AN ABSTRACT OF THE PAPER OF

John William Mann for the degree of Master of Forestry
in Forest Engineering presented on May 30, 1979
Title: Skyline Logging Production in the Southern Sierra
Nevada Mountains: A Case Study

Abstract approved: John E. O'Leary
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This paper describes the results of a time study conducted on the Sierra National Forest to determine production capacity of the Madill 044 Skyline Yarding Crane operating in a partial cut situation for old-growth mixed conifer stands. The yarder was rigged in the running skyline configuration and used a Danebo mechanical slackpulling (MSP) carriage. Yarding distances ranged from 40 to 900 feet and lateral yarding distances ranged from 0 to 185 feet. An average of 35 thousand board feet of timber per acre was removed from the study area.

Regression equations were developed for the individual elements of the yarding cycle and for total cycle time. Results indicate that skyline yarding distance, lateral yarding distance and number of logs per turn are the most significant variables related to predicting total turn time, with cubic volume per turn and the number of workers on the rigger crew playing a less important role.

A comparison of the regression developed for the Madill 044 with another regression model for a Washington Iron Works 108 skyline yarding crane suggests that there is an approximate 33% difference in total turn times predicted for the same logging conditions.

SKYLINE LOGGING PRODUCTION
IN THE
SOUTHERN SIERRA NEVADA MOUNTAINS:
A CASE STUDY

by

John William Mann

A PAPER

submitted to

Oregon State University

in partial fulfillment of

the requirements for the degree of

MASTER OF FORESTRY

Completed May 30, 1979

Commencement June, 1979

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INTRODUCTION

The use of cable logging systems in the forests of the southern Sierra Nevada mountains was once very common. The development of gasoline and diesel powered tractors changed this picture significantly so that for the past 30 to 40 years most timber harvesting in this area has been accomplished by ground skidding machines. From the 1940's to the mid-1970's, very few timber sales on national forest land in this vicinity have specified cable yarding equipment be utilized as a condition of the timber sale contract. During this period, the timber volumes that could be harvested from the more moderately sloping ground with relatively easy road access were adequate to meet the regional demands for lumber. The result has been that the commercial forest lands on slopes of less than 35-40% have received most of the logging activity while the steeper ground that is unsuitable for tractor logging has generally been avoided. Now, however, many national forests and private timberland-owning organizations are faced with the problem of how to harvest commercial timber from the steeper ground.

This increasing need for methods to remove timber from steep slopes with difficult access has led to greater and greater concern over the inadequacies of ground-based systems when used on such terrain. Severe adverse environmental impacts on soil, water, esthetic and other non-timber resource values have often resulted where tractors were used on steep ground. In order to alleviate this apparent misapplication of logging systems, the U.S. Forest Service approach has been to require the use of some type of alternative logging system on that land where the use of such equipment is warranted. In the Sierras, this alternative logging system is presently some type of cable yarding machine or a helicopter specifically equipped for logging.

Over the past 10-15 years, much progress has been made in the development of advanced systems designed to harvest timber from areas where environmental constraints are critical and tractors cannot safely or economically operate. Field trials of logging with helicopters (Binkley, 1972; Campbell, 1972a), balloons (Lysons, Binkley, and Mann, 1966; Binkley and Carson, 1968), and modified skyline cable systems (Binkley, 1965; Lysons, 1969; Campbell, 1971; Campbell, 1972b) have shown that these systems are all feasible under certain applications. Subsequently, attempts have been made to measure production on these logging systems and to describe the variables that influence production (Dykstra, 1975; Curtis, 1978; Kramer, 1978; Van Winkle, 1975). These studies predict cycle times using the critical parameters of the logging units and yarding systems upon which production is determined to be dependent for the conditions of each yarding situation. All of these authors cite the need to improve cost appraisal calculations and estimation of production rates. They also recognize the difficulties encountered in attempting to predict production rates for one set of logging conditions based on a regression equation developed from data collected on some separate set of conditions.

It is with these two latter facts in mind—namely, the need for more accurate cost appraisals and problems associated with extrapolation of regression equations--that this project was initiated. The southern Sierras have many areas that will have to be harvested by some type of modern cable or helicopter yarding system. Table 1 indicates the trend in harvesting system requirements for recent past and near future timber sales on the Sierra National Forest. Review of similar statistics for the Stanislaus and Sequoia National Forests show that this breakdown of logging system requirements is quite typical for national forest land in this part of California.

Table 1. Logging System Requirements by Percentage of Annual Allowable Cut for the Sierra National Forest, R-5.

	Tractor	Skyline	Helicopter
1971	100%	0	0
1972	91%	9%	0
1973	100%	0	0
1974	100%	0	0
1975	100%	0	0
1976	100%	0	0
1977	93%	7%	0
1978	88%	9%	3%
1979	84%	1%	15%
1980	78%	20%	2%
1981	85%	15%	0
1982	89%	11%	0
1983	73%	12%	15%

However, no scientific studies are available to timber sale appraisers or logging managers working in this vicinity that would indicate production potential of cable yarding equipment operating under the specific conditions unique to this topography and timber type. Additionally, how satisfactorily regression equations developed from data collected in other geographic locations might predict production potential for yarders working in this area has not been tested.

It is the intent of this report to provide information that will be useful in predicting production rates for one type of cable system, the running skyline, that seems to have extensive application in partial cutting of the old-growth mixed conifer stands found in this part of California. The regression developed for the observed system will be compared to a regression equation developed for a similar system operating on the Klamath National Forest in northern California.

Observation of the specific cable logging system operating in the southern Sierras was accomplished during the summer of 1978. The location was a timber sale on the Pineridge Ranger District of the Sierra National Forest, approximately 75 miles east of Fresno, California. The piece of equipment being used for yarding on this operation was a Madill 044 Mobile Yarding Crane owned by the contract logging company, Sugar Pine Enterprises. This yarder was rigged in a running skyline configuration with a Danebo slackpulling carriage. During the observation period, production time data was collected for analysis of the production potential of this machine while operating under the observed conditions. A description of this operation and an analysis of the collected data is the basis for this report.

STUDY OBJECTIVES

The objective of this study is to analyze the collected time study information so that the results may be used for timber harvesting appraisal purposes. Specific objectives are:

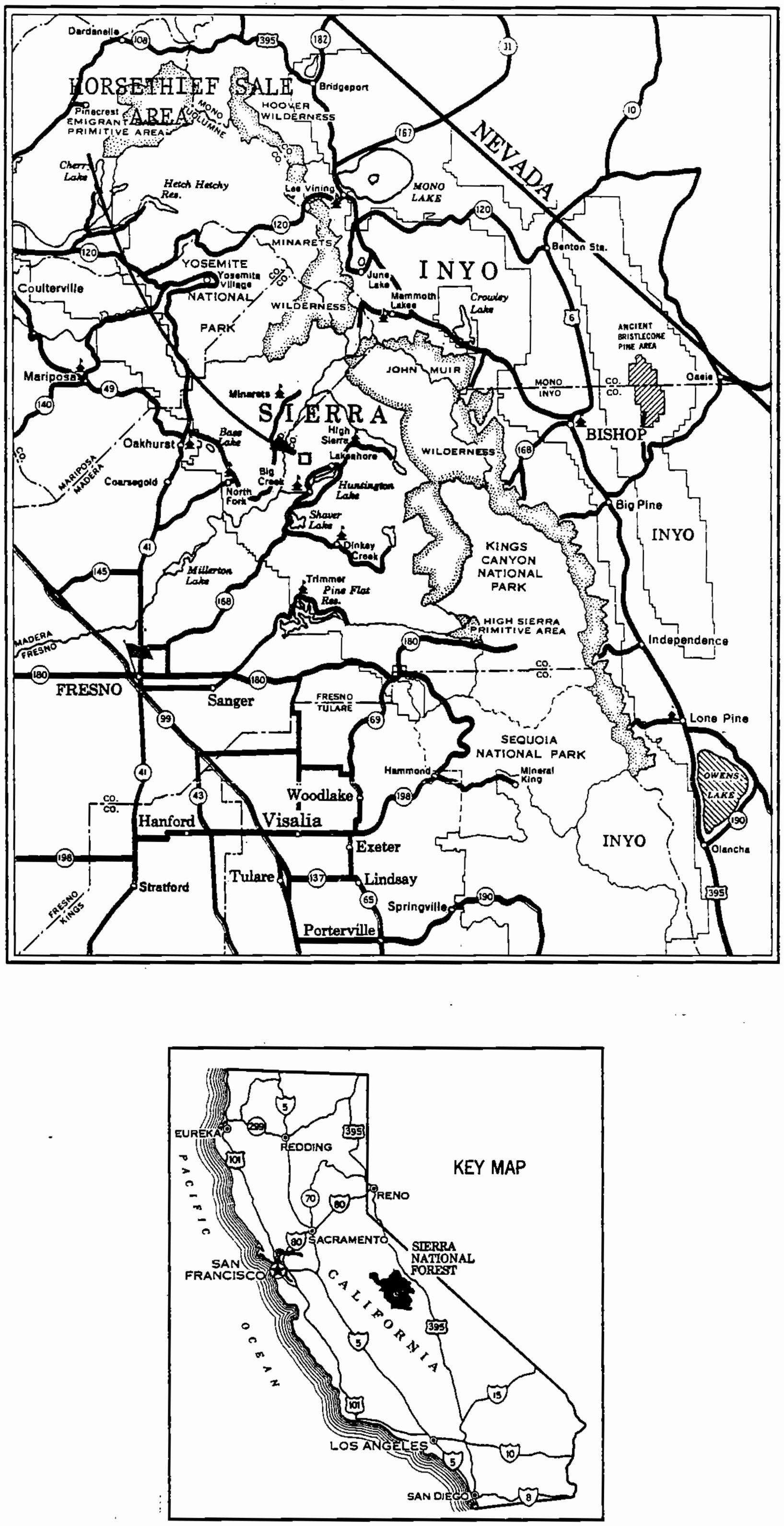
1. Develop a multiple regression equation to predict yarding production rates using the critical parameters of the logging units and yarding system upon which production is determined to be dependent.
2. Determine whether a difference exists between the equation developed from this study and that currently being used by the Forest Service to appraise running skyline operations in the California Region.
3. Describe the characteristics of the observed logging operation to promote a better understanding of some of the difficulties encountered in using this system.
4. Recommend further research in this topic area.

DESCRIPTION OF AREA AND SILVICULTURAL OBJECTIVES

The study area was part of the Horsethief Timber Sale on the Pineridge Ranger District of the Sierra National Forest. This location is in Fresno County, California approximately 10 miles north of the town of Big Creek (Figure 1). The entire sale encompasses an area of 3225 acres along a westerly facing slope that is part of the San Joaquin River watershed. Topography within the 13.3-acre area that was logged during the study period consisted of moderate to steep slopes often in excess of 50 percent. Elevations ranged from 6000 feet to 7700 feet.

No portion of this project area had been logged prior to the Horsethief Sale. The biological condition of the timber stands were, therefore, representative of virgin timber lands still found throughout the Sierra Nevada Range. A wide range of soil types, aspects, and elevations explain the diversity of timber types within the total sale area but the study area timber type was entirely an old-growth, mixed conifer stand. Volumes removed by species for the three study units are summarized in Tables 2 and 3.

The overall silvicultural objective of this sale was to reduce stand decadence by removing old, over-mature timber. A secondary intent was to improve residual stocking by removing trees in the intermediate and suppressed crown classes. These trees were often found to be infested with dwarf mistletoe and various heart-rot pathogens and because of this were judged to be of low vigor and an obvious source of further disease infestation for the residual



VICINITY MAP

KEY MAP

Figure 1. Location of the Project Area

Table 2. Timber Volume Removed by Species, Horsethief Study Area.

Species	Cu. Vol. (ft.^{3})	B.F. Vol. (Scribner)	Percentage of Total B.F. Vol.
Ponderosa/Jeffrey Pine	16,534	113,088	(33%)
Sugar Pine	9,669	66,363	(20%)
White Fir (A. concolor)	13,694	85,174	(25%)
Incense Cedar	14,057	74,383	(22%)
Total	53,954	339,008	

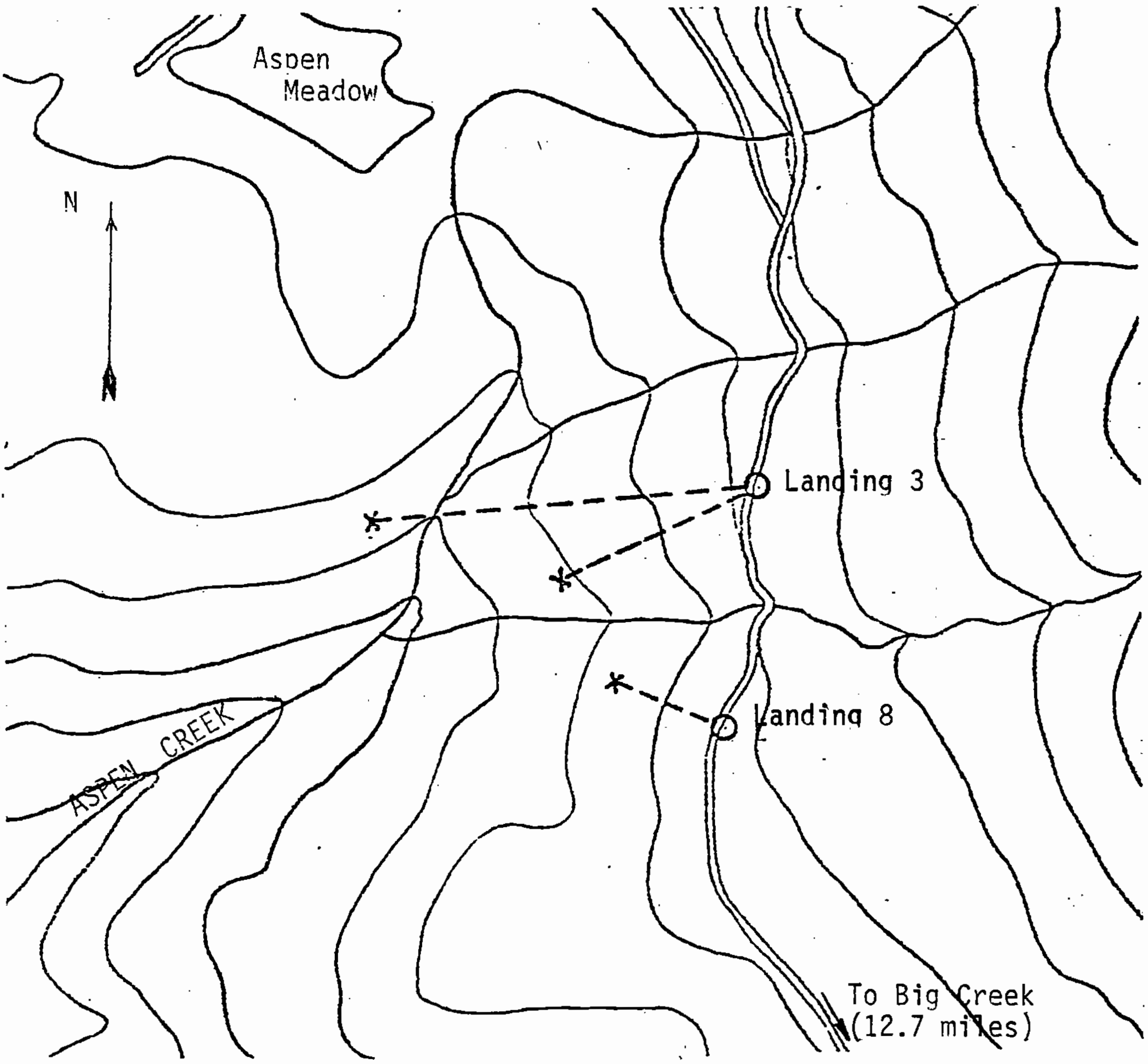
Table 3. Timber Volumes Removed From Each Study Unit

Unit	Volume by Species*(Board Feet)				
	PP/JP	SP	WF	IC	TOTAL
Landing 3, Corridor 1	36,039	33,794	37,797	34,759	142,389
Landing 3, Corridor 2	37,492	18,660	20,103	22,400	98,655
Landing 8, Corridor 1	39,557	13,909	27,274	17,224	97,964
					339,008

(*Abbreviations refer to the species listed in Table 2.)

timber stand. Removal of these individuals along with the overmature trees was designed to open the stand and allow for establishment of more thrifty reproduction. In the actual application of these objectives between 10 and 15 trees per acre on an average were designated for removal under this initial entry. The predicted per acre volume that was to be harvested from commercial timber land within the sale area was 35 thousand board feet per acre. In the 13.3 acres of the study area, the specific cutting method was a combination of the seed cut and overstory removal cut of the shelterwood method. Actual average volume per acre removed in the study area was 25.5 thousand board feet per acre. The detailed silvicultural prescription for this project including criteria for selection of trees to be designated for removal and those to be left as seed sources appears in the Environmental Analysis Report for the Horsethief Timber Sale (Meinel, 1976).

Three cable corridors eminating from two separate landing locations were selected for the study area. The topography, timber stand and overall logging conditions for these three corridors was felt to be representative of the conditions expected for many parts of the southern Sierra range. The logging plan layout for these units is shown in Figure 2.



Contour Interval= 100 feet
Scale: 1 inch= 500 feet

Figure 2. Study Area Unit Layout.

YARDING SYSTEM DESCRIPTION

The yarding system used was a Madill 044 Yarding Crane rigged as a running skyline with a Danebo slackpulling carriage (Figure 3). This yarder is manufactured in Nanaimo, British Columbia by S. Madill Ltd. It is constructed on a four axle, self propelled rubber tire mounted carrier and has three operating drums plus a separate strawline drum used for rigging the heavier lines. This is not an interlock yarder, as are many of the modern yarding cranes that are commonly rigged in the running skyline configuration, but the main and haulback drums are equipped with Witchita A.T.D. 324 water-cooled disk brakes. In yarding the extremely large, old growth timber that is typical of many parts of the southern Sierras, Witchita brakes are often considered an advantage over the various types of interlocking systems. General specifications of the yarder and the dimensions of the machine are displayed in Table 4 and Figure 6, respectively.

The machine is mounted on a turntable with a slewing ring which allows the yarder to operate from a rather small landing. The turntable design permits the yarded logs to be swung to either side of the undercarriage rather than decking them directly in front of the yarder. With this capability it is possible to utilize an existing haul road for a landing location without requiring major excavation for landing construction. Landing configurations used during the study period are shown in Figures 4 and 5. During yarding operations from these two landings the haul road had to be kept open to traffic. No log storage or truck loading could be accommodated next to the yarder. To overcome

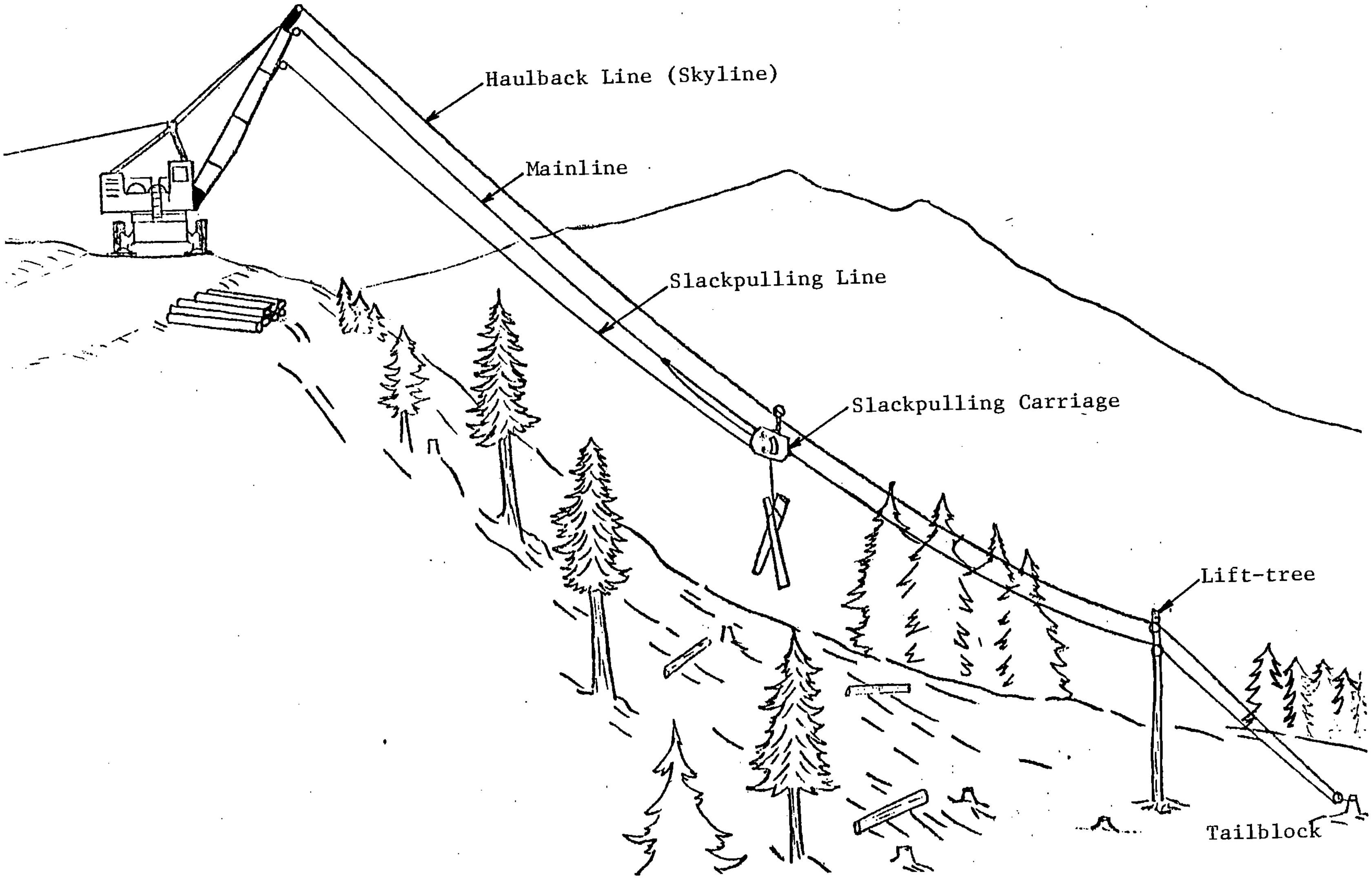


Figure 3. Madill 044 Skyline Yarding Crane Rigged in Running Skyline Configuration

this restriction, a rubber-tired skidder was employed to swing-yard the logs to another landing area away from the initial landing point. This tractor swing was a typical part of the cable yarding on this particular harvesting operation.

The yarder is stabilized by four retractable hydraulic outriggers and a single guyline mounted on a separate winch drum. Capacity of the guyline drum is 290 feet (88 meters) of 1 1/4 inch line. Because of the single guyline opposing the forces created in the operating lines, it is important to have this guy in direct lead with the direction of the corridor layout to insure that equilibrium of forces is maintained. Because the positioning of guyline anchors does not always allow for this direct lead, the yarder is equipped with two static guys that can be rigged from the yarder gantry to anchor points behind and lateral to the yarder position. These static guys act as safety lines should the main guyline fail.

The carriage used was a Danebo mechanical slackpulling design (MSP) to facilitate lateral yarding in this partial cut situation. In the running skyline configuration this carriage rides the haulback line via a 10 inch rider block attached to the top of the carriage with a block shackle (Figure 7). The haulback line then passes through a tailblock at the outer end of the skyline corridor and is returned back up the corridor to be attached to the carriage with an apron hanger assembly. Lateral yarding capability is achieved mechanically from the yarder with the slackpulling line which enters the carriage, passes around a 12 inch sheave and is then shackled into the mainline on the yarder side of the carriage. Thus the mainline becomes the dropline and

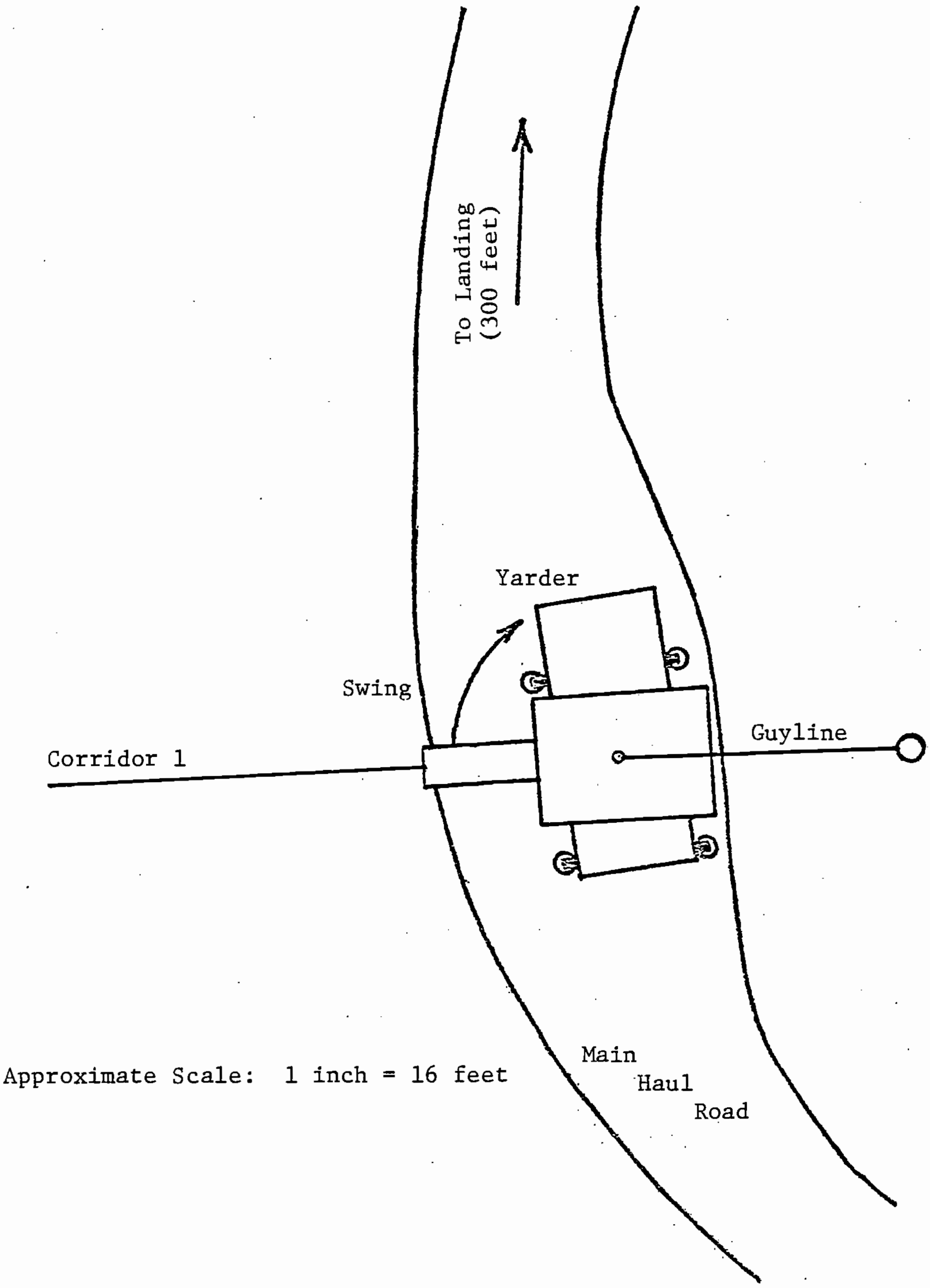


Figure 4. Layout for Landing Number 8

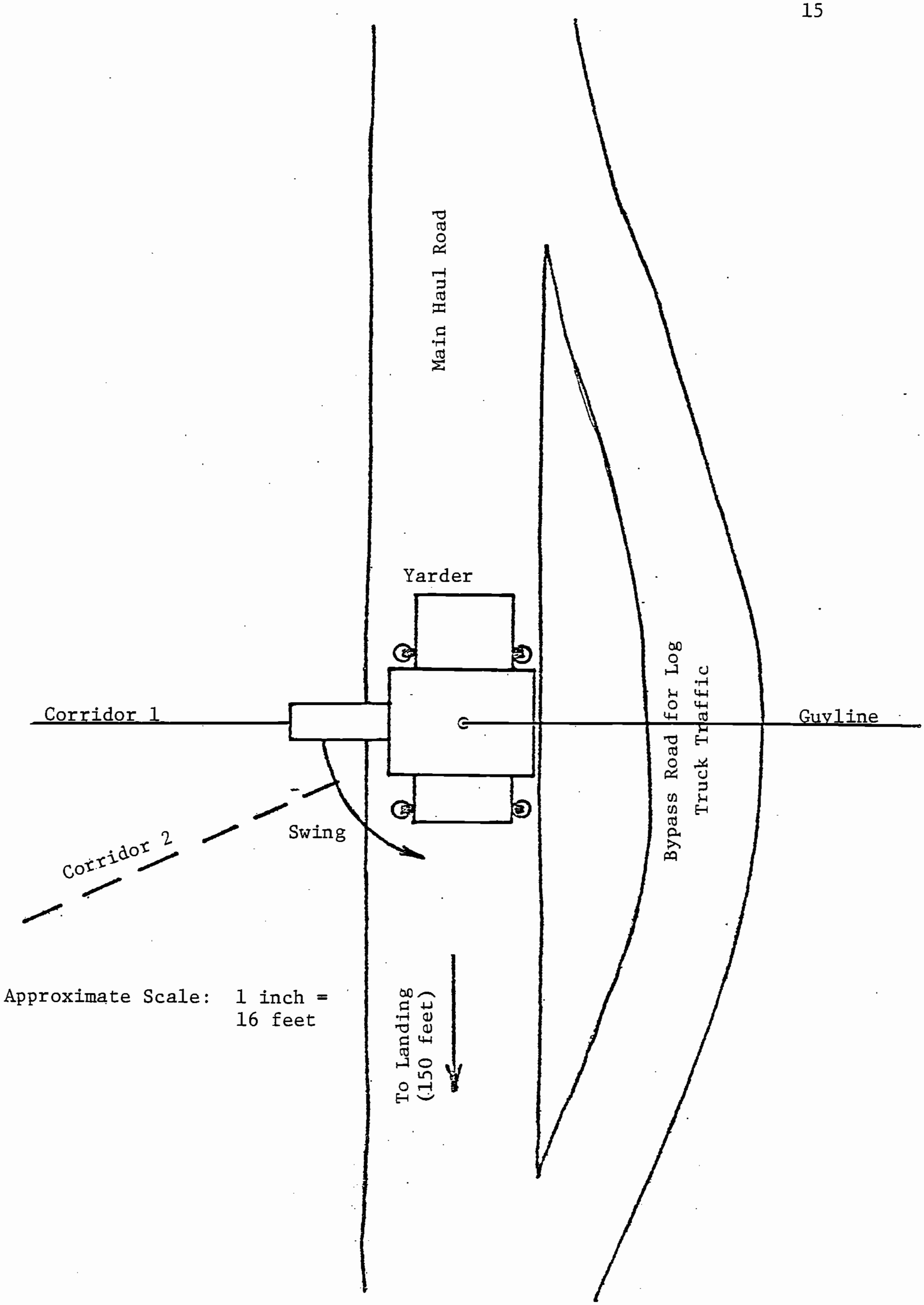


Figure 5. Layout for Landing Number 3

Table 4. MADILL 044 YARDING CRANE: GENERAL SPECIFICATIONS

Engine: GM Diesel, V-12

Rated Engine Power: 500 hp

Undercarriage: 4 axle, self propelled, rubber-tired, 20% gradeability

Tower: Boom height to ground (vertical) 60 feet (18.3 meters)

Working Weight: 165,000 lbs. (74,910 kg.)

Drum Capacities:

Drum Type	Operating Capacity		Diameter	
	(feet)	(meters)	(inches)	(mm.)
Main	1760	(536)	*1	(25)
	1390	(423)	1 1/8	(29)
	1130	(344)	1 1/4	(32)
Haulback	4500	(1371)	5/8	(16)
	3120	(950)	3/4	(19)
	2300	(701)	*7/8	(22)
Slackpulling	4300	(1301)	3/8	(10)
	2400	(731)	1/2	(13)
	1500	(457)	*5/8	(16)

(* denotes line sizes used during study.)

Line Speeds and Drum Pull:

	Maximum Line Speeds				Line Pull			
	Low Gear		High Gear		Low Gear		High Gear	
Drum	(FPM)	(MPM)	(FPM)	(MPM)	(lbs)	(Kg)	(lbs)	(Kg)
Main	900	(275)	1750	(533)	84,000	(39000)	43,000	(20,000)
Haulback	900	(275)	1750	(533)	78,000	(36000)	40,000	(19,000)
Slackpulling	1058	(322)	2078	(633)	12,100	(6000)	12,100	(6,000)

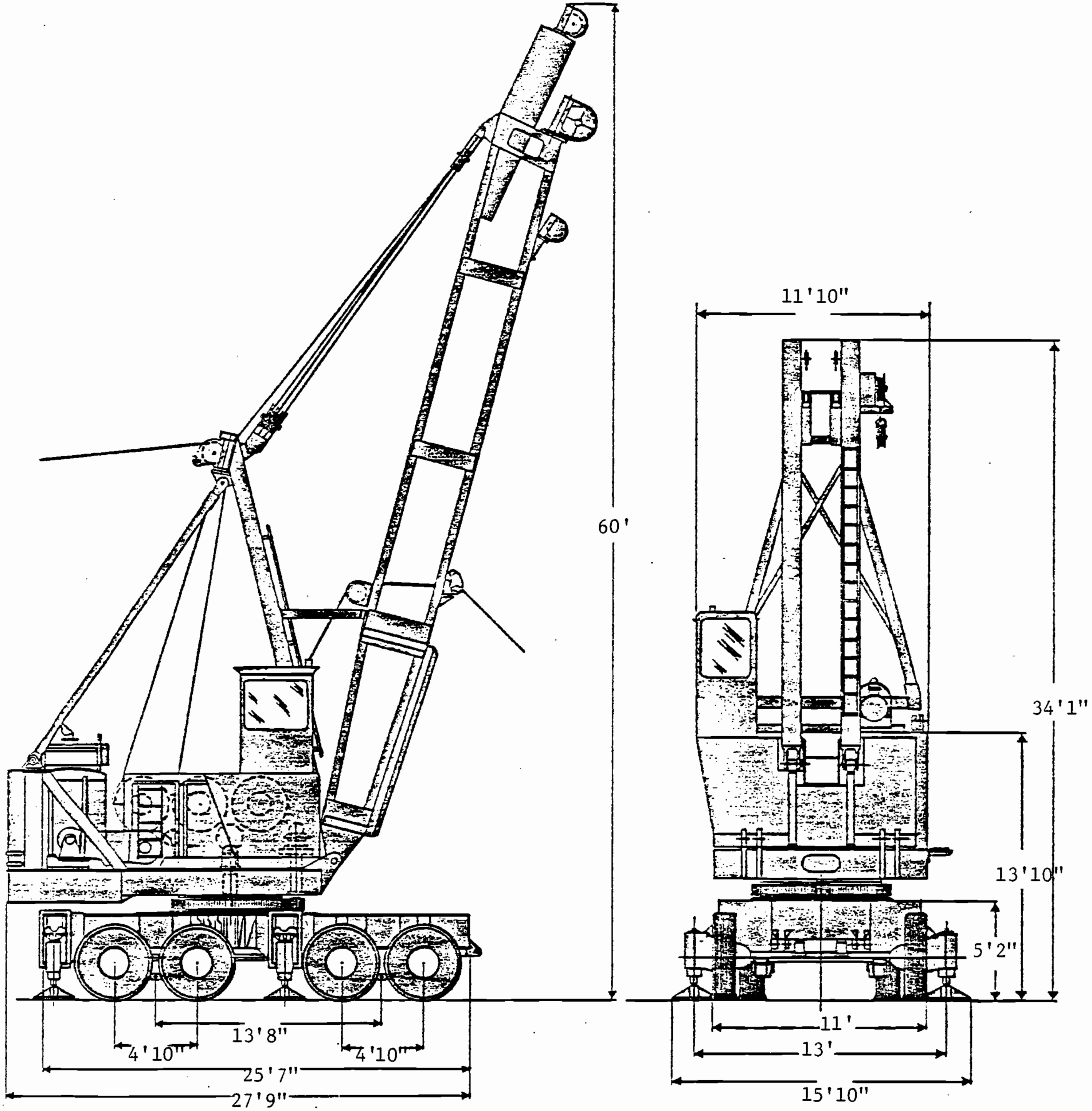


Figure 6. Madill 044 Skyline Yarding Crane

is fed through the carriage by reeling in on the slackpulling drum at the yarder. To aid in the feed of this dropline, the separate sheaves around which the slackpulling line and dropline pass are mounted on a common shaft so that when the yarder engineer pulls in on the slackpulling line both sheaves in the carriage turn in the same direction. As the dropline passes around its sheave in the carriage a pressure arm assembly holds the line against the turning sheave and the dropline is fed through the carriage to be picked up by the rigging slinger and moved laterally away from the corridor toward the logs that are to be yarded. Lateral yarding distance is limited by the length of the dropline (approximately 200 feet during the study) and the physical capability of the rigging slinger and chokersetters to pull this 1 inch diameter line (1.85 lbs/ft.) away from the skyline corridor.

The topography in this vicinity and for many parts of the Sierra Nevadas consists of long, continuous or convex slopes. This type of slope normally requires a spar at the outer end of the cable corridor in order to obtain the necessary deflection. On this operation the normal practice was to rig two 11 inch blocks some distance up in a standing tree at the outer end of the unit. This tree was referred to as the "lift" tree. Behind the lift tree and near ground level the tailblock was attached to a stump. Again, it is important to have this tail-block anchor in direct lead with the skyline corridor in order to stabilize the forces on the lift tree. If a single stump anchor was not available in the proper location, two tail-blocks would be rigged behind and lateral to the lift tree (Figure 8). For the three corridors that were yarded during this study, two (8-1 and 3-2) used lift trees and on the third (3-1) it was

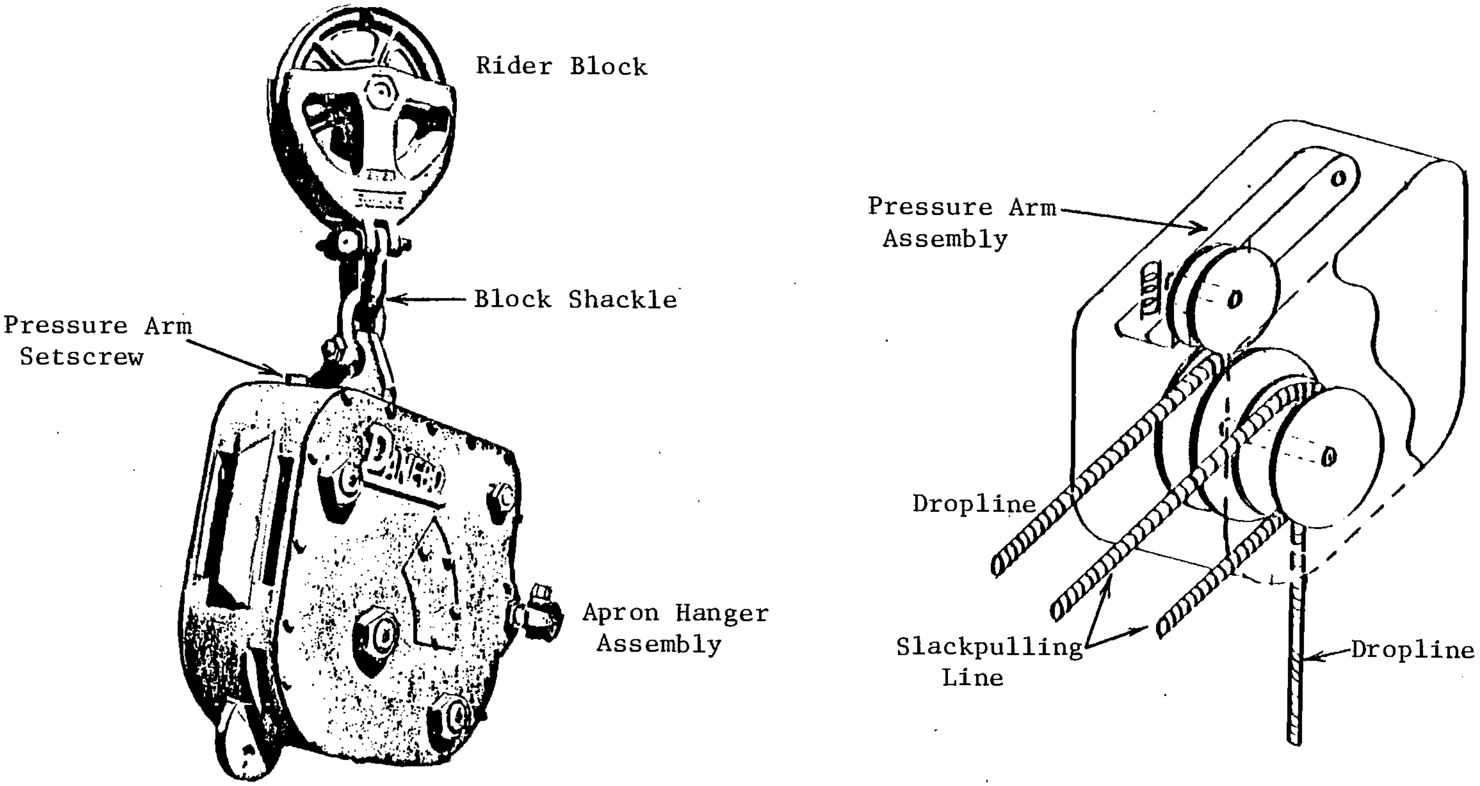


Figure 7. Danebo Mechanical Slackpulling Carriage

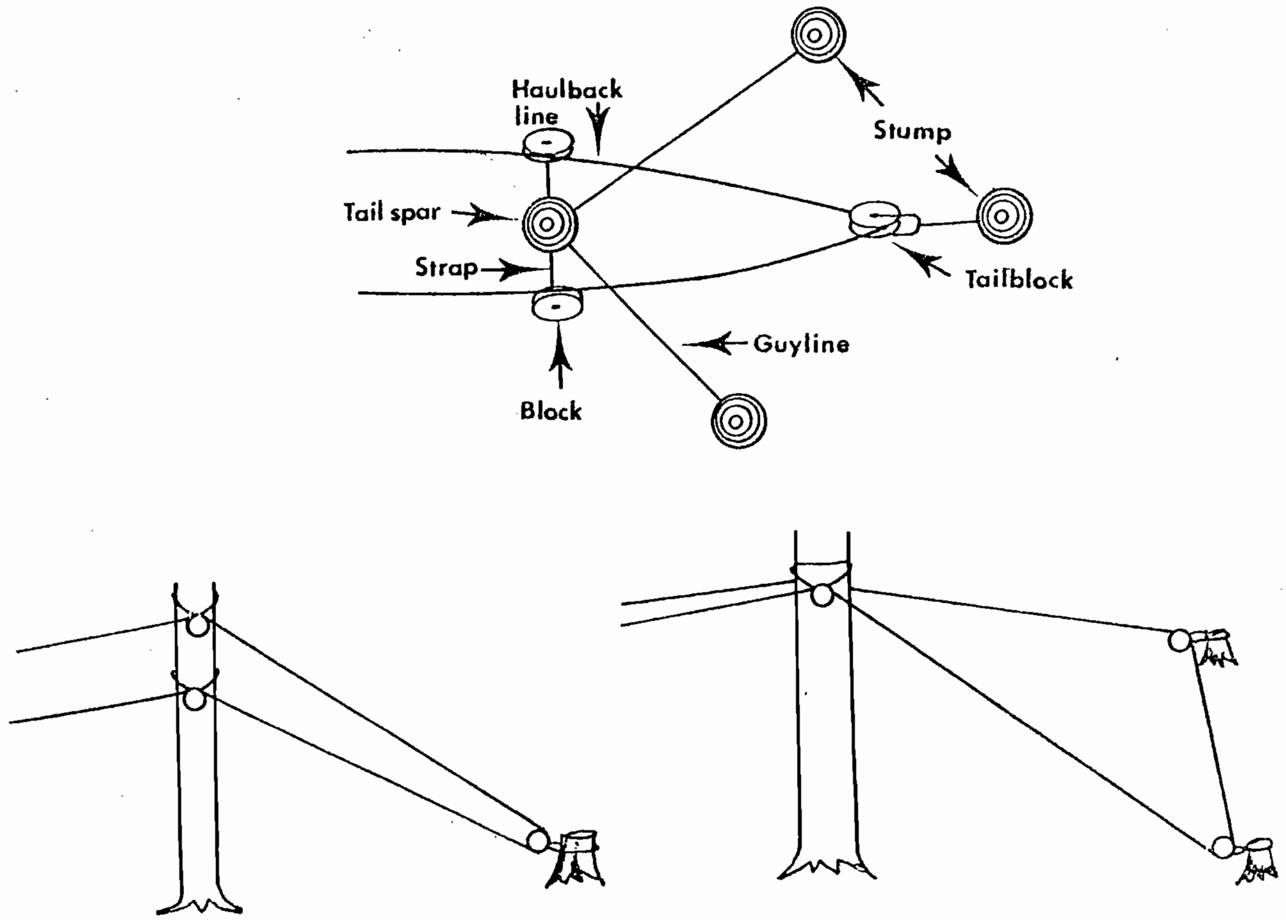


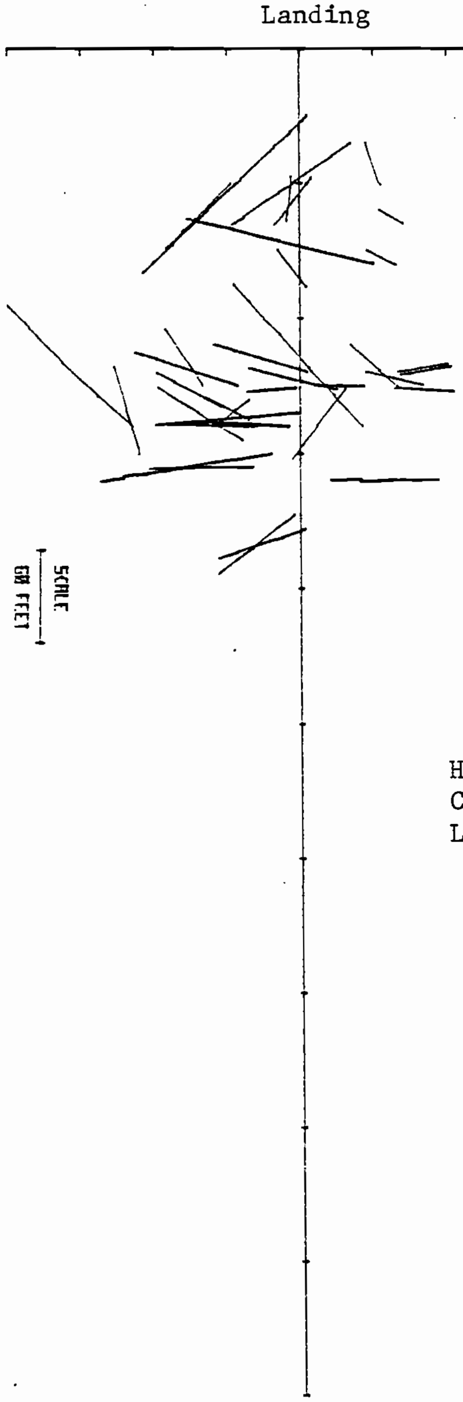
Figure 8. Running Skyline Lift-tree and Tailhold Designs

possible to reach the opposite facing slope so that a lift tree was not necessary. Ground profiles of these three corridors are displayed in Appendices 1 and 2.

DATA COLLECTION AND STUDY PROCEDURES

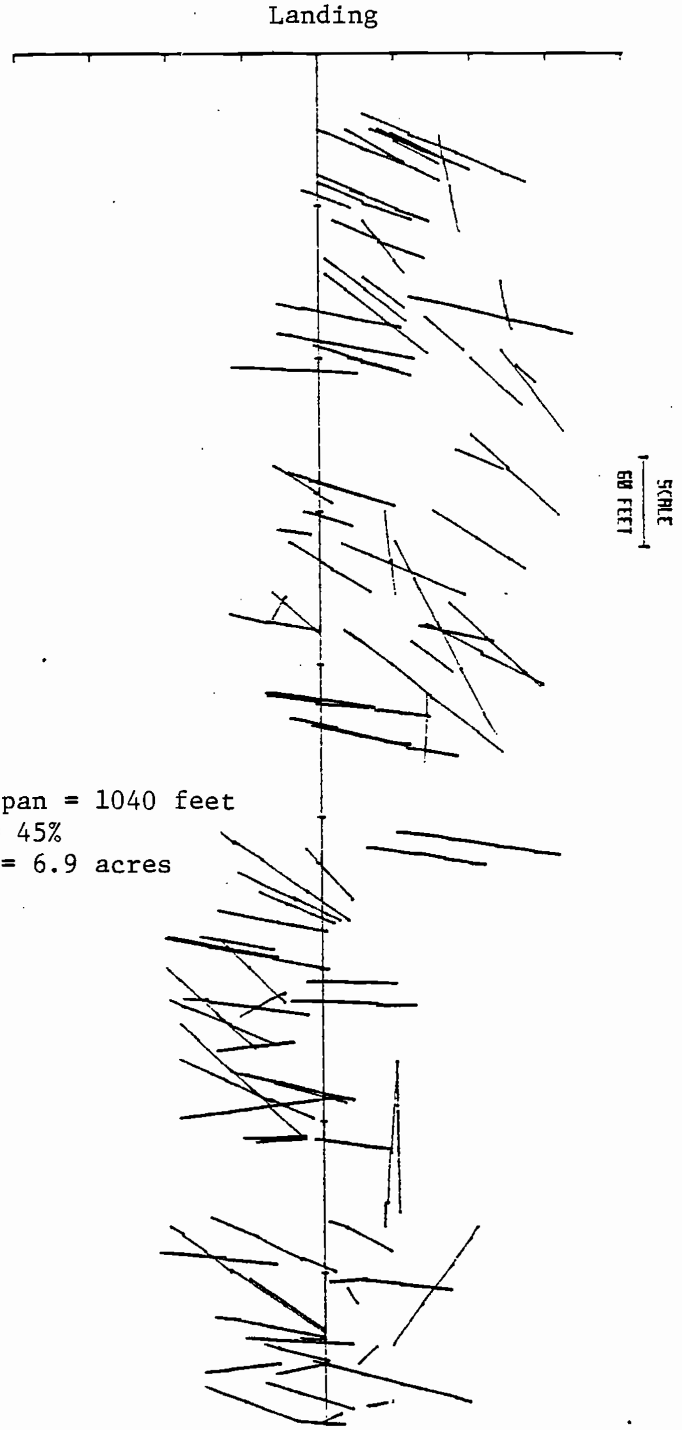
Location of the landings and cable corridors, and designation of lift trees, tail-block anchors and guyline anchors was accomplished by the hooktender prior to any timber felling within the study area. Ground profile and lift-tree or tailhold specifications for the three corridors studied were recorded during this layout period. As the trees were felled and bucked, each log was given a number which was painted on with orange tree marking paint. Specific information recorded for each log consisted of species, length, diameter at both ends, distance along the skyline corridor away from the landing, distance lateral from the corridor, and azimuth of the central axis of the log. From this information it was possible to calculate volume per log (cubic and board foot), weight per log, skyline slope distance, and lateral yarding distance. Thus, when the time study operation was underway the only data that had to be recorded were the numbers of the logs being transported per turn and the times of the various elements in each yarding cycle. This allowed the timekeepers to concentrate on recording accurate time information and relieved them of the task of estimating yarding distances and log sizes, as is often the procedure in other studies of this type. The information on log location and orientation in reference to the cable corridors was used to generate spatial distribution plots of the felling pattern for each corridor (Figures 9, 10, and 11).

Time was selected as the dependent variable for study of this yarding system. Two reasons for this choice are: 1) time can be fairly accurately measured and recorded with simple tools and 2) it can be easily related to



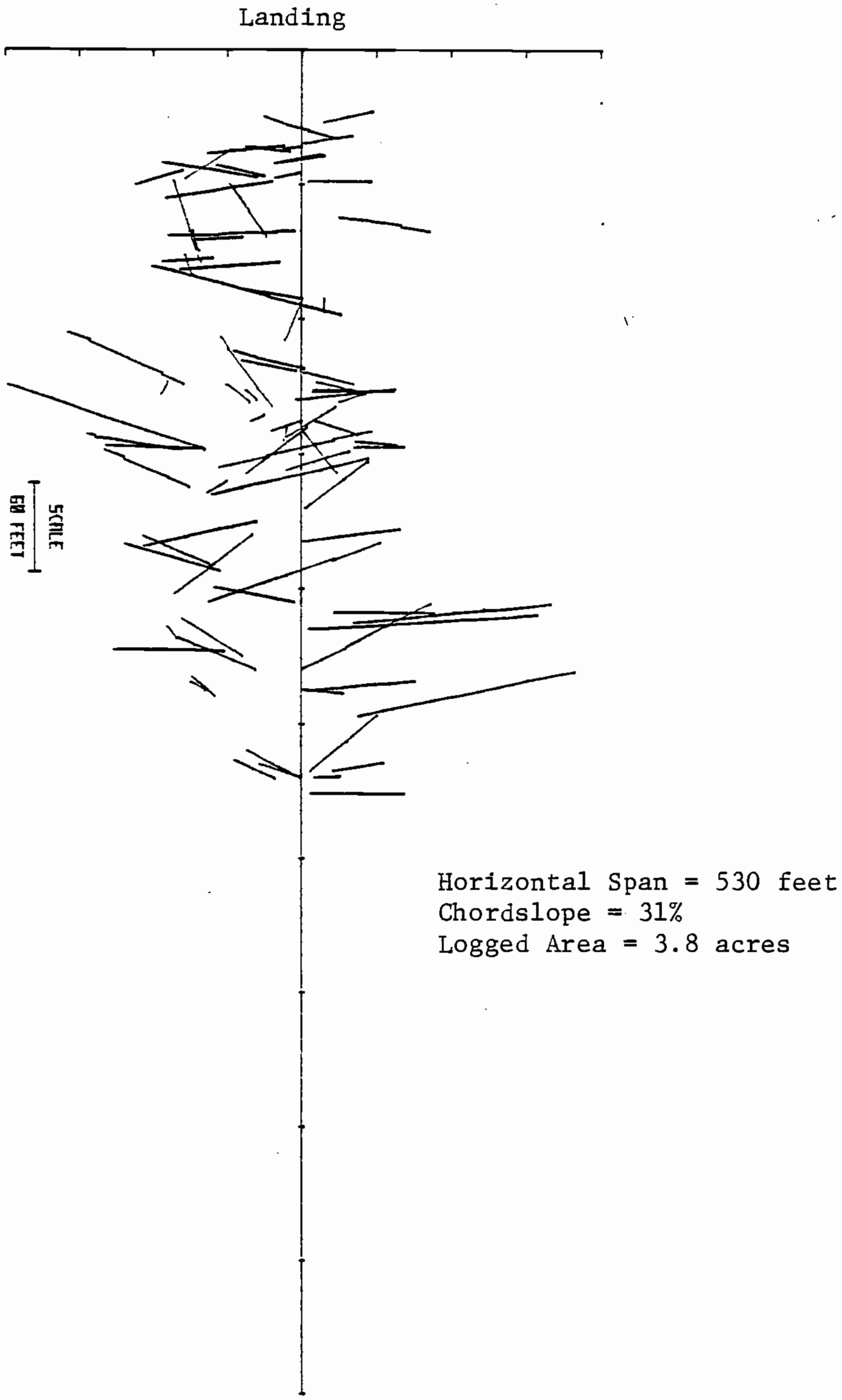
Horizontal Span = 350 feet
Chordslope = 35%
Logging Area = 2.6 acres

Figure 9. Spatial Distribution of Logs; Landing 8, Corridor 1



Horizontal Span = 1040 feet
Chordslope = 45%
Logged Area = 6.9 acres

Figure 10. Spatial Distribution of Logs; Landing 3, Corridor 1



Horizontal Span = 530 feet
Chordslope = 31%
Logged Area = 3.8 acres

Figure 11. Spatial Distribution of Logs; Landing 3, Corridor 2

both man and machine work efforts. In appraisal of timber harvesting costs, time is most often the basic measure that is referenced when any of the cost concerned variables are considered.

Time and motion study is a method often utilized to record the time requirements for a given task. This tool is used to analyze factors influencing the execution of a work cycle and to determine the method nearest to optimum that can be used within the limits of practicality. Barnes (1968, p. 5) describes the use as follows:

> Motion- and time study may be used to determine the standard number of minutes that a qualified, properly trained, and experienced person should take to perform a specific task or operation when working at a normal pace... The most common method of measuring work is stop-watch time study. The operation to be studied is divided into small elements, each of which is timed with a stop-watch. A selected or representative time value is found for each of these elements, and the times are added together to get the total selected time for performing the operation.

Production time for the six elements of the skyline yarding cycle was recorded for a total of 325 turns. Times were measured to the nearest tenth of a minute with a wristwatch. There were two timekeepers working throughout the data collection period; one on the landing and one in the vicinity of the chokersetters. The timekeeper at the landing was responsible for recording times of the outhaul, inhaul and unhook elements as well as any delays that occured while the skyline carriage was at the landing. The timekeeper positioned with the chokersetters recorded times for lateral outhaul, hook, lateral inhaul, and resetting delays that happened while the carriage was away from the landing. Both timekeepers recorded the numbers of logs being yarded during each turn.

Total cycle time was separated into six basic elements with two additional elements identified for resetting and delays. These eight possible time elements are described as follows:

OUTHAUL - The time required to move the unloaded carriage from the landing to the hooking site. Outhaul time starts when the carriage begins to move away from the landing after unhooking and ends when the yarder engineer receives the whistle signal from the rigging crew to stop the carriage.

LATERAL OUT - The time required for the rigging crew to pull the dropline from the carriage to a turn of logs. Included in the initial portion of this element is the time necessary for the rigging slinger to remove the returning chokers from the hook. Lateral out time starts when the haulback line is braked and the carriage is stationary at the end of the outhaul activity. It ends when the hook at the end of the dropline reaches the logs to be hooked for that turn.

HOOK - The time required to hook a turn of logs to the end of the dropline. The time for this activity began when the rigging slinger signaled the yarder engineer to stop pulling slack for lateral outhaul. It ended when the chokersetters had slipped the eye of the last choker over the hook on the end of the dropline and had walked a safe distance away from the logs to be yarded on that turn.

LATERAL INHAUL - The time required to laterally yard a turn of logs to the skyline corridor. This element began when the rigging slinger signaled the yarder engineer to commence lateral yarding and ended when the turn of logs arrived at the carriage.

INHAUL - The time required to move a turn of logs to the landing from the position on the cable corridor where the carriage was stopped for lateral yarding. This began when the hook at the end of the dropline hit against the underside of the carriage and ended when the turn of logs reached the landing and became stationary so that the chaser could begin unhooking the chokers.

RESET - An activity that occurred whenever a turn of logs was required to be rehooked sometime during the yarding cycle. Resetting normally happened during lateral inhaul when the logs hit an obstruction or a choker slipped off of a log. It began at the instant some element of the normal yarding cycle was interrupted and ended when that activity was resumed.

UNHOOK - The time required to unhook a turn of logs at the landing. It began when a turn of logs stopped at the landing and ended when the chokers were entirely freed and the carriage started to move for outhaul.

DELAYS - This activity was considered to be a foreign element within a work cycle that occurred at random but for a variety of reasons caused yarding operations to cease. A more complete discussion of delay types will follow the next section.

INDEPENDENT VARIABLES INFLUENCING PRODUCTION

In addition to the response variable, time, factors upon which cycle times were expected to depend were also recorded in detail. In any type of timber harvesting operation a large number of variables can have some influence on cycle times. Chamberlain (1965) listed twenty-six directly measurable variables influencing high-lead logging. For the purpose of this study, values for only nine of these "independent" variables were recorded. Other factors that may have been cited by other authors working in logging system analysis were either difficult to measure and considered unimportant for this study (weather, brush conditions, ground slope at point of hooking) or were kept constant throughout the study period (horsepower of yarder, line dimensions, number of chasers on the landing). The nine variables that were measured are defined as follows:

SKYLINE SLOPE DISTANCE - On each skyline road the ground slope distance along the skyline corridor was measured for each log to the nearest 5 feet.

LATERAL DISTANCE - The distance from the center of the cable corridor to the near end of each log was measured and recorded.

(These two variables and the azimuth along the central axis of each log were the basis for the plan view log plots explained on page 22.)

NUMBER OF LOGS PER TURN - The number of logs yarded during each cycle were recorded by both timekeepers.

CUBIC VOLUME - The large end and small end diameters of each log was measured with a log scaling rule or calipers prior to commencement of yarding. Cubic volume of each log was calculated using the following equation (Dilworth, 1974):

$$C.V. = 0.001818\ L\ [(D_1^{\ 2} + D_2^{\ 2}) + (D_1)\ (D_2)]$$

(Two-end conic rule)

where:

$C.V.$ = log volume in cubic feet

L = log length in feet

D_1 = large end diameter inside bark in inches

D_2 = small end diameter inside bark in inches.

BOARD FOOT VOLUME - Gross volumes in board feet were computed using the following formula, which is an approximation of the Scribner log rule (Dilworth, 1974):

$$B.F.V. = \left[\frac{(D_1^{\ 2} - 3D_1)}{20}\right] \qquad \text{(Knouf's rule)}$$

where:

$B.F.V.$ = log volume in board feet

L = log length in feet

D_1 = diameter inside bark at small end

TURN WEIGHT - Log weight and subsequently turn weights were generated by multiplying cubic volumes for each log by the following weight densities of the species involved:

Ponderosa/Jeffrey Pine = 45 lbs/ft.^{3}*

Sugar Pine = 52 lbs/ft.^{3}

White Fir = 46 lbs/ft.^{3}

Incense-cedar = 45 lbs/ft.^{3}

(*Source of weight values - Wood Handbook; U.S.D.A. Handbook No. 72)

AVERAGE BOARD FOOT VOLUME PER LOG - Calculated during the data analysis period by dividing board foot volume per turn by the number of logs per turn.

CHORDSLOPE - The skyline chord slope expressed as a percent of horizontal span for each of the three corridors was calculated from the profile and lift-tree data shown in Appendix 1.

NUMBER OF RIGGERS - During the study the rigging crew varied from two to four workers. The number of men working on the rigging crew was recorded for each turn.

DATA ANALYSIS

Yarding Cycle Summary

A summary of the preliminary analysis for the various elements of the yarding cycle is presented in Table 5. The percentage of total cycle time spent in each element is separated into two categories: 1) percentage of total time without delay times included, and 2) with delays included. Without considering delays, or looking only at productive time, the inhaul portion of the yarding cycle contributed the largest percentage of the total time, 22.5 percent. This was closely followed by lateral outhaul at 20.6 percent. Considering delay time into the summary, the overall delay times consumed 32 percent of the total time. This is closely in agreement with standard Forest Service appraisal practices which allow for a 40 minute effective work hour.

The means or average time of these individual elements represent the time requirements for each portion of the yarding cycle under average logging conditions observed during the study. Together they add up to the total average cycle time per turn. The total cycle time per turn averaged 4.56 minutes (without delays) and 6.71 minutes (including delays).

Table 6 exhibits the data summary for the independent variables that were measured to determine their possible influence on the response variable of time. All yarding on this project was uphill, with the yarding crane set on a landing point some elevation above the logs to be yarded.

Table 5. SUMMARY OF YARDING CYCLE TIME ELEMENTS

Time Element	Number of Turns	Minimum Time (Minutes)	Maximum Time (Minutes)	Total Time (Minutes)	Average Time (Minutes)	Percent of Total Time (w/o Delays)	Percent of Total Time (with Delays)
OUTHAUL	325	0.10	1.60	177.8	0.55	12.1	8.2
LATERAL OUT	325	0.10	2.80	304.7	0.94	20.6	14.0
HOOK	325	0.10	4.30	279.4	0.86	18.9	12.8
LATERAL INHAUL	325	0.20	2.20	210.7	0.65	14.3	9.7
INHAUL	325	0.10	3.00	334.9	1.03	22.5	15.4
UNHOOK	325	0.10	3.00	142.4	0.44	9.6	6.6
RESET	325	0.00	6.00	28.6	0.09	2.0	1.3
TOTAL TURN TIME (without delays)		1.70	13.10	1478.5	4.56	100	
DELAY	325	0.00	95.00	699.9	2.15		32
TOTAL TURN TIME (with delays)		1.70	108.10	2178.4	6.71		100

Table 6. SUMMARY OF INDEPENDENT VARIABLES

Variable	Average Value		Minimum Value		Maximum Value	
	(Standard)	(Metric)	(Standard)	(Metric)	(Standard)	(Metric)
Skyline Slope Distance	372.82 ft.	113.64 m.	40 ft.	12.19 m.	900 ft.	274.32 m.
Lateral Yarding Distance	46.82 ft.	14.27 m	0 ft.	0 m	185 ft.	56.39 m.
Number of Logs per Turn	1.77	1.77	1	1	4	4
Cubic Volume per Turn	152.15 ft.^{3}	4.31 m^3	7.90 ft.^{3}	0.22 m^3	468.7 ft.^{3}	13.26 m^3
Board Foot Volume per Turn	972.23 B.F.	972.23 B.F.	35 B.F.	35 B.F.	3,564 B.F.	3,564 B.F.
Turn Weight	7099.14 lbs.	3220.17 Kg.	357 lbs.	161.94 Kg.	24,371 lbs.	11,055 Kg.
Board Foot Volume per Log	753.65 B.F.	753.65 B.F.	35 B.F.	35 B.F.	3,564 B.F.	3,564 B.F.
Chordslope	35.4	35.4	31.0	31.0	45.0	45.0
Number of Chokersetters per Turn	2.98	2.98	2	2	4	4

Regression Analysis

The objective of the regression analysis was an attempt to quantify the influence of the nine factors that were thought to have some impact on cycle time for this yarding system. Regression equations relate dependent and independent variables to each other with a statistical relationship that is an approximation of an assumed functional interaction. This funtional interaction is a relationship between variables that can be expressed by some precise mathematical formula. The statistical relationship is not a perfect one like the functional relationship and the observations for the statistical relationship will not normally fall directly on the curve of the regression equation. Because the observations used to derive the regression do not fall on the line established in this statistical relationship there is always some portion of the variation of the dependent variable, time, that cannot be explained by the variations in the independent variables. A regression equation then can be described as a mathematical model that shows the coherence or correlation between observed data.

Regression equations were developed that relate time of execution for each element within the yarding cycle to one or more of the measured independent variables. Subsequently, an overall regression equation was determined to predict total cycle time. The intention was to develop an equation that would be useful to timber sale planners and logging managers that will be preparing and operating harvesting projects with this type logging system.

The stepwise regression search method was used with the Statistical Interactive Programming System (SIPS) available for the Oregon State

University CDC 3300 computer (Cyber Operating System). The acceptance or rejection of independent variables in each regression was based on: (1) a minimum probability level of 0.05 percent, (2) if the coefficient of multiple determination (R^2) was improved by at least one percent by adding that independent variable to the equation, (3) by observation of the minimum value obtained for the mean square error, and (4) by use of the Cp criterion to check for bias in the estimation of the dependent variable. The following abbreviations were used to represent the independent variables:

SYDIST - Skyline slope distance (feet)
LATDIST - Lateral yarding distance (feet)
NLOGS - Number of logs per turn
CUVOL - Cubic volume per turn (cubic feet)
BFVOL - Board foot volume per turn (gross)
TURNWT - Weight per turn (pounds)
VPLOG - Average board foot volume per log (gross)
CHDSLP - Skyline chordslope (percent slope)
RIGRS - Number of riggers working on each turn.

Other notations used are defined as follows:

n - Number of sample observations
* - Indicates the regression coefficient associated with an independent variable is significantly different from zero at the 0.005 probability level

** - Indicates the regression coefficient is significant at the 0.01 probability level but not at the 0.005 level

*** - Indicates the regression coefficient is significant at the 0.025 probability level but not at the 0.01 level.

The regression equations developed from this study are as follows:

1) Outhaul Time (in minutes)

Outhaul Time = 0.27715
+ 0.00097 (SYDIST)*
- 0.002605 (CHDSLP)***

$n = 325$
$R^2 = .6702$

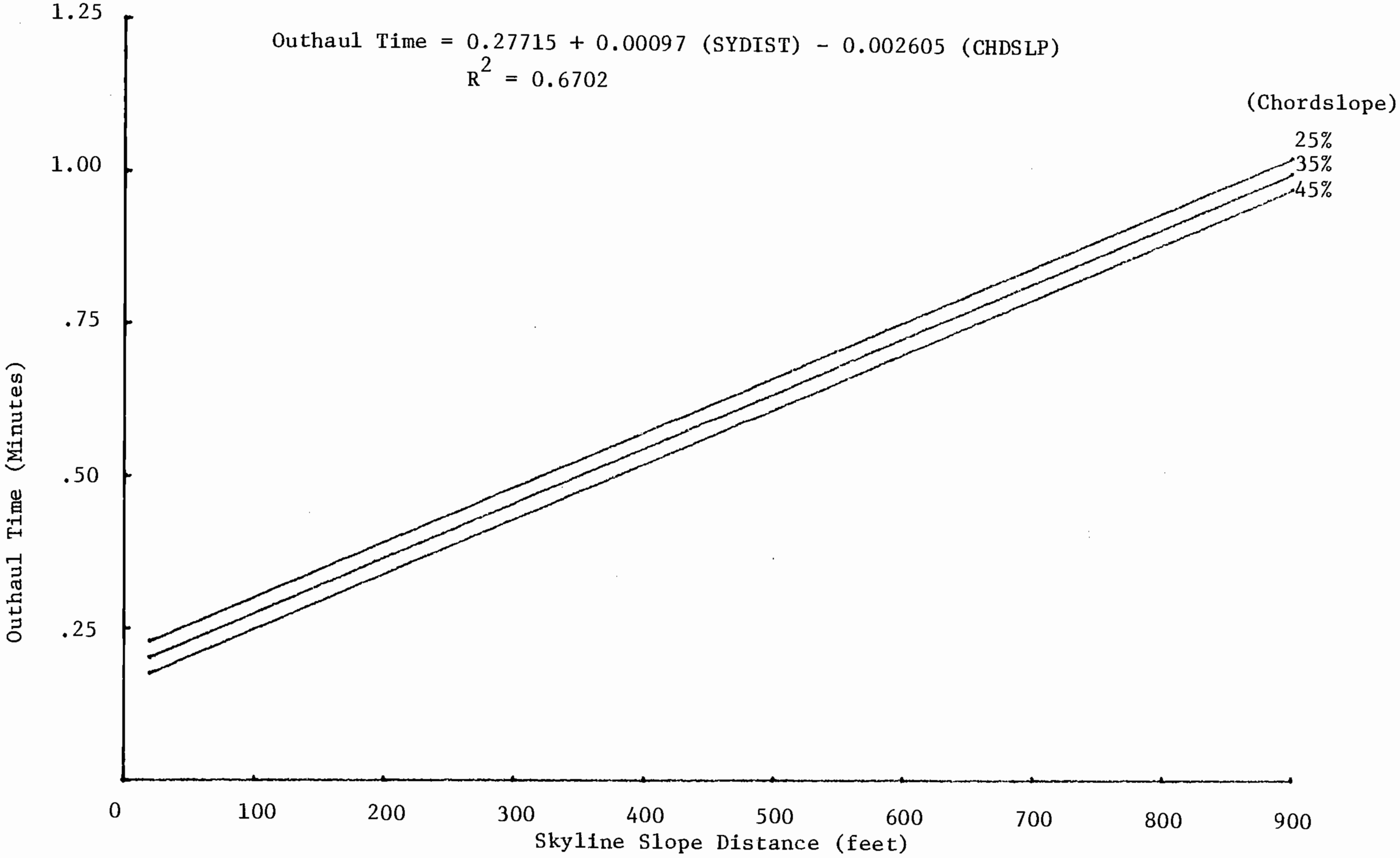
The time required to pull the carriage out depends on the skyline distance the carriage must travel and on the slope of the skyline road. Since chordslope was recorded as a positive value during the study a negative coefficient in the regression equation indicates that as chordslope increases, outhaul time decreases. This seems to support the idea of increased cable system efficiency for outhaul on steeper slopes.

2) Lateral Outhaul Time (in minutes)

Lateral Out = 0.47106
+ 0.00996 (LATDIST)*

$n = 325$
$R^2 = .5063$

Distance was the only variable that had any significant influence on pulling the dropline laterally away from the skyline corridor. It would



Outhaul Time = 0.27715 + 0.00097 (SYDIST) - 0.002605 (CHDSLP)

$R^2 = 0.6702$

Figure 12. Outhaul Time as a Function of Skyline Distance and Chordslope

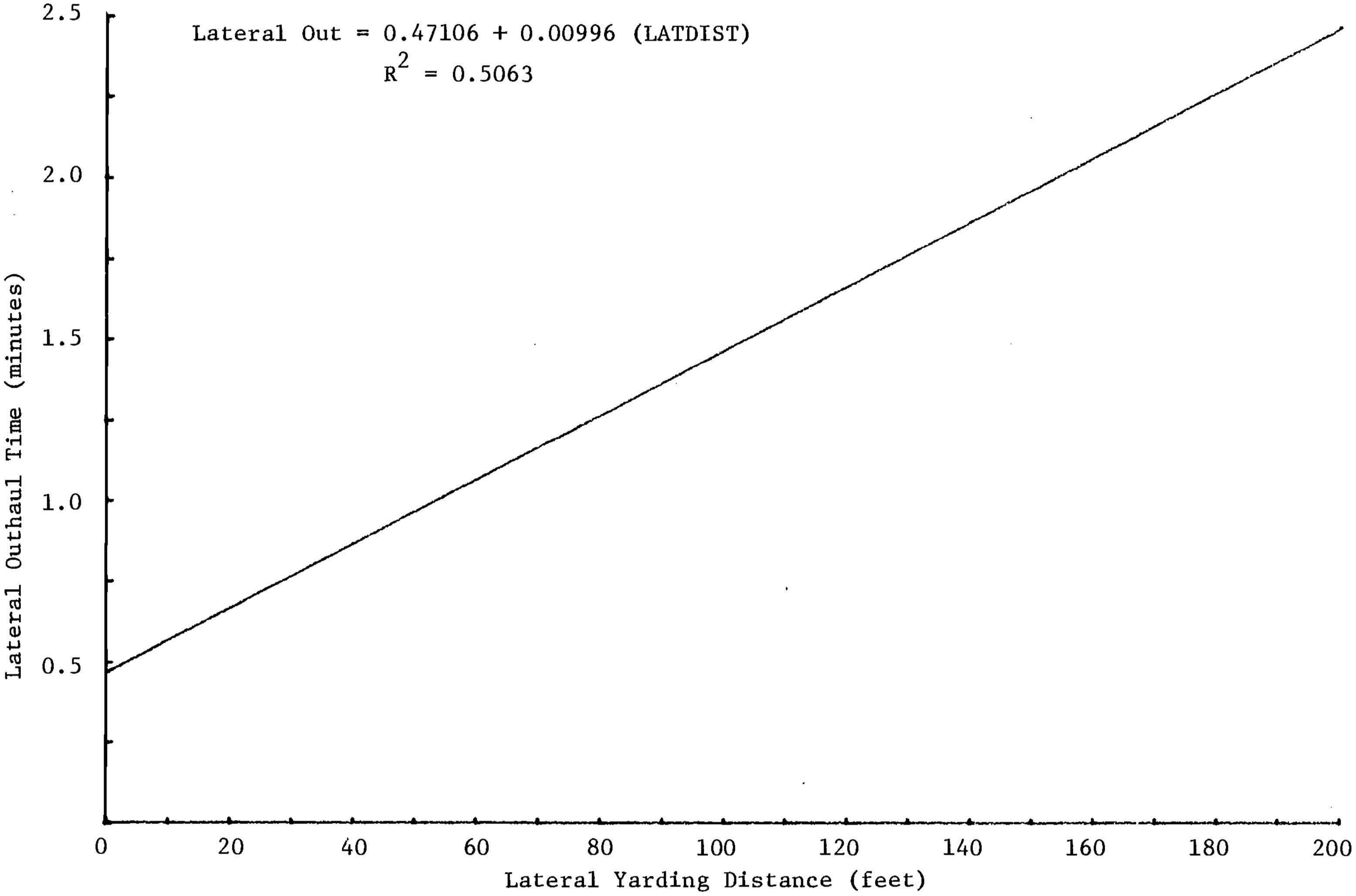


Figure 13. Lateral Outhaul Time as a Function of Lateral Distance

also seem logical to believe that the slope of the ground over which the line was pulled would enter into the picture. This could not be tested since all lateral yarding during the study period was over downhill pulls.

3) Hooking Time (in minutes)

Hook = 0.77355

+ 0.23800 (NLOGS)*

- 0.11220 (RIGRS)***

$n = 325$

$R^2 = .1488$

The low coefficient of multiple determination (R^2) indicates the high variance in this cycle element. A portion of this variation may be attributed to the fact that no distinction was made between turns in which the chokers were preset and those that were not. This is a much less machine- intensive element than any of the others and therefore some of the variability may be accounted for by man's natural work habits. Another factor thought to influence this element was the lateral yarding distance, especially if this distance was near the limit of the dropline length and there were wraps in the dropline and slackpulling line. In this case, the dropline could not be pulled out far enough and the rigging-slinger had difficulty reaching the log.

4) Lateral Inhaul Time (in minutes)

Lateral Inhaul = 0.24244

+ 0.00624 (LATDIST)*

+ 0.00016 (SYDIST)**

+ 0.00007 (VPLOG)*

$n = 325$

$R^2 = .3875$

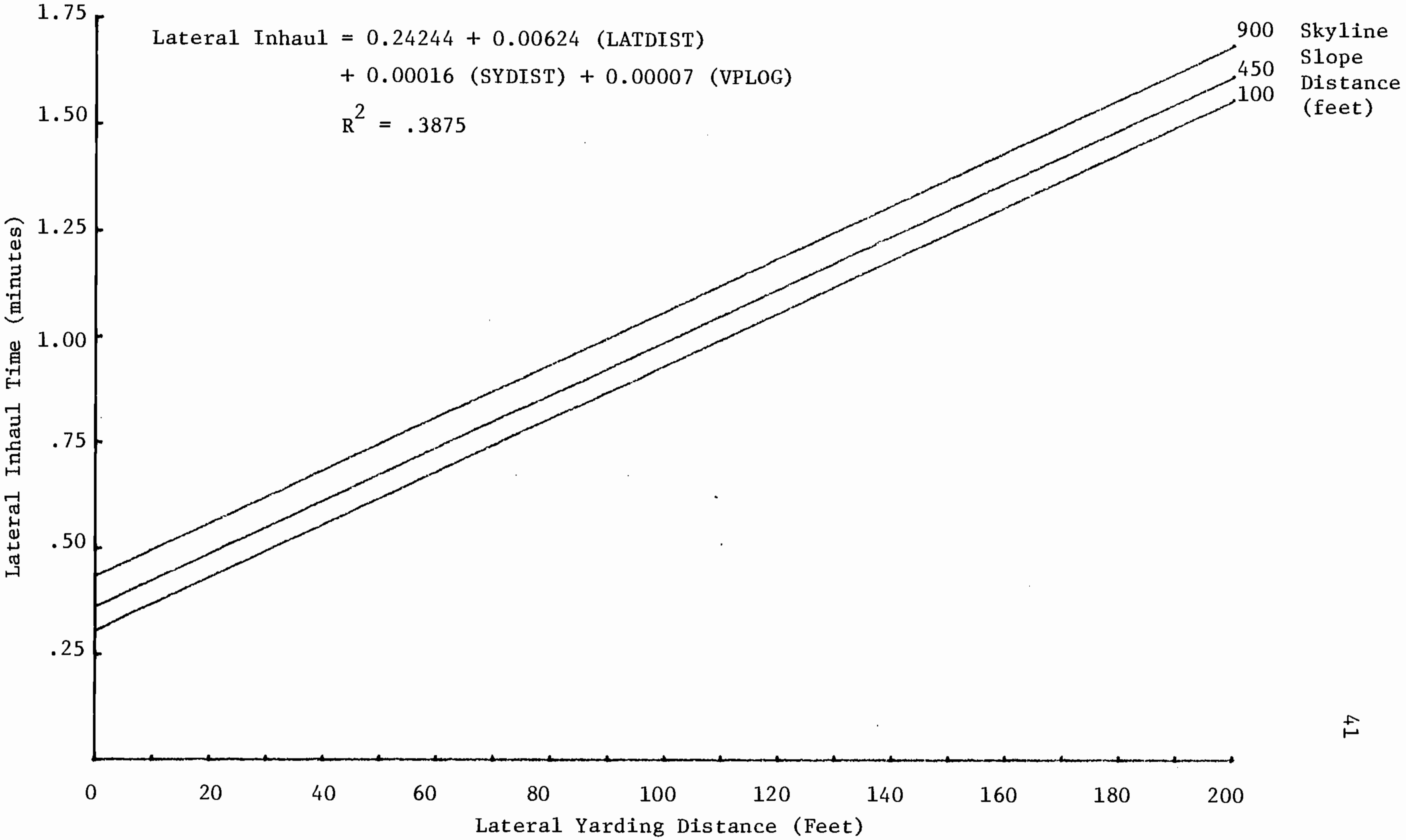


Figure 14. Lateral Inhaul Time as a Function of Lateral and Skyline Distances for an Average Log of 750 B.F.

Time to complete this element includes removing slack from the dropline, building up tension in the mainline/dropline and pulling in the load over whatever lateral distance it has to travel. The slack that may occur in the dropline is due to the slackpulling line at its mainline attachment point moving the line faster than it is being passed through the carriage.

5) Reset Time (in minutes)

Average time per reset = 0.09 min.

Standard Deviation = 0.47

$n = 48$

Because of the random and infrequent occurrence of this cycle element, no significant regression equation could be developed. Resets occurred irregularly during the lateral inhaul and inhaul elements. Turns that were being hauled in laterally were sometimes blocked by a tree or stump or logs slipped out of chokers that had not been set properly. Also, long logs that were being hauled in laterally were too long to swing from the lateral direction into the skyline corridor and would get caught in standing timber. In all of these events the lateral inhaul or inhaul process was interrupted while the rigging crew did what was necessary to rectify the situation.

6) Inhaul Time (in minutes)

$$\begin{aligned} \text{Inhaul} = & - 0.37737 \\ & + 0.00207\ (\text{SYDIST})^{*} \\ & + 0.00009\ (\text{BFVOL})^{*} \\ & + 0.01554\ (\text{CHDSLOP})^{*} \end{aligned}$$

$n = 325$

$R^2 = .6641$

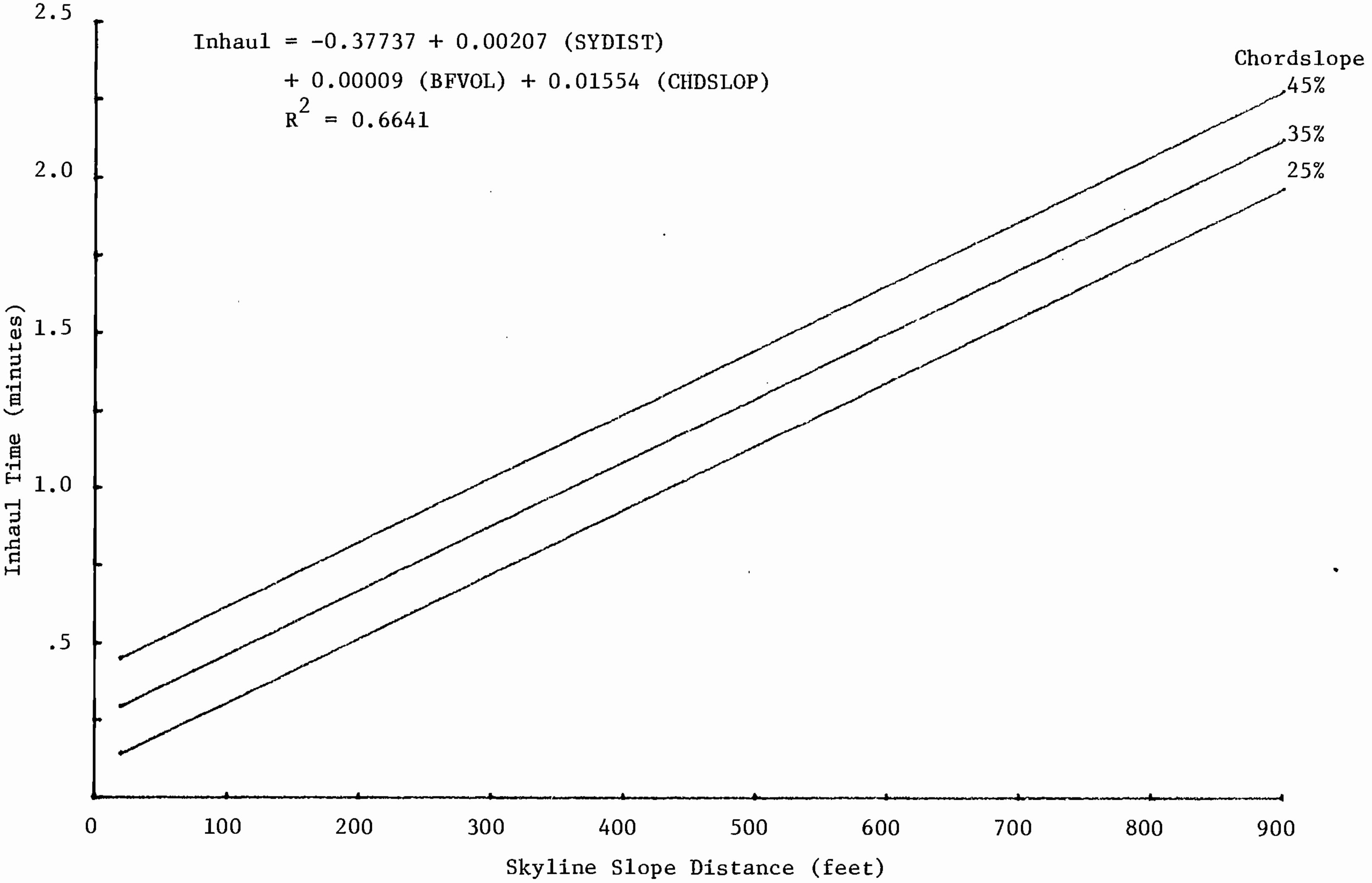


Figure 15. Inhaul Time as a Function of Skyline Distance and Chordslope--
1000 B.F. per Turn

The regression equation shows a linear relationship between inhaul time and load size, skyline slope distance, and chordslope. For a given skyline distance, the inhaul time will increase if the slope is steeper or the load larger. This particular yarder has sufficient power to haul a large load up a steep slope but the time involved is always expected to increase with increases in these variables.

7) Unhooking Time (in minutes)

Unhook = 0.27783
+ 0.09078 (NLOGS)*

n = 325

R^2 = .08

The one factor that caused exceptional variation in unhooking was where the choker bell was situated when the logs were lowered on the landing. If the bell was under a log or between two logs, the chaser could not unhook the load and the logs would have to be repositioned. None of the independent variables measured were able to predict when this might happen.

8) Total Turn Time (in minutes)

Turn Time = 0.61040
+ 0.00317 (SYDIST)*
+ 0.01958 (LATDIST)*
+ 0.33913 (NLOGS)*
+ 0.00167 (CUVOL)**
+ 0.33088 (RIGRS)**

n = 325

R^2 = .4727

This equation is for productive time only and does not include delay time in its data base. It can be a valuable aid for estimating average yarding times during the timber harvesting planning process. All of the variables contained in this equation could be estimated within reasonable limits so as to provide the sale appraiser or logging manager with an idea of production potential.

It is interesting to note that in this equation the number of workers on the rigging crew adds to the total turn time. This same situation has been noted in other studies of this type (Van Winkle, 1975). For this study, one possible explanation for this is that the extra riggers present on the chokersetting crew caused the rigging-slinger to issue more verbal orders in order to get the correct logs hooked for the next turn. This was probably due to the inexperienced chokersetters that were employed during the study period. Another possible explanation is that the hooktender (overall crew supervisor) would often be the extra man when there were four men on the rigging crew. When the hooktender was present at the hooking site there was usually some discussion between the hooktender and rigging-slinger as to what logs should comprise the next turn. This discussion normally occurred during the lateral outhaul phase and was often a source of slightly increased total turn time.

The average turn times in each of the three study units were compared with the predicted results from this total turn time equation using the logging conditions present in each unit. The results for each unit show a close correspondence to the predicted values.

Table 7. Predicted Vs. Actual Mean Total Turn Times for Each Unit

Unit	Avg. SYDIST	Avg. LATDIST	Avg. NLOGS	Avg. CUVOL	Avg. RIGRS	Avg. TTIME	TTIME Predicted	Variance*
Land. 8, Corr. 1	233	55	1.55	146	3	4.42	4.19	+5%
Land. 3, Corr. 1	473	46	1.91	157	2.75	4.78	4.83	-1%
Land. 3, Corr. 2	307	40	1.68	148	3.4	4.19	4.33	-3%

(*Variation between predicted time and actual average turn time for each unit expressed as a percent difference from the predicted time.)

Delays

Total delay time for the study period is summarized in Table 8. This is time for strictly operational delays as no interruptions were made for experimental purposes. Operational delays accounted for 32.0 percent of the total study period which indicates that the effective work hour on this operation was actually only 40.8 minutes long. This is downtime that occurred during actual yarding periods and does not include time that it takes to make skyline road changes. Because road changing and yarder setting changes were made so infrequently during the study period, this time was not included in the analysis. Conversations with the logging crew hooktender indicate that an average time to change a yarder setting would be approximately 2 to 2 1/2 hours while the expected time to change skyline roads working from the same landing would range from 20 to 40 minutes. Observations of the few road and setting changes that did occur fall within these ranges.

Table 8. SUMMARY OF TOTAL STUDY DELAY TIME

Delay Category	Number	Average Time (min.)	Total Time	Percentage of Delay Time	Percentage of Total Project Time
Prep. Time	6	15	90	12.9	4.1
Yarder (mechanical)	8	7.9	63	9.0	2.9
Landing	14	7.2	100.5	14.4	4.6
Carriage & Lines	23	15.3	352	50.3	16.2
Communications	2	3.2	6.4	0.9	0.3
Cleanup	3	23.3	70	10.0	3.2
Unspecified	2	9.0	18	2.5	0.7
Total	58	12.1	699.9	100.0	32.0

Delays seem to appear entirely at random and could not be predicted with any of the measured variables. They depend on factors that would be extremely hard to quantify mathematically but may be somewhat controllable when they are adequately described.

The major source of delay time on this study was the skyline carriage and operating lines which accounted for over one half of all delay time. Most of this time can be attributed to the design of the carriage itself. The slackpulling line, which came off of a fairlead on the left side of the yarder boom, was designed to enter the right side of the carriage. This required the slackpulling line and mainline to cross each other in the normal rigging configuration. Because these lines were in such close proximity to one another, they wrapped up together very frequently. When they became too entangled the mechanical slackpulling necessary for lateral yarding could not be accomplished and the operation stopped until the wraps could be unwound. This occurred in 11 of the 23 observed delays in this category.

Another source of delay time due to the carriage was the maintenance of correct tension in the pressure arm assembly which held the dropline against the turning sheave within the carriage during lateral outhaul. This tension could be adjusted by turning a compression spring set-screw on top of the carriage but the correct amount of tension was extremely difficult to maintain. Too much tension on the pressure arm would result in the dropline being held too tightly against the sheave and the line would not feed properly. Too little tension had the same net result. Time taken to correct the adjustment on the pressure arm accounted for 12 of the 23 delays in this category.

Explanations of the other delay categories are as follows:

Preparation Time - Time each morning after official crew starting time for the rigging crew to get their gear together and get to the hooking site from the landing.

Yarder (Mechanical) - Yarder overheated on several occasions and had to cool before work could resume.

Landing - Time needed for the landing to be cleared of logs to make room for the next turn or to let log-trucks pass when yarder was located on the main haul road.

Communications - Mechanical problems with the whistle signaling device.

Cleanup - Time necessary at the end of yarding on each corridor for merchantable damaged trees to be felled, bucked, and yarded.

Unspecified - Delays that occurred during yarding but the reason for which could not be determined.

PRODUCTION POTENTIAL

For the data collected during the study period, production graphs of average hourly production as a function of skyline slope distance and the other variables in the total cycle time regression equation were generated (Figures 16, 17, 18, and 19). For each graph the mean (average) values listed in Table 6 were used for the independent variables that were held constant. For the independent variables that were allowed to vary on the separate graphs, the values of the variables are noted.

Each of the three skyline road profiles were analyzed to determine the maximum allowable payload weight. This was accomplished with the aid of the Skyline Analysis Program (SAP) for the Hewlett Packard 9830 desk-top computer. Results of the analysis for all three corridors is presented in Appendix 2. The result of this analysis indicates that the maximum allowable skyline payload per turn for a dragging load was as follows for the three profiles:

Landing 3, Corridor 1	25,456 lbs.
Landing 3, Corridor 2	16,900 lbs.
Landing 8, Corridor 1	28,346 lbs.

Comparison of these figures with the data summarized in the histograms (Figures 20, 21, and 22) showing the distributions of actual weights and volumes per turn indicate that the production potential of the yarder was much greater than the average weight (7099 lbs.) and volume (152.15 ft.^{3} or 972 board feet) per turn that was observed. Less than three percent of the log turn volumes were in the range of 17,000 to 25,000

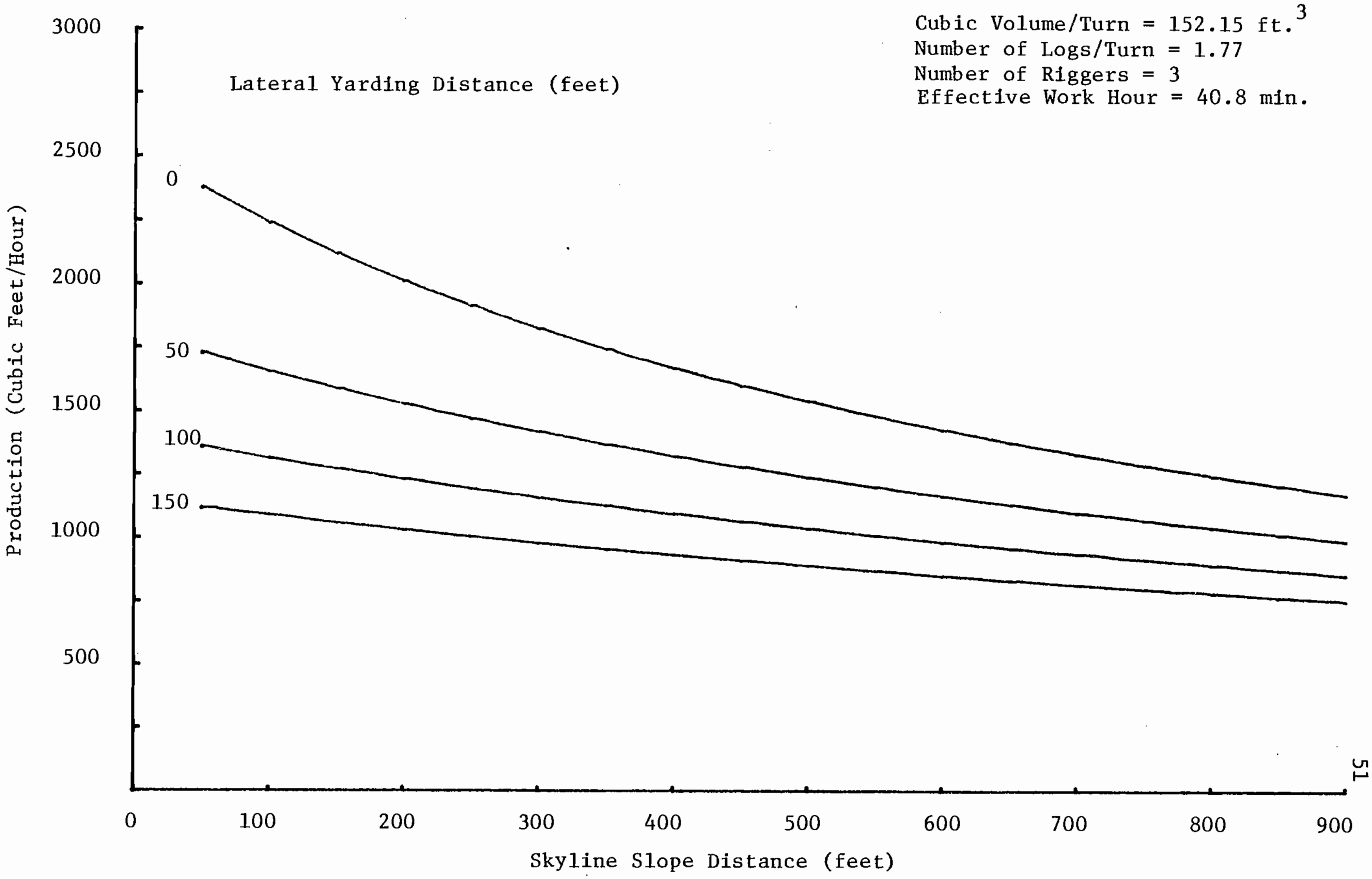


Figure 16. Production as a Function of Skyline Distance and Lateral Distance

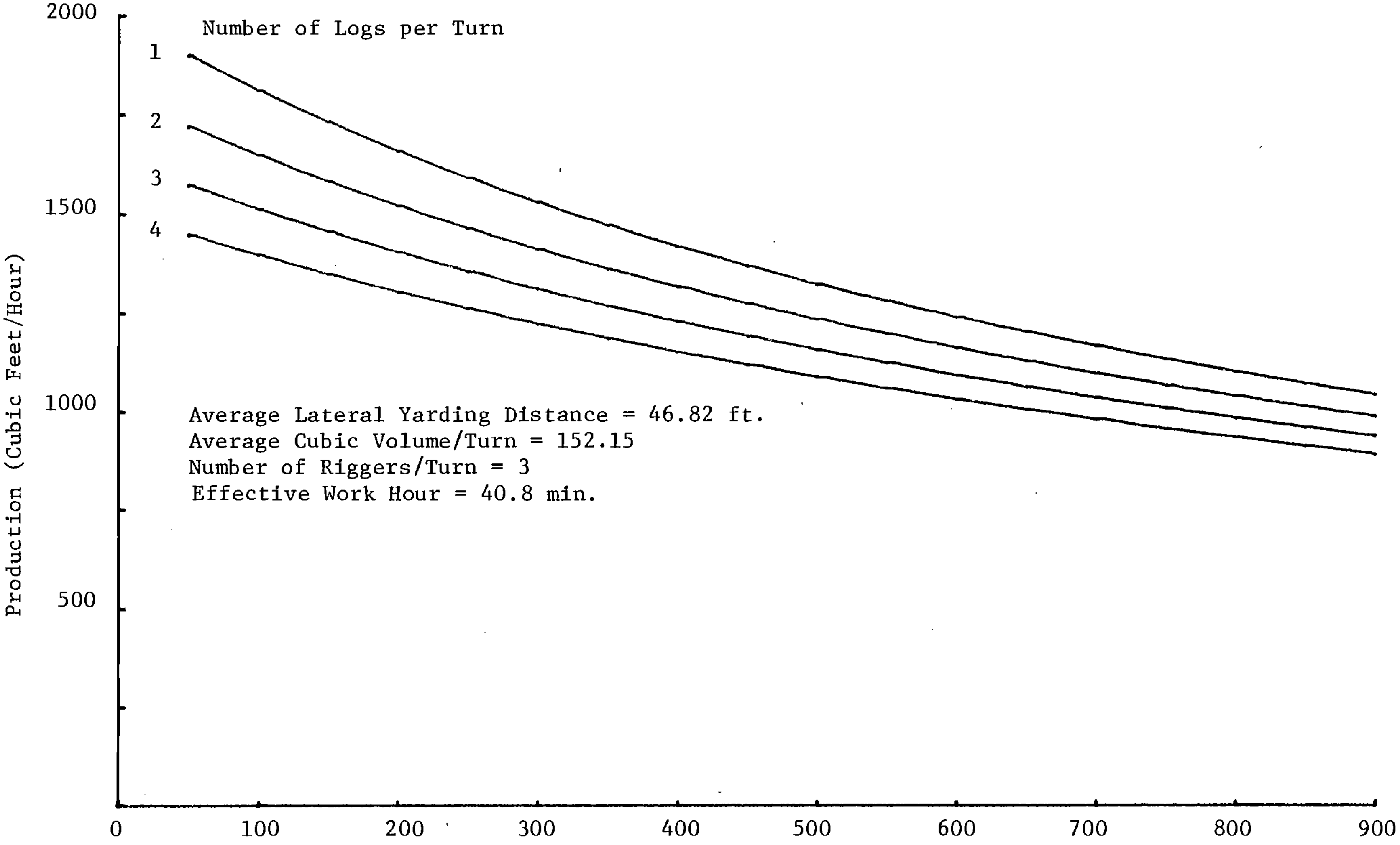


Figure 17. Production as a Function of Yarding Distance and Logs/Turn

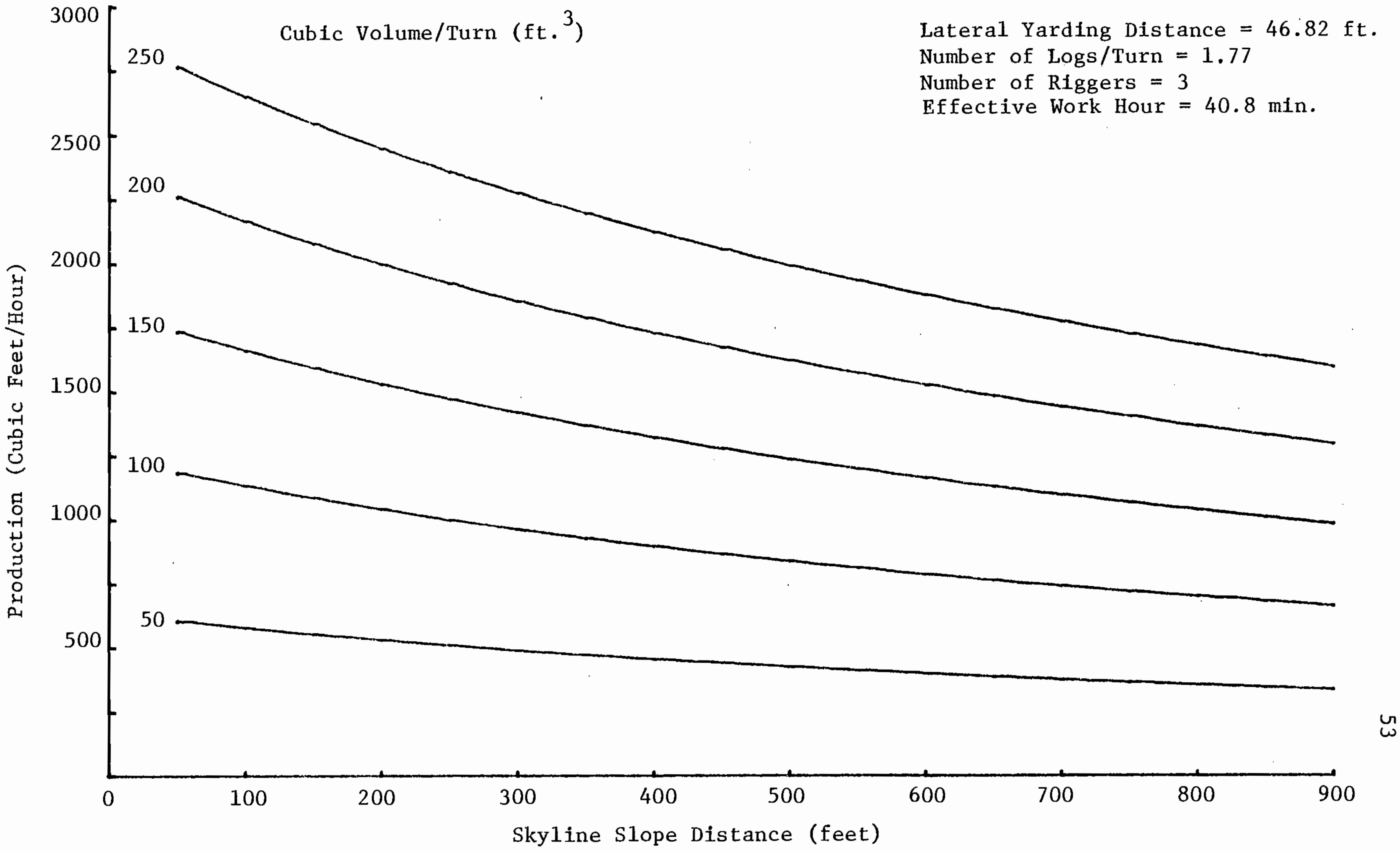


Figure 18. Production as a Function of Yarding Distance and Volume/Turn

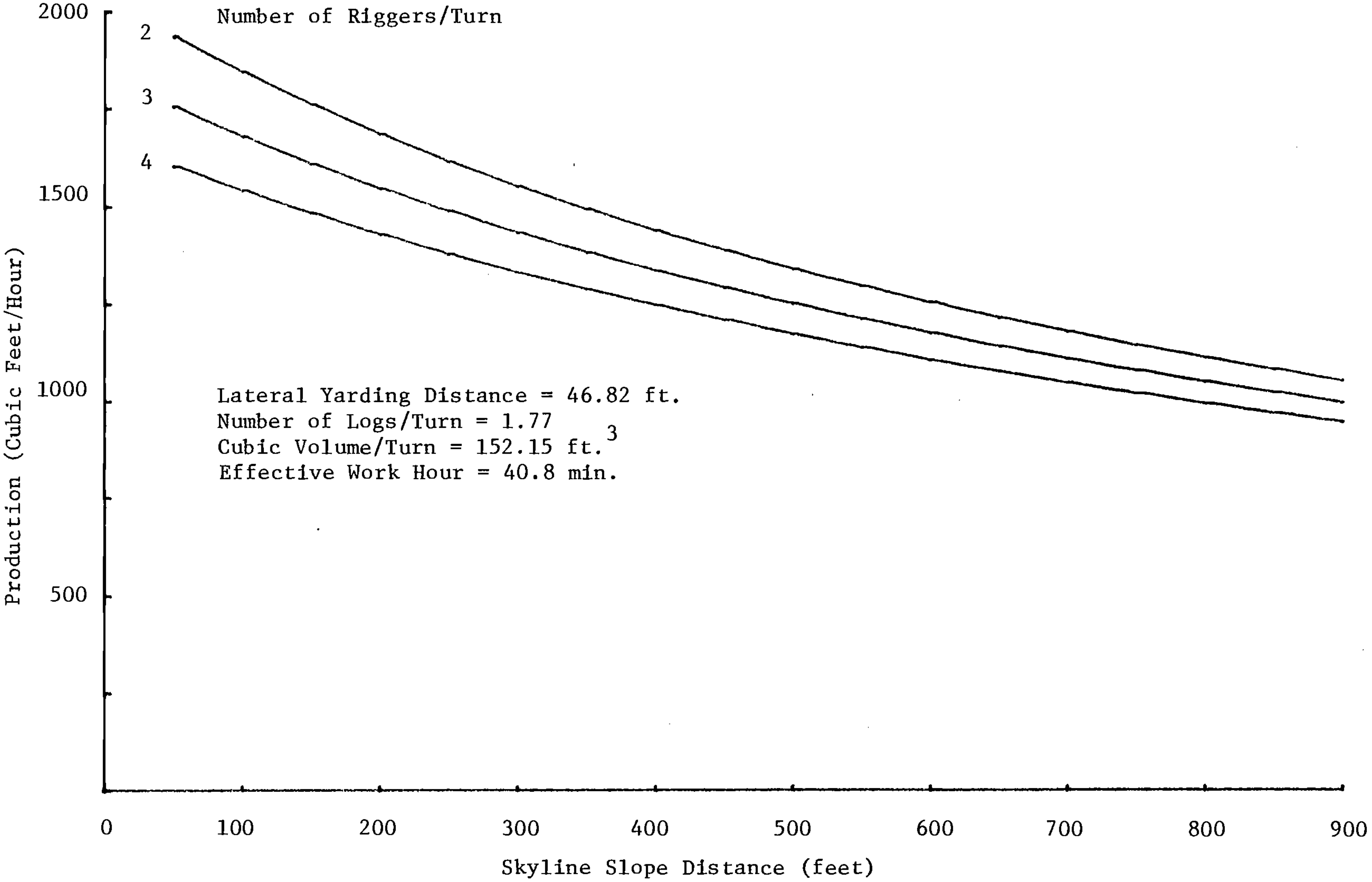


Figure 19. Production as a Function of Yarding Distance and Number of Riggers

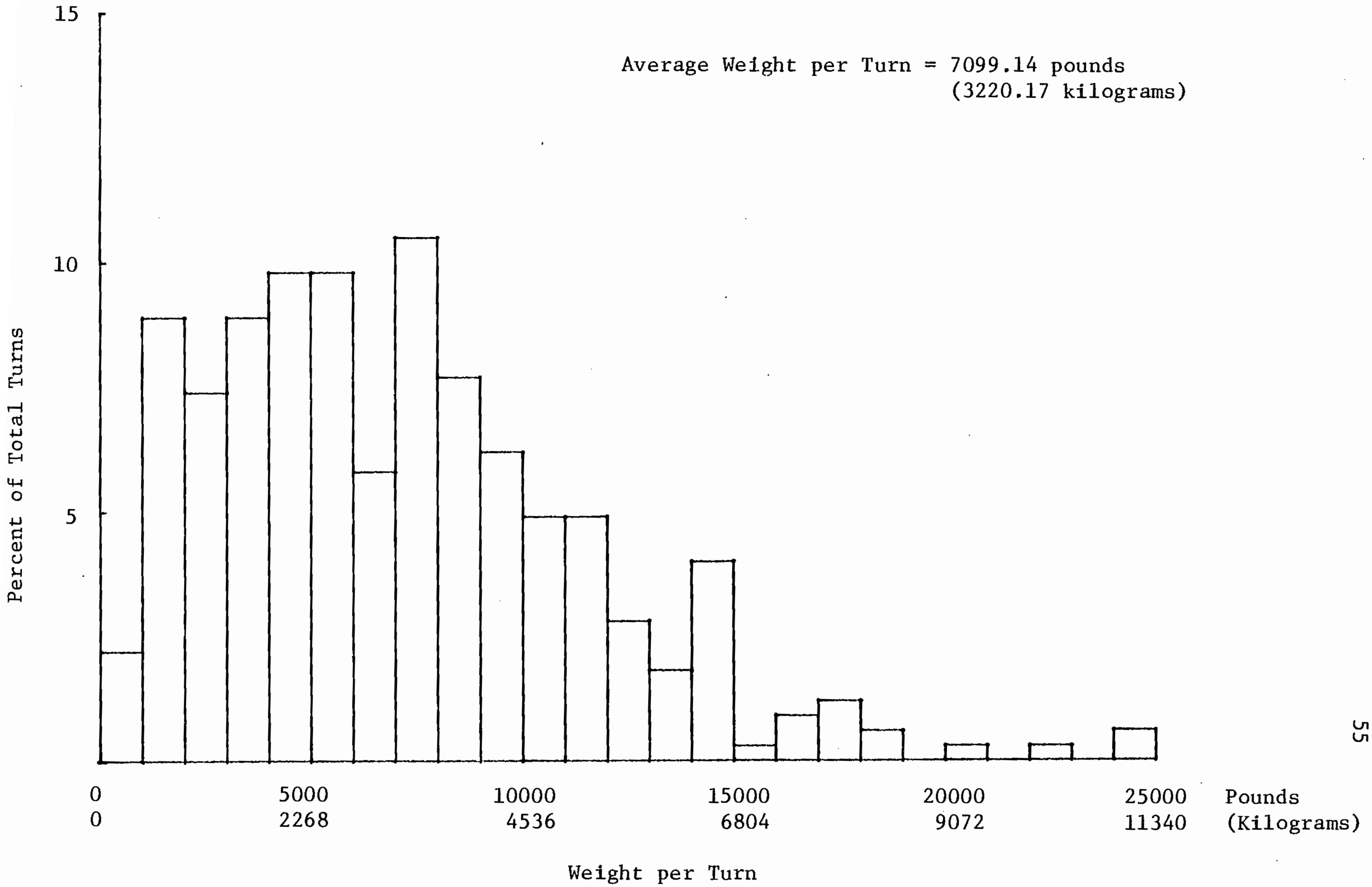


Figure 20. Distribution of Weight per Turn

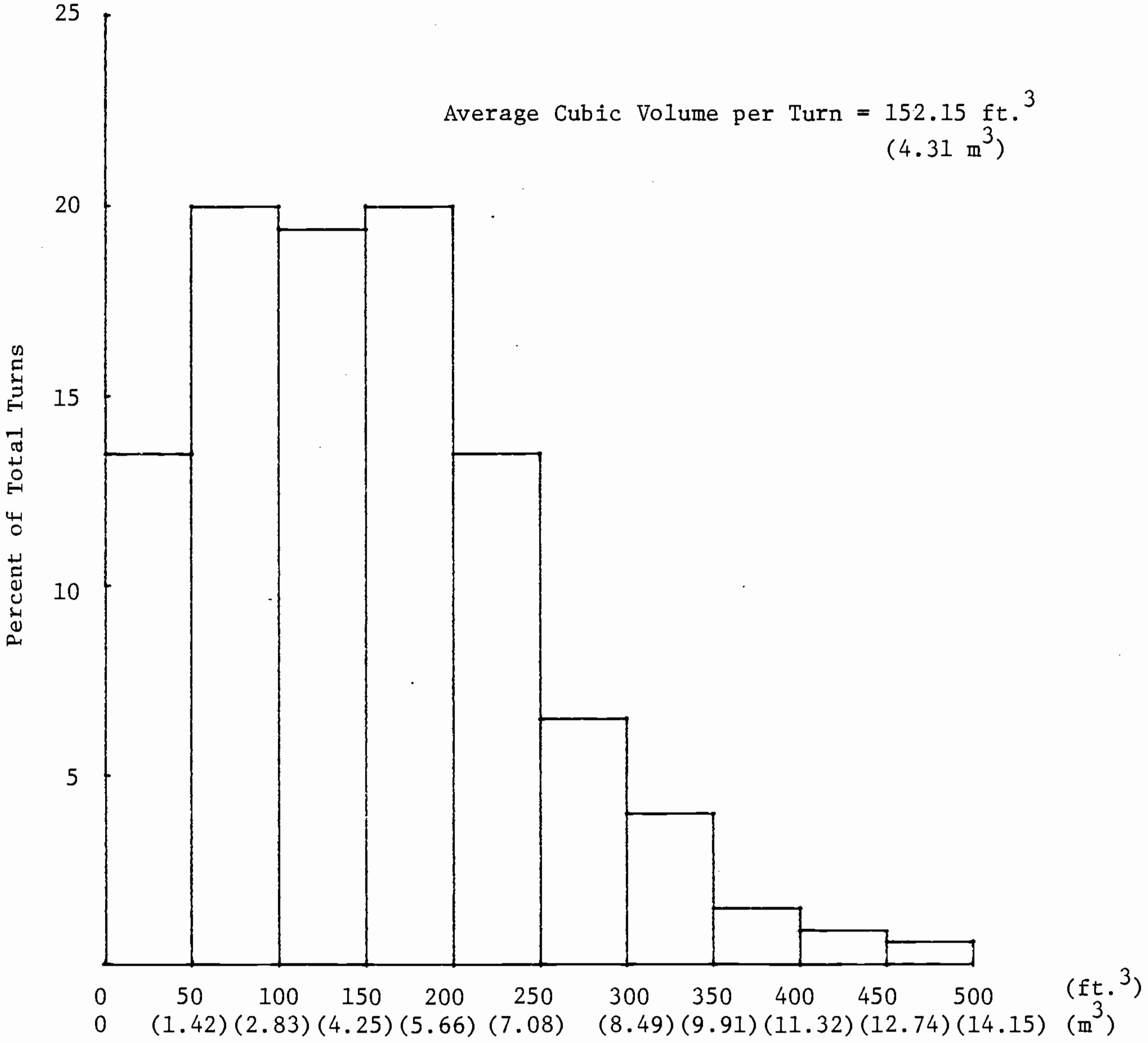


Figure 21. Distribution of Cubic Volume per Turn

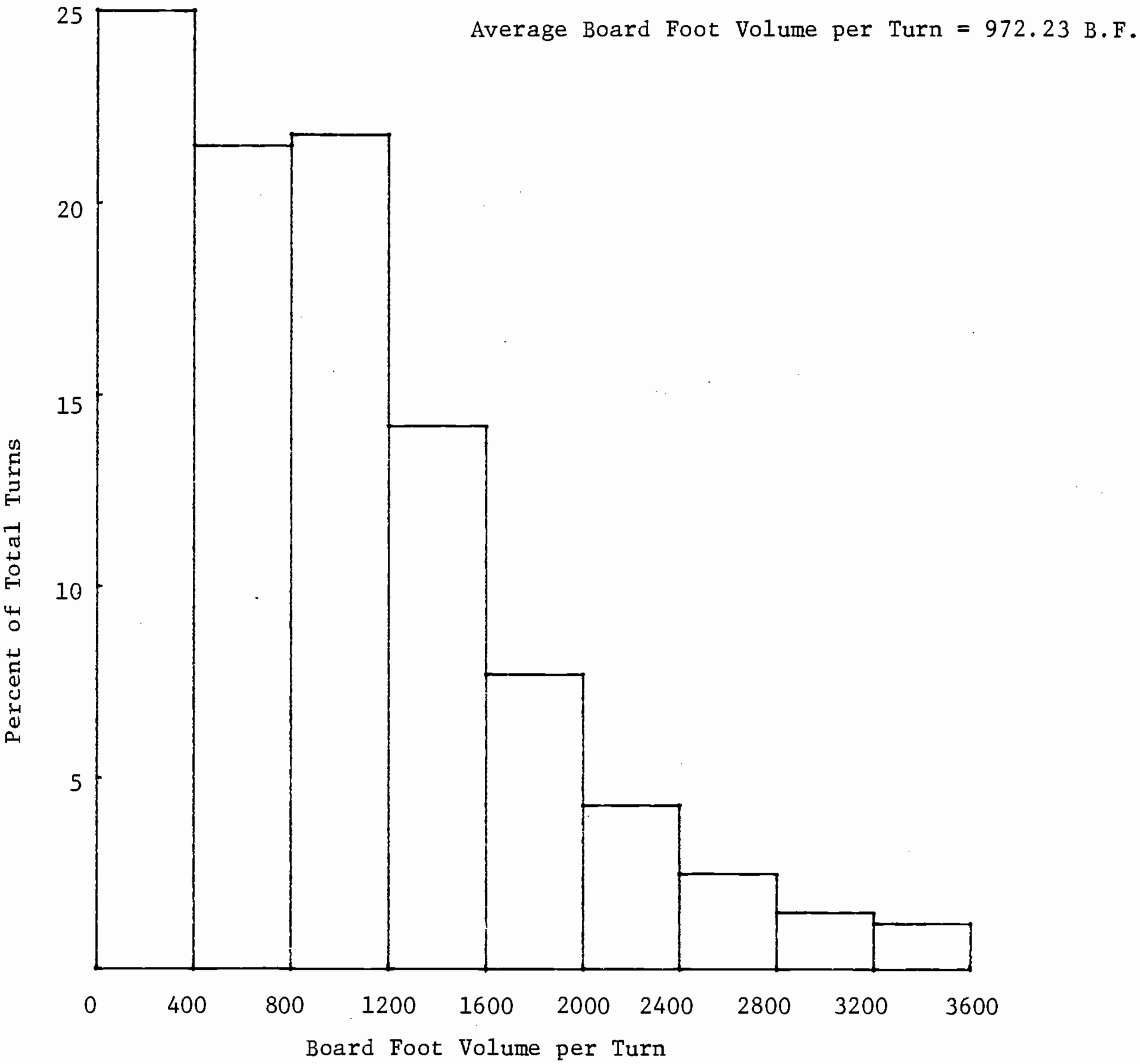


Figure 22. Distribution of Board Foot Volume* per Turn

(*Board foot volumes are gross volumes. No deductions were made for scaling defect.)

pounds which is the approximate range of the allowable payloads for this system. However, it is also important to note that the turn time and therefore production was at least partly dependent on the number of logs hooked per turn with lower production resulting from multiple log loads (Figure 17). With the extreme variation in log size and the spatial distribution (Figures 9, 10, and 11) expected in a partial cut of this type it is probably not worthwhile to try and indicate some optimum load weight other than to point out that the system was seldom loaded to its maximum allowable capacity.

PRODUCTION COSTS

A summary of predicted daily operating costs is presented in Table 9. The derivations of the individual elements of this daily cost are shown in Appendices 3 through 9. Equipment and fuel costs were acquired from equipment dealers or from the Forest Service R-6 Cost Guide for Empirical Appraisals, 1978. Labor costs are those actually paid the yarding crew during the study period.

Production costs for the predicted operating costs are presented in Table 10. Daily production was determined using the mean values shown in Table 7. Yarding time per day was considered to be seven hours. The average turn time of 4.56 minutes per turn and an effective work hour of 40.8 minutes (32% delay time) was used throughout.

Table 9. Daily Operating Costs for Six-Man Crew Working Ten Hours per Day (1979 costs)

Cost Item	Daily Cost
Madill 044 Skyline Yarding Crane	$1583.88
Danebo MSP Carriage	26.10
Yarder Signal Radio	11.37
Rigging Equipment	43.04
Crew Transportation	39.19
Chain Saws (on landing)	15.33
Labor	642.50
Total Daily Cost	$2361.41

Table 10. Daily Production Costs based on 7 Hours of Average Yarding Time per Day* (1979 Costs)

Production Unit	Daily Production	Unit Cost($)
Cunit	95.30	$24.78
M.B.F.	60.91	38.77

(*Yarding crew worked 10 hours per day but only an average of 7 hours per day was actually productive yarding time.)

COMPARISON OF REGRESSION EQUATIONS

The regression model used as a basis for appraisals of running skyline operations in the California Region was developed from data collected for two timber sales on the Klamath National Forest in 1975 (Van Winkle, 1975). The yarders observed in this study were both Washington Iron Works 108 Skylok Yarding Cranes. Each sale was analyzed separately and no overall regression was developed for the complete data set. It is extremely difficult to statistically compare these regressions with the one developed for the Madill 044 because other variables were measured and found to be important on the Klamath study. However, certain elements of the regressions developed by Van Winkle can be compared with the regression models for the Madill 044. The question that is posed in making these comparisons is whether or not the regression developed for the WIW 108 will adequately predict turn times (production) for another running skyline yarder operating under different conditions.

Conditions reported by Van Winkle for the Bullion Mt. Sale seem to be closest to the conditions observed during the Horsethief study. The resulting regression that was developed from the Bullion Mt. time data is as follows:

$$\begin{aligned}\text{Total Turn Time} = {} & 1.97418 \\ & + 0.0029766\ (\text{Skyline Distance}) \\ & + 0.0021786\ (\text{Chordslope}) \\ & + 0.76748\ (\text{BRUSH}) \\ & + 0.0140812\ (\text{Lateral Distance}) \\ & + 0.71946\ (\text{Riggers})\end{aligned}$$

This regression equation was obtained by summing the individual equations developed for each of the component activities. Therefore, there is no coefficient of multiple determination (R^2) available to indicate how much of the variation in total turn time is associated with the variation of the independent variables. R^2 values for the equations of the individual elements of the yarding cycle from the Bullion Mt. study are compared with the Horsethief study values in Table 11.

Table 11. Comparison of Coefficients of Multiple Determination

Yarding Cycle Element	Bullion Mt. - R^2	Horsethief - R^2
OUTHAUL	.3341	.6702
LATERAL OUTHAUL	.3192	.5063
HOOK	.1406	.1488
LATERAL INHAUL	.3982	.3875
INHAUL	.5329	.6641
UNHOOK	.0146	.0800

The variable BRUSH included in the Bullion Mt. regression was an indicator variable used to rate brush and slash conditions during the study. Possible values for this variable were:

0 = light or non-existent; did not restrict movement

1 = medium; caused some difficulty in movement

2 = heavy; considerably restricted normal movement.

The observed brush conditions on the Horsethief area suggest that a rating of zero would apply on all three units. This means that in using

Van Winkle's Bullion Mt. regression to predict average turn times for the Horsethief sale the brush variable would drop out of the equation. Since all of the other variables needed as input for use of the Bullion Mt. regression were actually measured on the Horsethief study, this equation can be used to predict total turn times for each unit. The results of using the average logging conditions for each of the three corridors as given in Table 7 to predict total turn times are shown in Table 12. Predicted turn times are provided using both the Bullion Mt. and the overall Horsethief regressions.

Table 12. Comparison of Predicted Total Turn Times (minutes)

Unit	Bullion Mt. Regression Predicted Time	Horsethief Regression Predicted Time	Actual Mean Times
Landing 8, Corridor 1	5.68	4.19	4.42
Landing 3, Corridor 1	6.08	4.83	4.78
Landing 3, Corridor 2	6.00	4.33	4.19

These comparisons are not meant to demonstrate that there is anything wrong with the Van Winkle equations. The original question was how appropriate it would be to use the regressions developed for one yarder as a model to predict production for a different machine operating under different conditions. The fact that the regression developed for the Washington 108 overestimates turn times for the Madill 044 by an average of 33% for the observed data indicates that using one regression to predict production for a variety of yarders rigged as running skylines and operating under a wide range of conditions will not provide very accurate results. Whether or not the accuracy of these results is within the limits of the needs of the U.S. Forest Service timber sale appraisal process is a question that has an answer which is beyond the scope of this report. If the indicated level of prediction accuracy is not satisfactory there is a clear suggestion that further examination of this topic is necessary.

SUMMARY AND CONCLUSIONS

This report has described the use of a modern skyline yarding crane in logging old-growth, mixed conifer stands of the southern Sierra Nevada mountains. Regression analysis of the time data collected for 325 yarding cycles on three separate skyline roads has resulted in the development of predictive equations for each element of the yarding cycle and for total turn time. Records of delay time show that thirty-two percent of all actual yarding time is devoted to operational delays. This information makes it possible to predict production of the Madill 044 yarder while working under similar conditions to those described. Analysis of the costs involved in operating this machine indicate per unit costs of timber production from stump to landing. These costs are $24.78 per cunit and $38.77 per thousand board feet. Additional costs for a tractor or rubber-tired skidder used in swing yarding are not included.

With respect to total turn time prediction, the two variables that have the most significant influence are skyline slope yarding disance and lateral yarding distance. Of secondary importance are the numbers of logs hooked on each turn and the number of men working on the rigging crew. The coefficient of multiple determination for the overall regression equation shows that approximately forty-seven percent of the variation of total turn time for the observed data can be explained by the variation in the independent variables described. This equation can be used by timber sale appraisers and logging managers to predict production when planning an operation for this machine.

Delay times account for a significant amount of operating time and there seems to be no adequate predictor of when these delays will occur. Most of the delay time recorded was due to problems with the skyline carriage and operating lines. The use of a skyline carriage that is more compatible with this particular yarder could reduce this delay factor. Another major source of delay was stopping the yarding operation to allow log truck traffic to pass because the yarder setting was on a haul road. Any plans for landings on roads that must be used for other traffic while yarding is underway should allow for similar delays.

The total turn time regression developed as part of this study was compared to a different regression model for a Washington 108 Skyline Crane operating on the Klamath National Forest. Using each regression to predict turn times for the same logging conditions revealed a thirty-three percent difference between the resulting predictions. The exact source of this variability could not be determined from the available information but differences in yarder design, topographic conditions and timber type are all involved. The feasibility of using one regression model as a predictive tool for a wide variety of running skyline yarders operating under different conditions is questionable based on these results.

SUGGESTIONS FOR FURTHER RESEARCH

As an initial study on skyline logging in the southern Sierras, this report has identified several possible areas that need additional examination. Four of these possible areas are briefly mentioned as follows:

1. In this study, 32% of the available operating time was occupied by non-productive delays. This percentage has reportedly been even higher in other studies (Dykstra, 1976). It may be useful to initiate a specific project to carefully consider the source of these delays and look for possible means of prevention or minimization.

2. Yarding simulation models such as that developed by Sessions in 1978 use a random tree felling pattern that places all simulated felled timber perpendicular to the skyline corridor. As can be seen in the spatial distribution plots generated as part of this project, the actual tree felling pattern observed on this operation shows trees at many different angles. The angle between the axis of the tree and the corridor may have some influence on yarding time. Incorporating a more realistic felling pattern into simulation programs may be beneficial in making these programs more useful for predictive purposes.

3. A regression model may fit the data used to develop that model extremely well but it may not actually reflect the true underlying relationships. To test the equations developed in this study, a follow-up could be accomplished to verify or nullify these indicated relationships. This type of test should use identical time data for this yarder while it is working on another area which could be a separate unit of the same

sale or a completely different harvesting project. The purpose of such a test would be to determine if the regression model and frequency distributions from this study represent time relationships between variables or if they are only a description of the data from this small population. The recommended statistical test would be a chi-squared test for goodness of fit between a given distribution and sample at a set probability level. For such a test to be useful, the sample set should be approximately as large as the original sample. This type of verification should probably be planned into future projects of this type from the outset in order to remove any uncertainty of the usefulness of the results.

4. Comparison of the regressions from the Madill 044 and the Washington 108 suggest that the production rates are not the same. A further implication is that it is not particularly useful to apply either of these models to other running skyline operations in the California region. If the data from both studies were collected in such a form so that they could be analyzed together perhaps a more comprehensive model could be developed for this system. Future efforts at collecting time data for estimating production should consider this suggestion.

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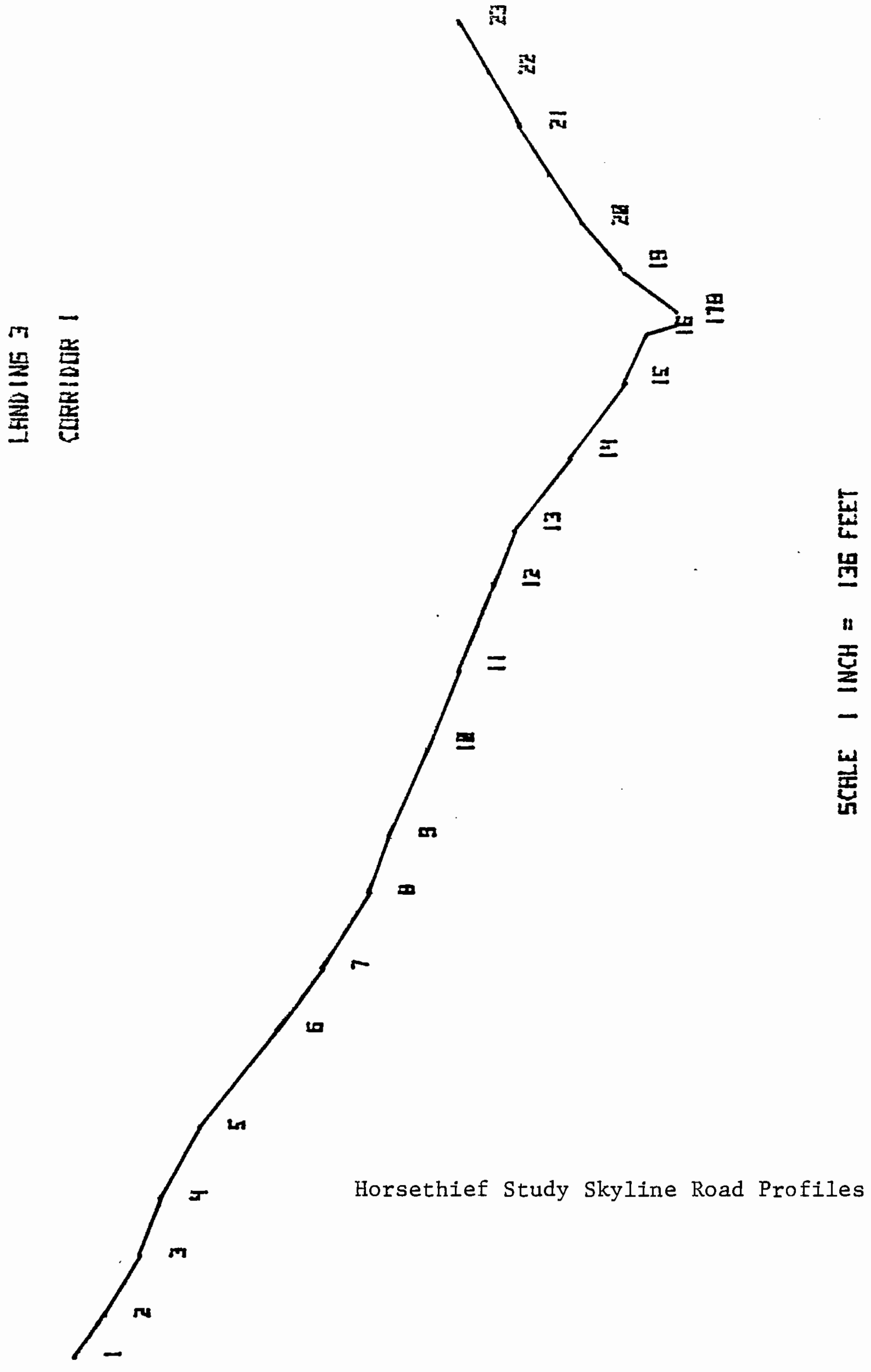
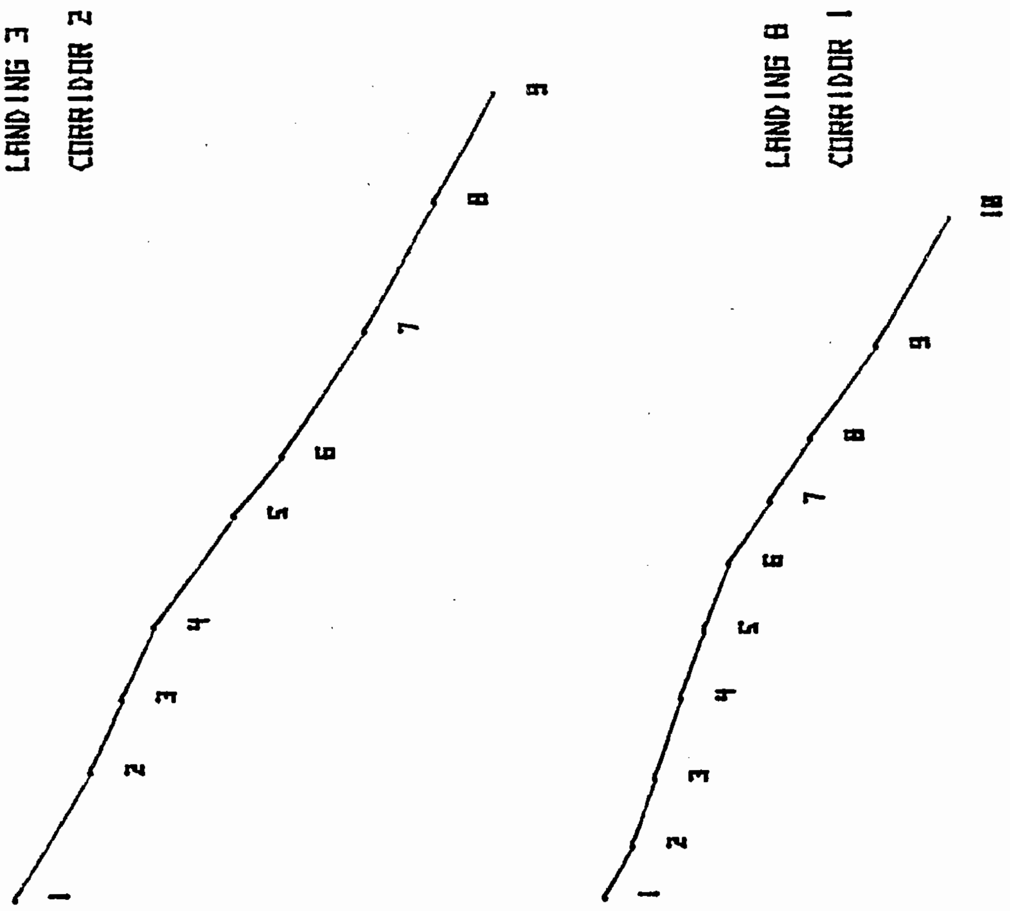
APPENDICES

Appendix 1



Horsethief Study Skyline Road Profiles

Appendix 1



Horsethief Study Skyline Road Profiles

APPENDIX 2

Skyline Analysis Program (SAP)

Running Skyline Load Analysis (Rigid Link Assumption)

Landing 3, Corridor 1

Allowable Haulback Tension = 26,500

Allowable Mainline Tension = 34,500

Haulback Line Wt. = 1.42

Main and Slack Line Wt. = 2.57

Headspar Height = 60

Tailspar Height = 3

Headspar T.P. = 1

Tailspar T.P. = 20

Inner Yarding Lim. = 1

Outer Yarding Lim. = 15

Carriage Weight = 750

Loaded Carriage Clearance = 15

Terrain Point	Log Load (Fly)	Log Load (Drag)	Line Length
2	32152	48229	2220
3	25811	38717	2208
4	19959	29938	2198
5	16971	25456	2196
6	17986	26978	2204
7	18537	27805	2208
8	18879	28318	2211
9	17978	26967	2209
10	17942	26913	2209
11	18134	27201	2209
12	19084	28625	2209
13	20077	30116	2210
14	26765	40148	2227
15	37455	56183	2252

Landing 3, Corridor 2

Headspar Height = 60
Tailspar Height = 50

Headspar T.P. = 1
Tailspar T.P. = 8

Inner Yarding Limits = 1
Outer Yarding Limits = 8

Terrain Point	Log Load (Fly)	Log Load (Drag)	Line Length
2	22113	33170	1121
3	15665	23498	1114
4	11266	16899	1110
5	13021	19532	1112
6	16275	24413	1116
7	27222	40833	1124

Landing 8, Corridor 1

Headspar Height = 60
Tailspar Height = 55

Headspar T.P. = 1
Tailspar T.P. = 8

Inner Yarding Limits = 1
Outer Yarding Limits = 8

Carriage Weight = 750

Loaded Carriage Clearance = 15

Terrain Point	Log Load (Fly)	Log Load (Drag)	Line Length
2	33713	30369	741
3	26743	40115	723
4	20675	31012	715
5	18897	28346	713
6	20389	30583	712
7	44326	66488	725

APPENDIX 3

Madill 044 Yarder Equipment Costs

Cost New FOB Fresno, CA 1979 (with all accessories and wire rope)	$ 578,000
Salvage Value (5 yrs., 20%)	- 115,600
Net Cost	= $ 471,400

$$\text{Average Investment} = \frac{(\text{Cost New}) + (\text{Deprec.}) + (\text{Salvage Value})}{2}$$

$$= \frac{(578{,}000) + (94{,}280) + (115{,}600)}{2}$$

$$= \$\ 393{,}940$$

Fixed Costs:

Depreciation (Net cost over 5 yrs.)	$ 94,280
Interest (9% of Average Investment)	35,454
Insurance (2% of Average Investment)	7,879
Taxes (5% of Average Investment)	15,758
Total Annual Fixed Costs	$ 153,370

Operating Costs:

Maintenance and Repair (50% of depreciation)	$ 47,140
Tires	3,500
Hydraulic Oil	1,000
Rigging	
Haulback line - 2300 ft. of 7/8" IPS x $1.36/ft.	= $3121
Mainline = 1760 ft. of 1" IPS x $1.70/ft. =	2995
Slackpulling Line - 1500 ft. of 5/8" IPS x 0.74/ft.	=1114
Total Annual Operating Cost	= $ 58,870
Total Annual Cost	= 212,240
Total Daily Cost (@ 134 days/yr.)	$ 1,583.88

APPENDIX 4

Cost of Danebo MSP Heavy Duty Carriage

Cost New - F.O.B. Fresno, CA - 1979	$ 6,000
Salvage Value (3 yrs. - 10%)	- 600
Net Cost	$ 5,400

$$\text{Average Investment} = \frac{(\text{C.N.}) + (\text{Deprec.}) + (\text{S.V.})}{2}$$

$$= \frac{(6{,}000) + (1{,}800) + (600)}{2} = \$\ 4{,}200$$

Fixed Costs:	
Depreciation (Net cost over 3 yrs.)	= $ 1,800
Interest (12% of Average Investment)	504
Insurance (2% of Average Investment)	84
Taxes (5% of Average Investment)	210
Total Annual Fixed Costs	$ 2,598
Operating Costs:	
Maintenance and Repair (50% of deprec.)	= $ 900
Total Annual Operating Costs	= $ 900
Total Annual Cost	$ 3,498
Total Daily Cost (@ 134 days/yr.)	$ 26.10

APPENDIX 5

Costs Allocated to Yarder Signal Radio

Cost New - 1979	
2D Model 30-2 (Rothenbuhler Engineering)	= $ 3,750
Extra Transmitter	= 1,000
	$ 4,750
Salvage Value	= 0
Net Cost	$ 4,750
Average Investment = $\frac{(C.N.) + (Deprec.)}{2}$	
$= \frac{(4750) + (950)}{2}$	= $ 2,850
Fixed Costs:	
Depreciation (Net cost over 5 yrs.)	= $ 950
Interest (12% of Average Investment)	= 342
Insurance (2% of Average Investment)	= 57
Total Fixed Costs	$ 1,349
Operating Costs:	
Radio Batteries	= $ 75
Maintenance and Repair	= 100
Total Annual Operating Costs	$ 175
Total Annual Cost	$ 1,524
Total Daily Cost (@ 134 days/yr.)	$ 11.37

APPENDIX 6

Cost of Rigging Equipment

Costs New - 1979

Rigging Hardware - 2 sets	$ 6,703
Climbing Spurs, Belt, Rope	244
20" Splicing Needle	24
Riggers Maul	39
Riggers Pass Chain (3/8" x 7 1/2')	102
Riggers Bar	67
Chain Saw Wedges (4)	20
Power Saw	370
Axe	25
	$ 7,594
Salvage Value	- 0
Net Cost	$ 7,594

$$\text{Average Investment} = \frac{(\text{C.N.}) + (\text{Deprec.})}{2}$$

$$= \frac{(7594) + (3797)}{2} = \$\ 5{,}696$$

Fixed Cost:

Depreciation (Net cost over 2 yrs.) = 3,797

Interest (12% of Average Investment) = 683

Insurance (2% of Average Investment) = 114

Taxes (5% of Average Investment) = 228

Total Fixed Costs $ 4,818

Operating Costs:	
Maintenance and Repair (25% of deprec,)	$ 950
Total Annual Operating Costs	$ 950
Total Annual Cost	$5,768
Daily Cost (@ 134 days/yr.)	$ 43,04

APPENDIX 7

Costs of Chain Saws on Landing

Cost New (1979) per chain saw (2 necessary) $ 450

Salvage Value 0

Net Cost = $ 900

Average Investment = $ 900

Fixed Costs:

Depreciation = $ 900

Interest (12% of Average Investment) = 108

Insurance (2% of Average Investment) = 18

Taxes (5% of Average Investment) = 45

Total Fixed Costs = $1,071

Operating Costs:

Maintenance and Repair (75% of deprec.) = $ 675

Fuel (.5 gal/day) (134 days) ($.75/gal) (2 saws) = 101

Oil (.5 pint/day) (134 days) ($.95/pint) (2 saws) = 127

Chain Replacements (2 chains/season) ($20/chain) (2 saws) = 80

Total Annual Cost = $2,054

Total Daily Cost (@ 134 days/yr.) = $ 15.33

APPENDIX 8

Crew Transportation Costs

Cost New - 1979 - (crew cab pickup truck)		$ 8,000
Salvage Value (3 yrs,, 30%)		- 2,400
Net Cost	=	$ 5,600

$$\text{Average Investment} = \frac{(\text{C.N.}) + (\text{Deprec.}) + (\text{Resale Value})}{2}$$

$$= \frac{(8000) + (1867) + (2400)}{2} = \$\ 6{,}134$$

Fixed Costs:

Depreciation (Net cost over 3 yrs.)	=	$ 1,867
Interest (12% of Average Investment)	=	736
Insurance (2% of Average Investment)	=	123
Taxes (5% of Average Investment)	=	307
Total Fixed Costs		$ 3,033

Operating Costs:

Fuel - (50 mi./day) (1 gal./10 mi.) ($.75/gal) (134 days/yr.)	=	$ 503
Maintenance and Repair (75% of deprec.)	=	1,400
Oil and Lube	=	75
Tires (1 set of 4 per year)	=	240
Total Annual Operating Costs	=	$2,218
Total Annual Cost	=	$5,251
Total Daily Cost (@ 134 days/yr.)	+	$ 39.19

APPENDIX 9

Labor Costs for Yarder Crew (Hourly Wages)

Hooktender	$ 10.00
Yarder Engineer	9.50
Rigging Slinger	9.25
Chaser	6.50
Chokersetters (2)	6.00
Hourly Overhead and Fringe Benefits per Crew Member (6)	3.00

Total Daily Labor Costs:

[$46.25 + 6 (3.00)] x 10 hrs./day = $642.50