTIMUM PREBUNCH SPAR SPACING EQUATION

The average lateral yarding distance is equal to the distance from the prebunching spar to the centroid of the area to be prebunched. The following is the derivation of the average lateral slope distance equation:



$L_2 = \sin \theta/_2 \ (d_2)$, $L_1 = \sin \theta/_2 \ d_1$,

Area of A $= \frac{d_2 L_2}{2} = \frac{d_2^2 \sin \theta/_2}{2}$, area of B $= d_2 L_1$,

$$\hat{X} = \frac{(\tfrac{1}{2}L_1)(d_2 L\ ) + (L_1 + 1/3L_2)(\frac{d_2 L_2}{2})}{(\tfrac{1}{2}d_2 L_2) + (d_2 L_1)} = \frac{\tfrac{1}{2}L_1^2 d_2 + L_1 d_2^2 \sin\theta/_2 + (1/6)d_2^3 \sin^2\theta/_2}{(\tfrac{1}{2}d_2^2 \sin\theta/_2) + (d_2 L_1)}$$

$$\hat{Y} = \frac{(\tfrac{1}{2}d_2)(d_2 L_1) + (2/3d_2)(\tfrac{1}{2}d_2 L_2)}{(\tfrac{1}{2}d_2 L_2) + (d_2 L_1)} = \frac{\tfrac{1}{2}d_2^2 L_1 + 1/3 d_2^3 \sin\theta/_2}{(\tfrac{1}{2}d_2^2 \sin\theta/_2) + d_2 L_1}$$

ave. latsd $= \sqrt{\hat{X}^2 + \hat{Y}^2}$:

$$= \sqrt{\left(\frac{\tfrac{1}{2}L_1^2 d_2 + \tfrac{1}{2}L_1 d_2^2 \sin\theta/_2 + 1/6 d_2^3 \sin^2\theta/2}{(\tfrac{1}{2}d_2^2 \sin\theta/_2) + (d_2 L_1)}\right)^2 + \left(\frac{\tfrac{1}{2}d_2^2 L_1 + 1/3 d_2^3 \sin\theta/2}{(\tfrac{1}{2}d_2^2 \sin\theta/_2) + (d_2 L_1)}\right)^2}$$

(continued on next page)

Volume to be yarded to a prebunching spar:

area = $2\,(A + B) = d_2L_2 + 2d_2L_1 = d_2^2 \sin \Theta/_2 + 2d_2L_1$

volume per ft^2 = $\dfrac{V}{43560.}$ = cunits/$_{ft}2$

adjust for average ground slope; S

adjustment = $\cos\,(\tan^{-1}\,(\frac{S}{100})\,)$

$= \dfrac{V \cos(\tan^{-1}\,(\frac{S}{100})\,)}{43560}$

total volume to be yarded = $\dfrac{(d_2^2 \sin \Theta/_2 + 2d_2L_1)\;((V)\cos\,(\tan\,(\frac{S}{100}))}{43560}$

(continued on next page)

This example is based on the average prebunching spar change time and the regression equation for prebunching turn time developed in this paper.

$s = 30\%$
$d_1 = 160$ feet
$\theta = 20^0$
$V = 20$ cunits
$P = 17$ minutes

$v = .50$ cunits
$L = 27.8$
$\beta_0 = 3.544$
$\beta_1 = 0.01538$
$\beta_2 = 0.0015712$

Equation to be minimized:

$$\frac{\dfrac{17}{2d_2(27.8)+\sin 10^0(d_2^2))(20)(\cos(\tan^{-1}(\frac{S}{100})))} + 3.544+0.01538\sqrt{\left(\dfrac{\frac{1}{2}(27.8)^2(d_2)+\sin^2(10^0)d_2^3/6+\frac{1}{2}(27.8)\sin 10^0 d_2^2}{(27.8)d_2-\frac{1}{2}\sin 10^0(d_2^2)}\right)^2+\left(\dfrac{\frac{1}{2}d_2^2(27.8)+\sin 10^0 d_2^3/3}{27.8d_2+\frac{1}{2}\sin 10^0(d_2^2)}\right)^2}+.00157(160)}{.50}$$

Itterate for minimum value of the equation:

d_2	Value of equation
200	13.27
150	13.38
250	13.63289
175	13.24567
185	13.24179
180	13.24076

∴ 180 feet slope distance below first spar is the optimum location for the second spar.

To find third spar location replace:

d_1 with 160 + 180 = 340 feet

L with 59 feet

d_2	Value of equation
150	12.63403
160	12.66461
140	12.62484
130	12.64179
145	12.62649
135	12.62969

∴ 140 feet slope distance below second spar is the optimum location for the third spar.

APPENDIX L

BREAKEVEN ANALYSIS FOR COST OF PREBUNCHER

Using the conventional yarding estimate obtained with Keller's equation:

Swinging = $14.40/cunit
Conventional yarding = $40.51/cunit
Prebunching production = 4.32 cunits/hour

Solve for breakeven unit cost; X

$$\frac{X}{\text{cunit}} + \frac{\$14.40}{\text{cunit}} = \frac{\$40.51}{\text{cunit}} \quad , \quad X \; \frac{\$26.11}{\text{cunit}}$$

$$\text{Hourly cost} = \left(\frac{\$26.11}{\text{cunit}}\right)\left(4.32\ \frac{\text{cunits}}{\text{hour}}\right) = \frac{\$112.80}{\text{hour}}$$

Deduct the hourly costs not associated with the investment cost of the prebuncher (cost from Appendix H, Table 22).

Labor	$38.14
Fuel and lube	3.00
Maintenance and repair	1.36
Radio	0.44
Cable	0.78
Crew vehicle	1.83
Blocks, ladder, rigging	0.15
TOTAL	$45.70

Breakeven depreciation cost per hour for prebuncher = $112.80 - $45.70 = $67.10.

Assumptions:
- -220 eight-hour work days per year
- -Maintenance and repair = 50% of depreciation
- -Insurance, interest and taxes are 18% of the average annual investment.
- -Depreciation period is four years
- -Work only five months per year

Y = breakeven initial investment cost for prebuncher,

$$\frac{1.5Y}{4\text{ years}\left(\frac{5\text{ months}}{12\text{ months}}\right)\left(\frac{220\text{ days}}{\text{year}}\right)\left(\frac{8\text{ hrs}}{\text{day}}\right)} + \frac{1.25Y}{(2)\left(\frac{220\text{ days}}{\text{year}}\right)\left(\frac{8\text{ hrs}}{\text{day}}\right)} \quad 0.18 = \$67.12$$

Y = <u>$116,672.79</u>