AN ABSTRACT OF THE THESIS OF

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in Forest Engineering presented on August 9, 1973

Title: SIMULATING SKYLINE YARDING IN THINNING YOUNG FORESTS

Abstract approved: Dean Edward Aulerich

Dean Edward Aulerich

Cable logging systems are being applied frequently in thinning young-growth forests, but the dynamics of these systems are relatively unknown. This study is part of a research project to develop aerial logging systems for thinning and to analyze them for economic, silvicultural, and environmental implications. The objectives of my study were:

1) To measure the influence of thinning intensity, slope steepness, load size, skyline distance, lateral rigging distance, and number of workers on yarding times.
2) To develop a model to simulate these relationships under varying working conditions of the skyline system and to identify proposals for improved logging methods.

I observed a cable-thinning operation on a 35-40 year old Douglas-fir stand on gentle and medium steep slopes. Three thinning intensities of 70, 50, and 20 percent, respectively, were applied. The skyline yarding work cycle was separated into six regular and

three irregular elements. I used the multimoment time study method to observe these elements and obtained values for the variables that influenced these elements.

Stepwise multiple linear regression analysis was used to analyze the effect of these variables on time required to finish an element. I developed regressions for four regular elements, carriage out, lateral out, lateral in, carriage in, and for total regular yarding time. Regressions with the observed variables did not produce adequate results for other elements. I analyzed only their frequency distribution. I tested the results of the analysis against a sample from the same yarding system in a different operation. Close correspondence in a chi-square and t-test, respectively, suggests the reliability of the regressions.

Several suggestions were made for modifications that may improve the skyline system. They concern hooking and unhooking, the cable configuration, and lateral yarding.

I developed a simulation model in the GPSS-computer language to simulate skyline thinning. The elements of the model can be modified to adjust to distinctive situations. I tested the influence of lateral yarding distance on total yarding time and simulated a regular approach with limited lateral yarding distance and a "line thinning" method.

Simulating Skyline Yarding in Thinning Young Forests

by

Hans-Ulrich Sinner

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Thank you everybody.

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Young Forests

I. INTRODUCTION

Douglas-fir type forests between 20 and 70 years old occupy 3.3 million acres (1.35 million hectares[1]) in western Oregon and Washington. They represent 23 percent of this forest type west of the Cascade Range summit and have an estimated volume of 37.9 billion board feet[2] (269 million cubic meters[3]) (Williamson and Price, 1971). This percentage and volume will increase as old-growth forests are cut and regenerated. Thinning is a basic tool to manage those stands. Internationally the aim of thinning is defined as follows (Ager and Fries, 1969):

> Thinning is an important feature of sustained yield forestry. Its aim is generally to improve the status and development of the remaining stand by means of a reduction of the number of stems. Another aim may be to supply a demand of wood, which cannot be covered by clear felling only.

Until recently forests have been thinned mostly by crawler tractors, rubbertired skidders, and skyline machinery adapted from equipment used in old-growth logging. Rowley (1970) has described the most commonly used ground-based machines. Akre (1967) and O'Leary (1970) have presented some of the skyline systems that are presently used for thinning on steep ground. Concern has increased about physical changes in soil and damage to remaining timber caused by skidders and tractors. In addition, the use of these machines is limited to gentle ground and fair weather. Hence, cable systems are

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[1] 1 acre = 0.4047 hectares

[2] Scribner log rule

[3] 1 cubic meter roundwood = 141 board feet

being applied more frequently in thinning young-growth forests.

The dynamics of small skylines are relatively unknown. Studies have been mainly oriented towards the mechanics of the systems (Lysons and Mann, 1967; Binkley and Lysons, 1968; Carson, 1970; Campbell, 1970). Factors as range, set up time, log volume per turn, production per day, and cost of systems have not been investigated for general use.

II. OBJECTIVES

Researchers at the School of Forestry, Oregon State University have recently started a research project to develop aerial logging systems for thinning and to analyze them for economic, silvicultural, and environmental implications. The project focuses on small mobile skylines and has three purposes (Froehlich and Aulerich, 1972):

1) To develop reliable basic data on production rates and harvesting costs of skyline systems for land managers planning to enter young stands in the future,
2) To learn how the operating efficiency of skyline systems may be increased, and
3) To determine the profitability of skyline and other logging systems when used to thin young stands.

My study is part of this project. It is limited to one skyline system and has the purpose of obtaining information about the use of this system in commercial thinning of young forests. Specifically it will:

1) Measure the influence of thinning intensity, slope steepness, load size, skyline distance, lateral rigging distance, and size of the working crew on yarding times for thinned material
2) Develop a model to simulate these relationships under varying working conditions of the skyline system and to identify proposals for improved logging methods.

In order to achieve these objectives I used the multimoment time study method to observe a skyline thinning show. I evaluated the time study data with a multiple linear regression analysis and built a model in the GPSS-language to simulate skyline yarding.

III. PROCEDURES

Area, Unit Layout and Thinning Regime

Personnel of the Forest Engineering Department conducted a thinning operation in the school forest during the summer of 1972. A 35-40 year old stand on site-III land was selected. It was stocked with Douglas-fir (Pseudotsuga menziesii Mirb.), sporadically mixed with Grand fir (Abies grandis (Dougl.) Lindl.). Some hardwood patches were intermingled with the conifers. The stand had a density of 200-230 stems per acre (500-570 stems per hectare)[4] and a volume of 10-14 Mbf[5] per acre (175-245 cubic meters per hectare) (Appendix A).

We chose three desired levels of removal, based on the spacing of remaining merchantable[4] trees:

Cutting intensity	Removal (percent)	Residual stems (per acre)	Residual stems (per hectare)	Average spacing (feet)	Average spacing (meters)
heavy	70	65	160	25 x 25	7.6 x 7.6
medium	50	109	270	20 x 20	6.1 x 6.1
light	20	170	427	16 x 16	4.9 x 4.9

We assigned a unit of 10-12 acres (4.0-4.9 hectares) for each thinning intensity on two slopes of 0-25 percent and 26-60 percent steepness. The units were named to express the thinning intensity (H=heavy,

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[4] Stems containing at least a 16 feet (4.88 meters) long log with a diameter (inside bark at the top end) of six inches (15.2 centimeters) or more.
1 foot = 0.3048 meter
1 inch = 2.54 centimeters

[5] Mbf = thousand board feet

M=medium, L=light), and the slope steepness (1, 2). The codes for the six units are (Figure 1):

On gentle ground (0-25% slope)	H1 M1 L1
On steep ground (26-60% slope)	H2 M2 L2

All stems producing a merchantable log were considered for thinning. The selection of trees to cut followed the rules for a selective type thinning (Douglas-fir Second Growth Management Committee, 1947). Specifically, trees were judged according to the following criteria (listed by priority) (Froehlich and Aulerich, 1972):

Leave: Better dominants and codominants

a) smaller dominants
b) large codominants
c) better intermediates to maintain spacing

Remove: Defective trees - crooks, sweep, poor form
Large limby dominants - wolf trees
Merchantable intermediates and overtopped
Better formed dominants and codominants to maintain spacing

A contract logger did all the logging work including selection of the trees according to these specifications. His workers generally followed the rules for selection of leave and cut trees, but did not reach the planned cutting intensities. After the logging had been finished the actual removal was closer to 60, 50, and 40 percent, respectively, instead of the planned 70, 50, and 20 percent (Aulerich and Johnson, 1973).

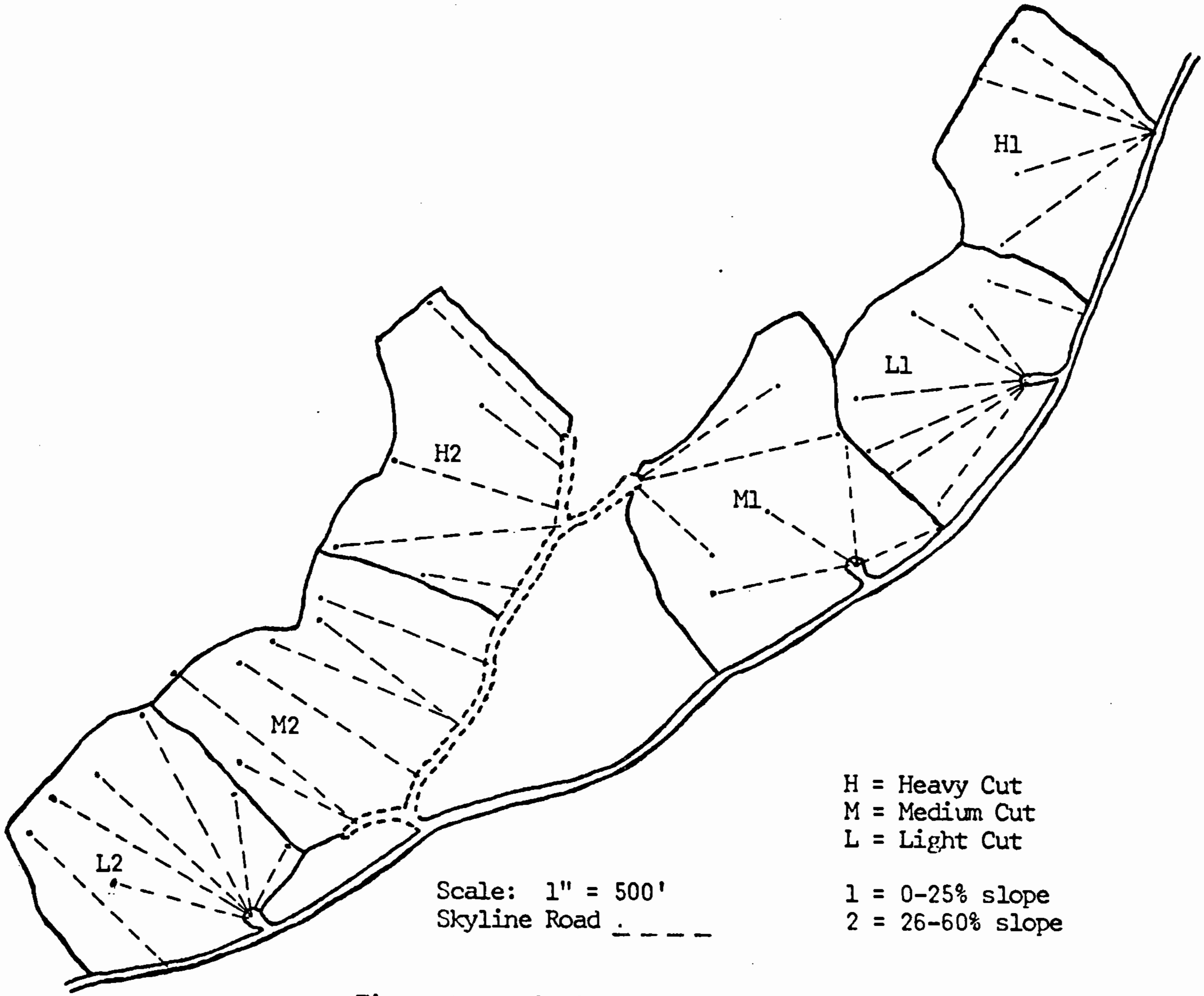

Figure 1. Thinning unit layout

The Yarding System

The contractor used a rubbermounted three drum yarding machine; a Schield-Bantam yarder T-350 with a 453-Detroit diesel engine. The machine was rigged as a slackline-skyline system for this operation, with haulback line, a Ross nonclamping carriage, and two or three chokers (Figure 2). Two guylines hold the yarder in place. A mechanism to block the mainline is built into the carriage. A ferrule near the end of the mainline snaps into this lock each time the mainline is pulled in. This arrangement causes a lift of the front end of a load hauled to the landing, while the rear end drags on the ground. The partial lift requires less power to pull a load and prevents hang ups by stumps, rocks, or other logs in the skyline road (Carson, 1970 (Figure 3). The lock has to be released by hand.

The carriage has no slackpulling device but the mainline serves as a loadline. All lateral linepulling must be done by hand.

The yarding system is specially designed for thinning and is a rather small unit by Pacific Northwest standards. Matching the purpose of logging small wood, the lines are relatively light:

Type	Length		Diameter	
	(feet)	(meter)	(inch)	(centimeter)
Skyline	1000	305	3/4	1.90
Mainline	900	275	5/8	1.59
Haulback line	1600	488	7/16	1.11
Chokers	10	3	1/2	1.27

In skyline thinning the yarder usually is located on a logging road. No special landing is built at the top of each skyline road.

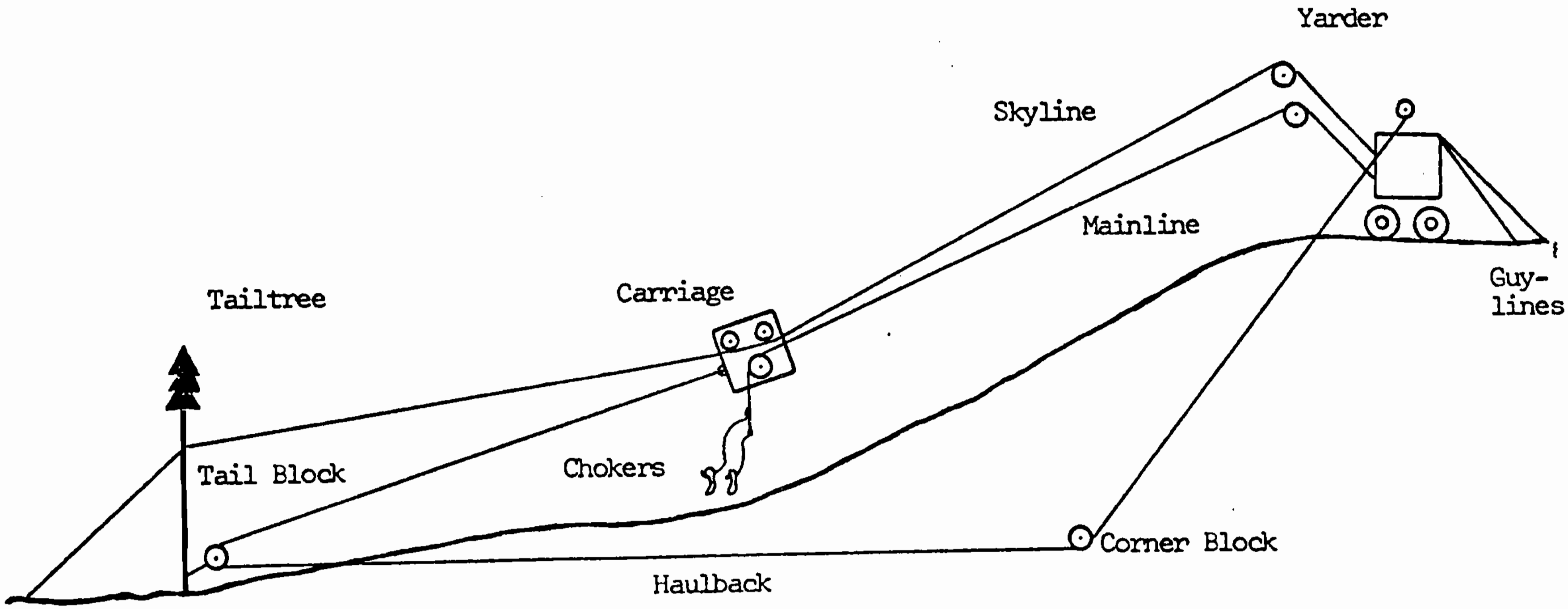

Figure 2. System Configuration

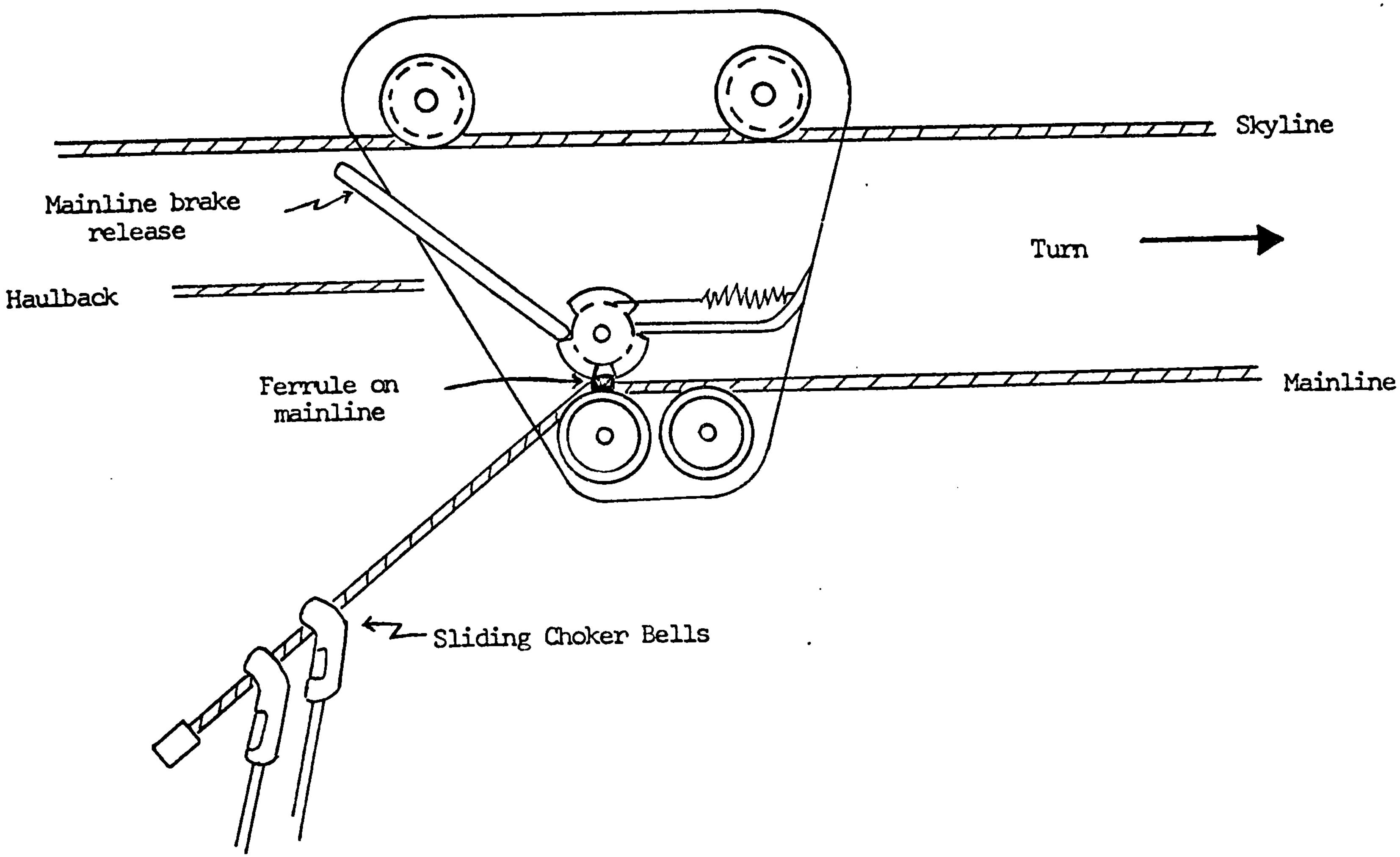

Figure 3. Carriage construction

The logs are decked on the downslope of the road. However, several special landings were built for this operation, partly to adjust the yarding system to the ground conditions in the units and partly to leave a buffer strip along the forest road (Appendix A).

Normally four persons are working with this system: a yarding engineer to operate the machine, a chaser to unhook the logs at the landing, and two chokersetters out in the woods. They communicate with a battery-operated single channel radio transmitter that sends signals to a whistle mounted on the yarder. The chokersetters wear this radio as a belt.

Time Study Analysis - The Multimoment Method

I selected time as the dependent variable for studying the yarding. Time can be accurately measured with simple tools and is equally related to both, man- and machine work. It is the basic measure to which other variables, like transported volume or operation cost, refer.

Motion and time studies are methods to record the time requirements for a given task. They are tools used to analyze factors influencing the execution of a work cycle, and to find a method nearest to an ideal that can be practically used. Barnes (1968, p. 5) describes their 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.

In a preliminary study to investigate the working cycle I decided to use the multimoment time recording method. This mode gives a definite result concerning the frequency percent of elements (KWF, 1970). At regular time intervals an observation is made on the element that is occuring, but the exact length of each activity in the working cycle is not recorded. This method is especially adapted for long observations, for studies with many elements, and for activities that are very short. The record sheet is a simple frequency list and easy to fill out (Figure 4, Appendix C). No calculations are necessary to obtain times for each element. The multimoment time study method equals the method of activity sampling (ILO, 1969) or work sampling (Barnes, 1956, 1968) described in American literature[6], but with regular time intervals between the observations. I prefer, however, the term used in Europe, multimoment method. An observer can use this method like other time study methods, to record the duration of each single element, if he uses a short time interval.

A time interval of 0.1 minutes was chosen. This interval is easy to observe on a decimal minute stopwatch. Time lengths for each element can be recorded with sufficient exactness. To test the accuracy of observations I noted start- and stop time of an observation period and controlled the conformity of the accumulated

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[6] Other names for this method are: snap-reading method (Tippett, 1934), ratio-delay study, observation ratio study, random observation method.

F911 SKYLINE YARDING

CREW:

DATE __________ SHEET ________

START: __________

STOP: __________

UNIT NAME ______________________

TURN NO.	CARR. OUT	LAT. OUT	HOOK	LAT. IN	RESET	CARR. IN	UN-HOOK	DELAY	TOTAL	SL DIST	LAT DIST	LAT SLOPE	NO. LOGS	TAG NO.	COMMENTS

Figure 4. Time Study Record Sheet

observations with the control time. Time studies with a deviation of more than three percent between both times are invalid (KWF, 1970). All my observations showed a maximum error of one percent.

Elements of the work cycle

Regular elements are defined portions of the total working cycle. They are variable elements that occur during every, or almost every, cycle. The elements that occur less frequently are called irregular, they interrupt the normal working cycle or happen in addition to it. Both regular and irregular elements are measured by the length of time required to complete the task connected with them. The general rules for breaking down a work cycle into elements are documented by Barnes (1968) and the International Labour Office (1969).

I arranged the work cycle skyline yarding into six regular and three irregular elements. The yarding cycle can be divided into numerous more elements (Chamberlain, 1965). I considered them as subactivities within the elements that were unimportant for the purpose of this study. The regular elements generally follow the standard activities that constitute a skyline operation (Binkley, 1965).

Carriage out

The yarding engineer raises the skyline to clear the landing. The carriage is pulled out by the haulback line or by gravity on steep slopes to a hooking area in the woods. The activity ends with the stop-signal from the rigging crew.

Rigging out lateral

The skyline is slackened, the chokersetters grab the chokers and open the lock in the carriage to release the mainline. Both pull the rigging to a proposed hooking site. Then they signal to stop the mainline drum.

Hooking

The chokersetters wrap steel cables, the chokers, around logs and hook the ends into the chokerbells. They then step back to safety and signal to pull the load in (end of the activity). This activity may be repeated until a full load has been assembled.

Rigging in lateral

The yarder pulls the load lateral towards the carriage at the skyline road until the ferrule on the mainline snaps into the carriage. The skyline is raised again during this activity. The haulback line is braked. It holds the carriage in place preventing damage to remaining timber along the skyline road.

Carriage in

The carriage with the load is pulled uphill towards the landing. The chokersetters spot out the next turn, then rest during this activity. The activity ends when the engineer slacks the skyline to place the load on the landing deck.

Unhooking

At the landing the load is swung on the deck, the skyline is slackened again, so that the chaser can open the choker hooks to release the logs. He signals to the engineer that the work cycle can be restarted, when he is back in safety.

Reset

This is an occasional element that occurs irregularly. It interrupts the activities rigging in or carriage in, when an obstacle (e.g. a stump, or standing tree) forces a change in the load or re-arrangement of the chokers. The reset state ends after the choker-setters have restored normal conditions and the interrupted element can continue (e.g. after the skyline is raised again).

Delay

Delays are foreign elements within a work cycle that occur at random. Two types of interruptions were distinguished: operational delays and downtime. Operational delays are relatively short breaks in the yarding cycle, caused by men or machine. Downtime is chiefly caused by major equipment failures that force the working crew idle, to repair work, or do other tasks. For this study I considered each interruption of more than ten minutes duration as downtime.

Moving

The moving activity occurs when a number of working cycles have been finished. After all logs that can be reached from one skyline road have been yarded, the lines are released and wound on their drums. The yarder then moves to the next landing. There it is secured with guylines. The entire crew, except the yarder engineer, pulls the skyline and haulback line to the end of the skyline road and riggs the tail tree.

I developed a man- and machine chart to show for each activity the task of each worker and for the yarding machine (Figure 5).

Variables

A huge number of variables can influence cable yarding. Chamberlain (1965) listed 26 directly measurable variables influencing high-lead logging. For the purpose of this study values for only seven variables were obtained. Other factors were either difficult to measure and considered unimportant to this study (weather, ground vegetation) or were kept constant throughout the study (horsepower of yarder, diameter of lines). The seven variables were defined as follows:

Skyline distance

The length on the slope of each skyline road. I had measured this distance in advance and marked trees along the road every 50 feet. During the yarding operation I recorded the distance the carriage was pulled out from the yarder to a hooking area. I estimated the range between the 50-feet marks to the closest ten feet.

Operation	Chokersetter (2)	Chaser	Yarder engineer	Machine
CARRIAGE OUT	Watch carriage, give stop-signal	Idle	Raise skyline, control speed of carriage	Tension skyline, in-haul haulback line, outhaul mainline
LATERAL OUT	Signal to drop skyline, unlock mainline, pull rigging out lateral	Idle	Drop skyline, control mainline drum	Release skyline, outhaul mainline
HOOKING	Set chokers on logs, step to safety, signal inhaul	Idle	Idle	Idle
LATERAL IN	Observe inhaul, signal if load reaches carriage	Idle	Raise skyline, control mainline speed, brake haulback line	Tension skyline, inhaul mainline, brake haulback line
CARRIAGE IN	Spot out next turn, idle	Idle	Control mainline speed, deck load	Inhaul mainline, outhaul haulback
UNHOOKING	Idle	Climb landing deck, unhook logs, return to safety, signal	Drop skyline, idle	Release skyline, idle
RESET	Rearrange load	Idle	Control lines and tension	Lines out and in, skyline released and tensioned
DELAY	Equipment-idle Other-depends on case	Equipment-repair Other-depends on case	Equipment-repair Other-depends on case	Equipment-cause of delay; other-idle
MOVING	Take down tail tree, move equip., pull lines out, rigg up tail tree	Loosen guy lines, help pulling lines out, strain guylines	Control line inhaul, move yarder, control line outhaul	Inhaul all lines, move to new landing, outhaul all lines

Figure 5. Man- and Machine Chart - Elements in Skyline Yarding

Lateral distance

The angular distance, which the rigging was pulled out from the carriage to a hooking site, not the distance in a right angle to the skyline road. I estimated this range to the closest ten feet. For longer lateral distances I used a selfwinding tape-measure.

Lateral slope

The slope direction the rigging was pulled out. I determined this variable in part of the observations only in three classes, uphill, sidehill, and downhill.

Number of logs per turn

The load size of each turn that was hooked, pulled in lateral and hauled to the landing. I recorded the number of logs that were actually yarded, but did not include logs that eventually slipped off the choker and were not reset.

Slope steepness

The inclination of the ground along a skyline road. A surveying class from the School of Forestry calculated slope steepness in percent for each road[7].

Actual thinning intensity

The percent of stems removed in comparison to the original stand.

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[7] Conversation with Robert L. Wilson, Associate Professor of Forest Engineering, OSU.

Professor Johnson imparted these values for each unit[8].

Crew size

The number of workers occupied with the system.

I recorded 685 skyline yarding turns during summer and fall 1972, with a minimum of 50 turns in each study unit. To obtain adequate information about all variables and about the irregular elements, I tried to record times over longer periods, preferably half or whole working days.

[8] Conversation with K. Norman Johnson, Assistant Professor of Forest Engineering, OSU.

IV. DATA ANALYSIS

Time Study Results

In a first evaluation of the data I calculated mean values of all variables for each unit. The means of independent variables give the average logging characteristics in a unit during the time study (Table I). For all 685 observations in all units they were:

Skyline distance	310 feet (95 meters)
Lateral distance	50 feet (15 meters)
Load per turn	2.5 logs
Cutting intensity	50 percent
Slope steepness	21 percent

The means of the dependent variables are the time requirements for each element of the yarding cycle under average logging conditions in a unit (Table II). Together they add to the total yarding time per turn. Each element requires a given percentage of this total time (Table II). The skyline yarding turn averaged approximately 7.5 minutes. Twenty-six percent of this time accounted for yarding along the skyline. Lateral yarding and hooking plus unhooking consumed 27 percent each. Resets and delays used up the remaining 20 percent.

TABLE I. CHARACTERISTICS OF STUDY UNITS

CHARACTERISTIC	STUDY UNIT H1	M1	L1	H2	M2	L2	Average
Actual cutting intensity (percent)	60	48	38	65	55	37	50
Slope steepness (percent)	14.2	16.2	7.5	31.7	31.3	24.5	20.9
Average skyline distance (feet)	290.1	195.5	158.0	257.1	474.5	490.0	310.9
(meters)	88.4	59.6	48.2	78.4	144.6	149.3	94.8
Average lateral distance (feet)	46.5	47.0	40.6	46.6	50.1	65.8	49.5
(meters)	14.2	14.3	12.4	14.2	15.3	20.1	15.1
Average number of logs per turn	2.3	2.4	2.7	2.0	2.9	2.9	2.5
Maximum skyline distance (feet)	540	390	420	620	650	620	540
(meters)	165	119	128	189	198	189	165
Maximum lateral distance (feet)	200	180	140	250	130	170	178
(meters)	61	55	43	76	40	52	54
Number of skyline roads	4	7	7	5	6	7	6
Area in skyline roads (percent)	8	8	10	8	10	13	9.5
Number of observations	148	71	65	270	76	55	114

TABLE II. AVERAGE SKYLINE YARDING TIME IN MINUTES AND PERCENT, BY ACTIVITY AND UNIT

ACTIVITY		STUDY UNIT H1	M1	L1	H2	M2	L2	Average
Carriage out	(min)	0.85	0.62	0.43	0.76	1.00	0.97	0.77
	(percent)	11.81	9.17	6.86	12.46	11.24	9.62	10.19
Lateral out	(min)	0.91	1.14	1.03	0.76	1.25	1.30	1.06
	(percent)	12.64	16.86	16.43	12.46	14.04	12.90	14.04
Hooking	(min)	0.80	1.18	1.52	0.84	1.78	1.98	1.35
	(percent)	11.11	17.46	24.24	13.77	20.00	19.64	17.88
Lateral in	(min)	0.90	0.93	0.68	0.68	1.08	1.65	0.99
	(percent)	12.50	13.76	10.85	11.15	12.13	16.37	13.11
Reset	(min)	0.54	0.71	1.11	0.40	0.80	0.99	0.76
	(percent)	7.50	10.50	17.70	6.56	8.99	9.82	10.07
Carriage in	(min)	1.09	0.87	0.72	1.04	1.74	1.62	1.18
	(percent)	15.14	12.87	11.48	17.05	19.55	16.07	15.63
Unhooking	(min)	0.80	0.58	0.46	0.94	0.87	0.69	0.72
	(percent)	11.11	8.58	7.34	15.41	9.78	6.85	9.54
Delay	(min)	1.31	0.73	0.32	0.68	0.38	0.88	0.72
	(percent)	18.19	10.80	5.10	11.15	4.27	8.73	9.54
Total turn	(min)	7.20	6.76	6.27	6.10	8.90	10.08	7.55
	(percent)	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Activity	Average time (minutes)	Average time (percent)
Carriage out	0.77	10.19
Carriage in	1.18	15.63
Lateral out	1.06	14.04
Lateral in	0.99	13.11
Hooking	1.35	17.88
Unhooking	0.72	9.54
Reset	0.76	10.07
Delay	0.72	9.54
Total	7.55	100.00

Regression Analysis

The objective of data analysis is to discover the influence of factors that were observed in an experiment on the dependent variable. Regression equations relate independent and dependent variables to each other as approximation of an assumed functional interaction that may or may not exist (Draper and Smith, 1966; Landschuetz, 1967). A regression equation can be described as a mathematical model that shows the coherence between observed data.

I used a standard computer program available at Oregon State University, *STEP, to generate regression equations for the activities in skyline yarding. This program executes a stepwise linear regression analysis of up to 80 variables (Yates, 1969).

For practical consideration I limited the number of steps in each final regression equation to four and let variables rise to the second power only. A logging engineer can use the resulting functions for hand calculations when planning his yarding operation.

As all observations were from the same machine and similar working conditions, I set a 0.05 probability level to define significance of variables. This is a high probability level for field observations, where numerous uncontrolled factors can affect variation. I used a F-test to define the statistical significance of the reduction in variance of each variable that had entered the regressions. Many variables were also significant at the 0.01 probability level[9].

The regression equations were significant for four elements of the yarding cycle,

Time carriage out (Y_1)

Time lateral out (Y_2)

Time lateral in (Y_4)

Time carriage in (Y_5)

and for total yarding time per turn (Y_9), a variable that combines all six regular elements of the work cycle. All times are expressed in 1/10 minutes[10].

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[9] In the following regression equations,

** indicates significance of a variable at the 0.01 probability level,

* indicates significance of a variable at the 0.05 probability level.

[10] Move the decimal point of all coefficients, including constant, in an equation one digit to the left to express time values in minutes.

Nomenclature - Range of independent variables

Variable	Code	Range of variable
Skyline distance	D	0-650 feet
Lateral distance	L	0-200 feet
Number of logs per turn	N	1-5 logs
Slope steepness	S	0-36 percent
Actual thinning intensity	I	37-65 percent
Crew size	C	3-5 men
Time required to fulfill activity j	Y_j	----
Multiple correlation coefficient	r	----
Standard deviation of the regression	s	----

Carriage out (Y_1)

$$Y_1 = 2.522 \qquad r = 0.78951$$

$$+ 0.0208\,(D + S)^{**} \qquad s = 1.65362$$

$$- 0.000013\,D^2\ ^{**}$$

$$+ 0.00035\,S^2\ ^{*}$$

Time required to pull the carriage out depends on the skyline distance the carriage is hauled out and on slope in the skyline road. Time increases on steeper slope (Figure 5). Speed of the carriage depends mainly on the inhaul velocity of the haulback line. With steeper ground, however, friction and relative weight of this line increase. This effects the inhaul-speed of the haulback line and slows down the carriage. An additional reason might be that the operator reduced the speed of the lines on steep ground to control the movement of the carriage better and to stop it at the required point.

<u>Rigging out lateral</u> (Y_2)

$$Y_2 = 5.51 + 0.216\,L^{**} - 0.00059\,L^2\,^{**} - 0.00114\,I^2\,^{**}$$

$r = 0.85263$

$s = 3.79716$

Heavier cutting reduces lateral pulling time, as it is easier to move through a wide spaced stand (Figure 6). Because the system requires manual slack pulling, the chokersetters have to pull the full length of mainline, when moving laterally (Figure 2). For this reason I had originally considered two more factors as significant variables: skyline distance and lateral slope. Yet, both factors proved insignificant in the regression analysis and were eliminated in the final regression. From my observations, I explain this as follows: the workers move at the same pace under any circumstances. But they work harder when pulling slack at a hooking area further down the road or uphill from the skyline road (diamond leading).

<u>Rigging in lateral</u> (Y_4)

$$Y_4 = -\,0.5349 + 0.1774\,L^{**} + 0.6774\,N^{**} + 0.013\,(L \times N)^{**} - 0.00053\,L^2\,^{**}$$

$r = 0.83385$

$s = 4.12758$

The curve for both, rigging out and rigging in, follows a parabola with zenith close to the maximum lateral yarding distance (Figure 6, 7). Rigging out combines the subactivities: drop the

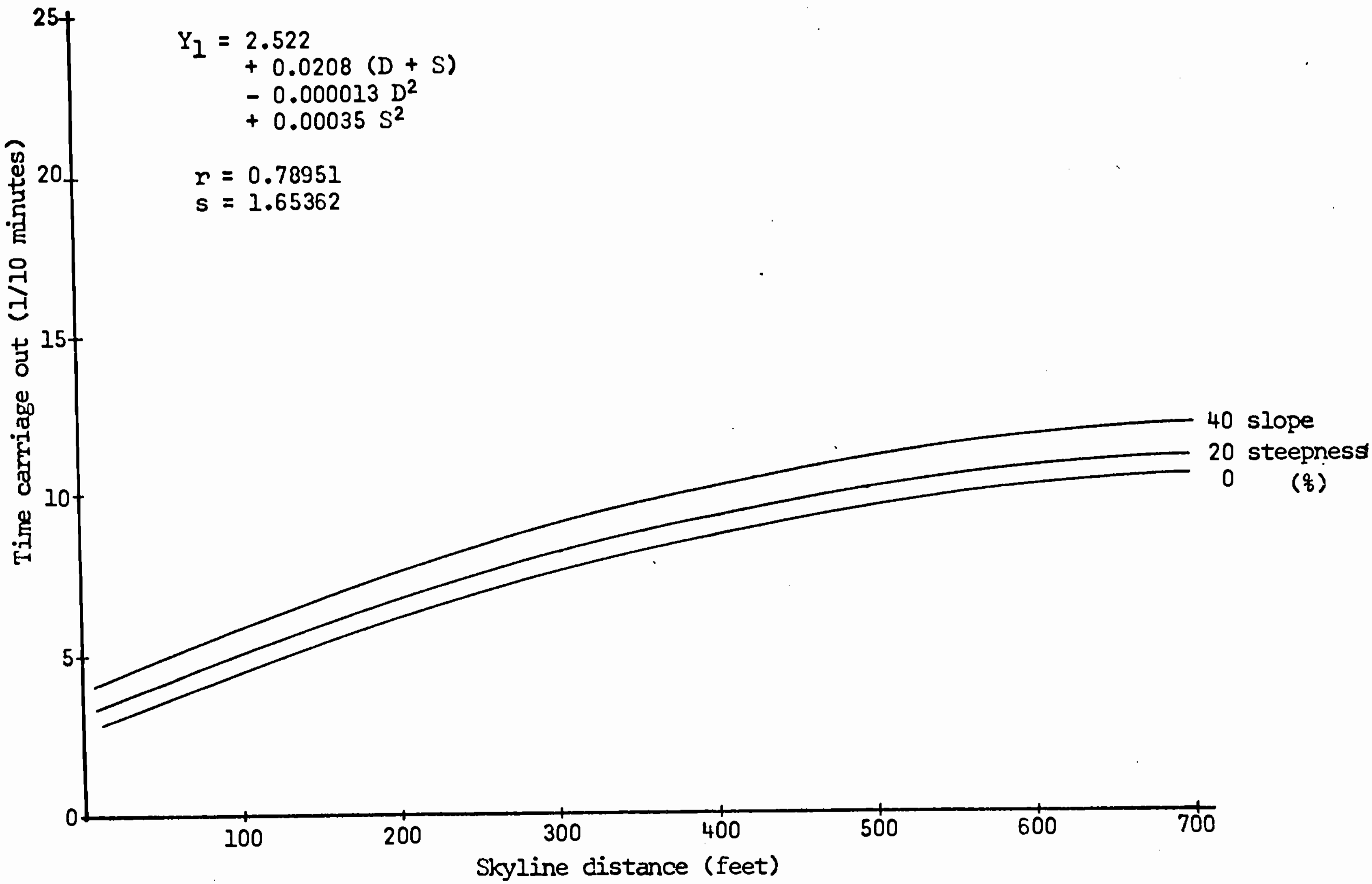

Figure 6. Time carriage out by skyline distance and slope steepness

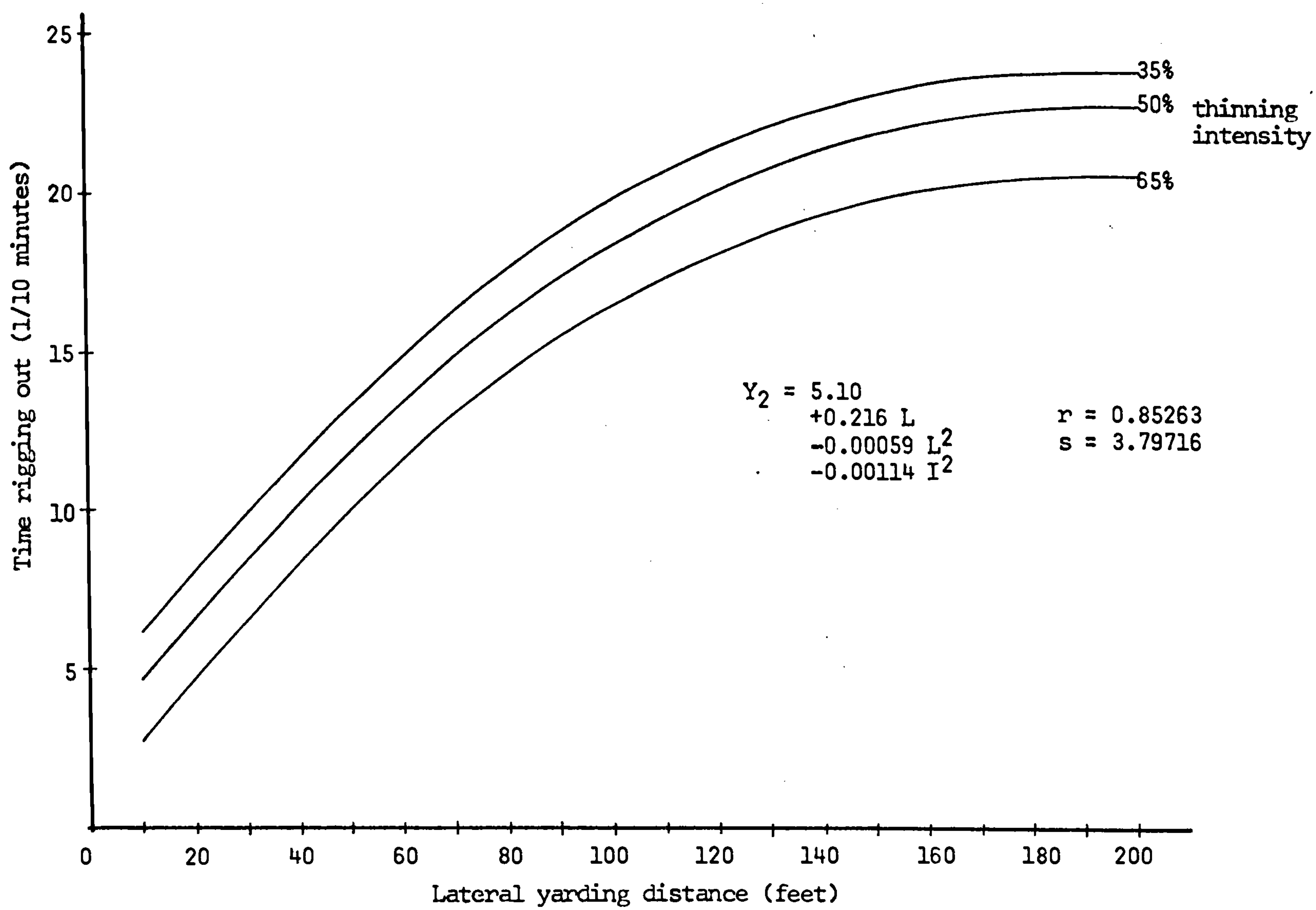

Figure 7. Time rigging out lateral by lateral distance and thinning intensity

skyline, grab the chokers, open the lock in the carriage, and pull the rigging to a log. Rigging in contains: raising the skyline, braking the haulback line, building up tension in the mainline, and finally pulling the load in. Subactivities, other than actual movement of the rigging from or to the skyline, are almost constant in either case. They are basic parts of the elements, but they account for relatively less time in the total activity, if a longer lateral distance occurs. This explains the shape of the regression function for both elements.

Carriage in (Y_5)

$$Y_5 = 1.9313 + 0.0257\,D^{**} + 0.4346\,N^{**} + 0.0362\,S^{**}$$

$r = 0.81363$

$s = 3.06641$

The regression equation shows a straight linear relationship between time and skyline distance, slope, and load size (Figure 8): for a given skyline distance, inhauling time increases if slope becomes steeper or the load heavier. This increase in time is small, with a maximum difference around 3/10 of a minute. The yarding machine has sufficient power to pull a large load up steep slopes. But large loads lengthen loading times, as the load has to be gathered in several steps in thinning. They also cause damage to the remaining stand, when logs laying in different angles to the skyline road are hauled in laterally as one turn. A load size of three or four logs, however, should be utilized whenever possible to achieve high

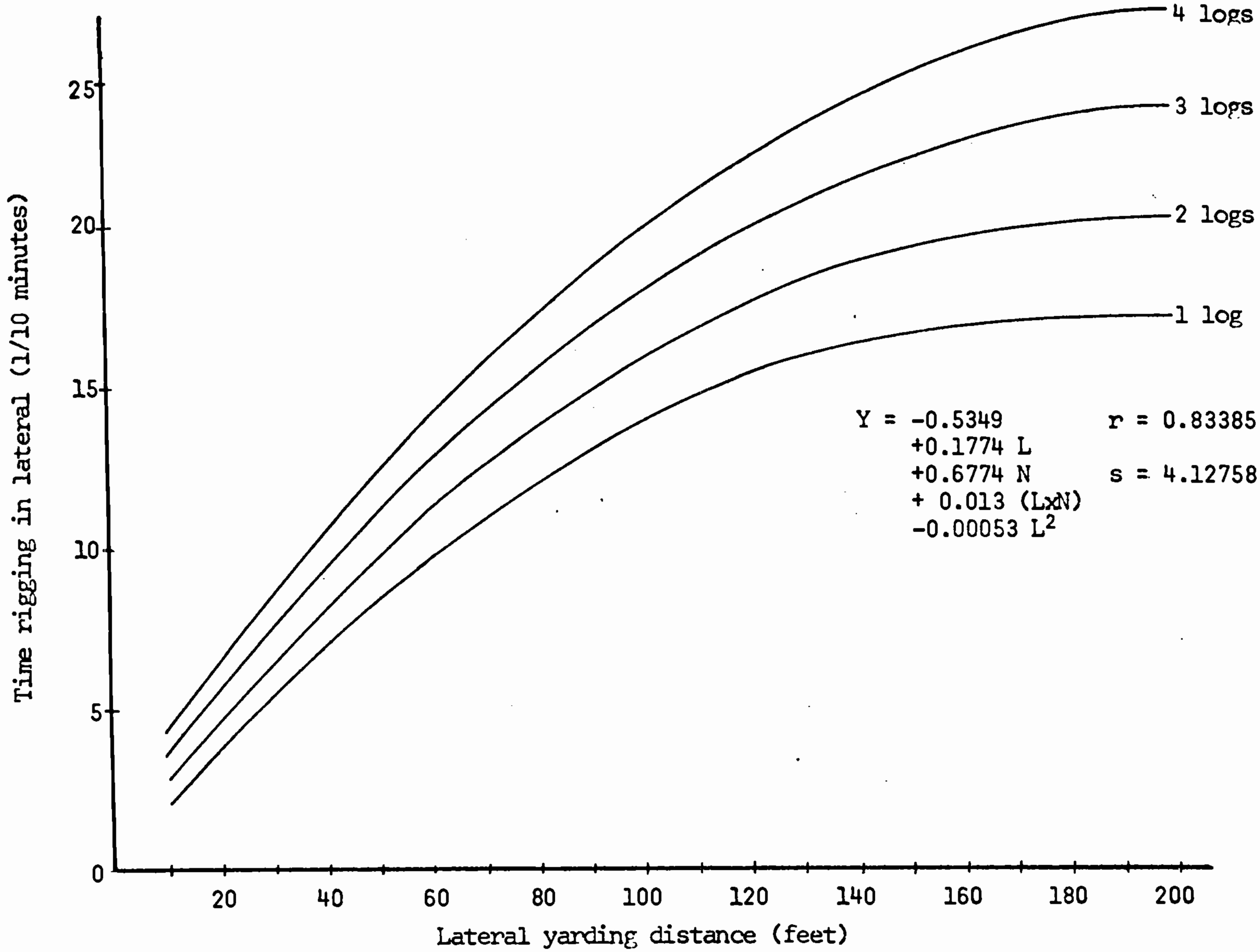

Figure 8. Time rigging in lateral by lateral distance and load size

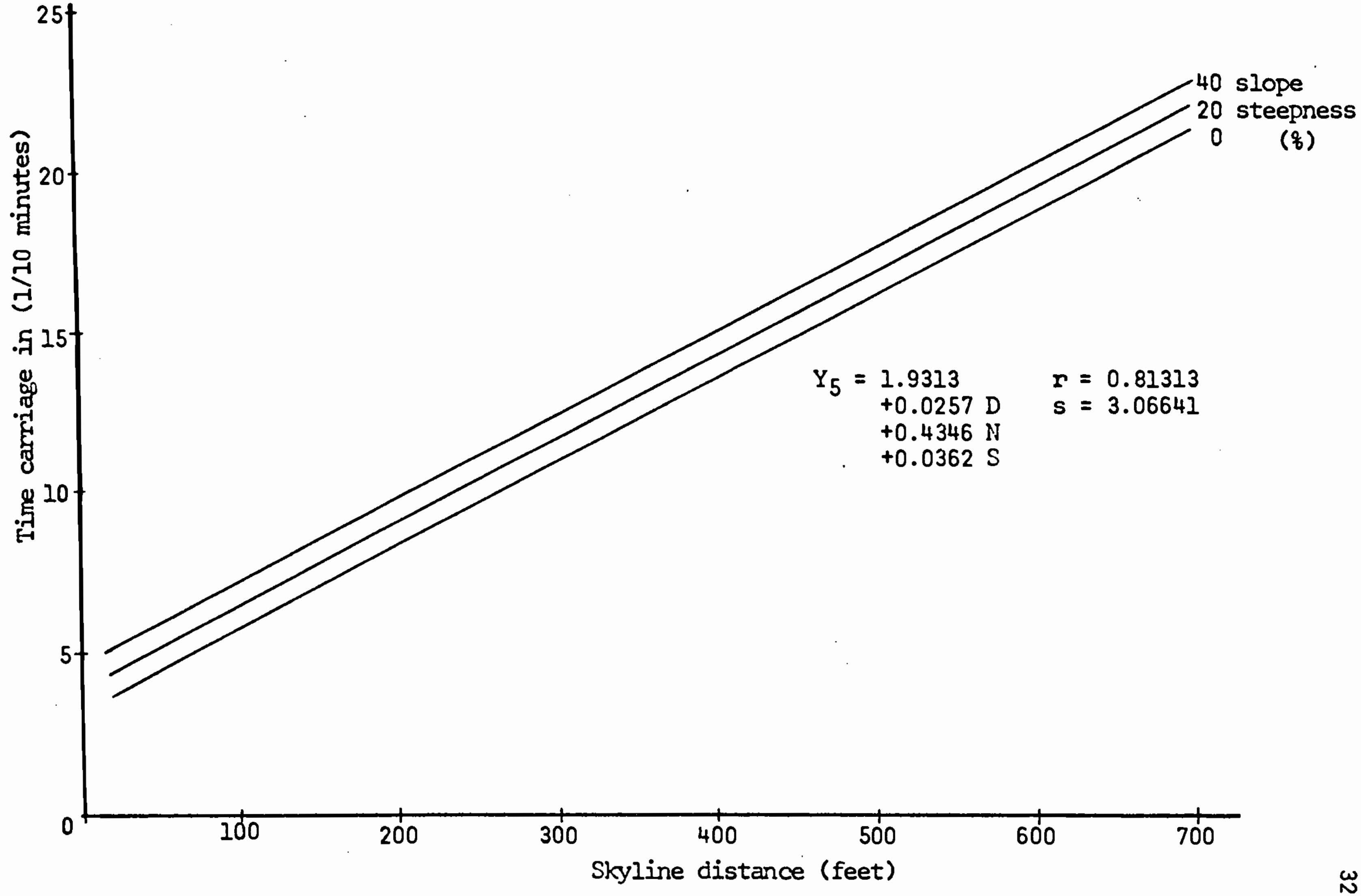

Figure 9. Time carriage in by skyline distance and slope steepness - three logs per load

production rates for the system. The increase in time caused by yarding loads of this size is negligible compared to total turn time.

Total yarding time (Y_9)

The regression equation for total yarding time comprises all elements but the irregular ones, reset and delay. It is established on all factors that were recorded during the entire time study.

$$Y_9 = 44.0479 + 0.0605\,D^{**} + 0.2359\,L^{**} + 6.0140\,N^{**} + 0.1605\,S^{**} - 0.2090\,I^{**} - 5.7036\,C^{**}$$

$r = 0.83213$

$s = 11.82696$

This equation contains crew size as a variable. During a few observations the normal crew size of four workers was reduced and no chaser was available. The yarder engineer then left his place to unhook the chokers, after hauling the turn in and swinging it to the deck. The engineer alone was almost as fast as the chaser in these observations. During a few other turns, a fifth worker joined the crew and helped to pull the rigging out. In both cases crew size turned out to be an insignificant factor in the regressions for rigging out and unhooking, respectively. However, crew size becomes significant when the whole yarding cycle is analyzed and small time fractions are summed.

This equation is a valuable aid for estimating average yarding times. I compared observed average times in each study unit with the predicted results from the total time equation under the same logging conditions as in Table I. As the regression equation does not consider resets and delays, I added the time accounted for these elements during the time study (Table II) to the values calculated by the regression equation. The results for each unit and for the average of all observations show a close correspondence between observed and predicted results (in 1/10 minutes):

Unit	Total time per turn observed	Total time per turn predicted
H1	72.0	71.6
M1	67.6	65.0
L1	62.7	61.7
H2	61.0	62.5
M2	89.0	83.8
L2	100.8	98.4
Average	75.5	71.3

A person planning a thinning operation can chose figures for the factors skyline distance, lateral distance, number of logs per turn, crew size, slope, and thinning intensity and insert them in the equation. The factors depend partly on the conditions of the area he is planning to thin, partly on the yarding equipment he will use, and partly on his conception about thinning intensity, lateral yarding distance, or logs per load. On the basis of total yarding time per turn, one can compute the number of logs yarded and their volume per hour or per day. These production rates again are prerequisite for cost- and return calculations.

As an example, I computed production rates per hour and per day[11] in each study unit under average logging conditions as before. The number of turns per day varies between 48 and 77 in the units. Between 139 and 208 logs are yarded daily. This figure depends extensively on the average load size per turn. Volume per log throughout the study varied little around an average of 51.5 board feet (0.35 cubic meters)[12]. Calculated volume production is 1082 board feet (7.7 cubic meters) per hour, 8652 board feet (61.4 cubic meters) per day on the average (Table III).

Analysis of other Elements

The stepwise analysis did not produce adequate results for the two elements hooking and unhooking. The variables I considered in this study did not explain a sufficient part of variation in the data for these two elements. The irregular elements, reset, delay, and moving, did not occur with enough frequency to make a regression analysis possible.

Hooking

I had considered thinning intensity, slope, and number of logs to hook as factors influencing hooking time. However, several runs of the program with combinations of these factors did not produce adequate results. During the time study I recognized other factors

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[11] Eight hour working day

[12] Communication with K. Norman Johnson, Assistant Professor of Forest Engineering, OSU. Volume was computed from log scaling tickets.

TABLE III. PREDICTED HOURLY AND DAILY TIMBER PRODUCTION[1]

		STUDY UNIT					
	H1	M1	L1	H2	M2	L2	Average
Time per turn predicted[2] (minutes)	7.16	6.50	6.17	6.25	8.38	9.84	7.13
Logs per turn	2.3	2.4	2.7	2.0	2.9	2.9	2.5
Turns per hour	8.4	9.2	9.7	9.6	7.2	6.1	8.4
Logs per hour	19.3	22.1	26.2	19.2	20.9	17.7	21.0
Volume per[3] hour (board feet)	995	1137	1349	989	1075	911	1082
(cubic meter)	7.1	8.1	9.6	7.0	7.6	6.5	7.7
Turns per day[4]	67	73	77	76	57	48	67
Logs per day[4]	154	175	208	152	165	139	168
Volume per[3,4] day (board feet)	7931	9012	10707	7828	8498	7158	8652
(cubic meter)	56.2	63.9	75.9	55.5	60.3	50.8	61.4

[1] Under average logging conditions as shown in Table 1
[2] Including reset and delay as shown in Table 2
[3] 1 cubic meter - 141 board feet
[4] Eight-hour working day

that may influence the variance in the data. For instance, a log that had partly penetrated the ground was more difficult to hook. In other cases, the rigging was not pulled out far enough and the chokersetter had difficulties reaching a log. But thinning intensity, slope, and number of chokers used caused differences in time required to wrap chokers around logs and build a load: In units H1 and H2, the system worked with two chokers only, whereas in all other units three chokers were used. In H1 and H2 the average load was 2.3 and 2.0 logs and required 0.8 and 0.84 minutes, respectively. For all other units the average load was 2.725 logs, requiring 1.6 minutes for hooking.

A comparison of average hooking time per log suggests influence from the factors cutting intensity and slope steepness. In heavy thinnings it was easier to locate a turn of logs and walking was simpler on flat ground.

Unit	Average load per turn (logs)	Average hooking time per turn (1/10 minutes)	Time per log (1/10 minutes)
H1	2.3	8.0	3.5
M1	2.4	11.8	4.9
L1	2.7	15.2	5.6
H2	2.0	8.4	4.2
M2	2.9	17.8	6.1
L2	2.9	19.8	6.8
Average	2.5	11.3	4.5

Unhooking

One factor caused exceptional variation in unhooking, height of the landing deck. As more logs were hauled in and decked, the chaser had to climb the log pile to unhook a turn. This was extremely dangerous as the logs lie loose and may roll off if weighted. This factor increased unhooking time considerably, especially towards the end of a skyline road when most logs had been hauled out. The problem did not occur during the preliminary study, so that I did not recognize it. Besides, measurement of the deck would have required a second person taking times at the landing, while I was alone and observed all activities from the hooking area in the forest. During part of the study the contract logger put an International S7-Hough articulated-frame skidder on standby at the landing. The chaser used it to swing logs to cold decks along the logging road. However, it was idle most of the time. I do not consider this as an adequate solution, as it requires additional log-handling and an expensive machine.

The frequency distribution for both hooking and unhooking in 0.5 minutes time-intervals resembles a standard frequency distribution (Figure 10, 11). I used a chi-square test for goodness of fit with a binomial-, Poisson-, lognormal-, and negative exponential distribution, but could not obtain sufficient conformity at the 0.05 probability level (Linder, 1960; Hengst, 1967).

Reset

Resets occur irregularly during the activities rigging in lateral, and carriage in. Turns that were hauled in laterally were blocked by a tree or stump. Logs slipped out of chokers that had not been

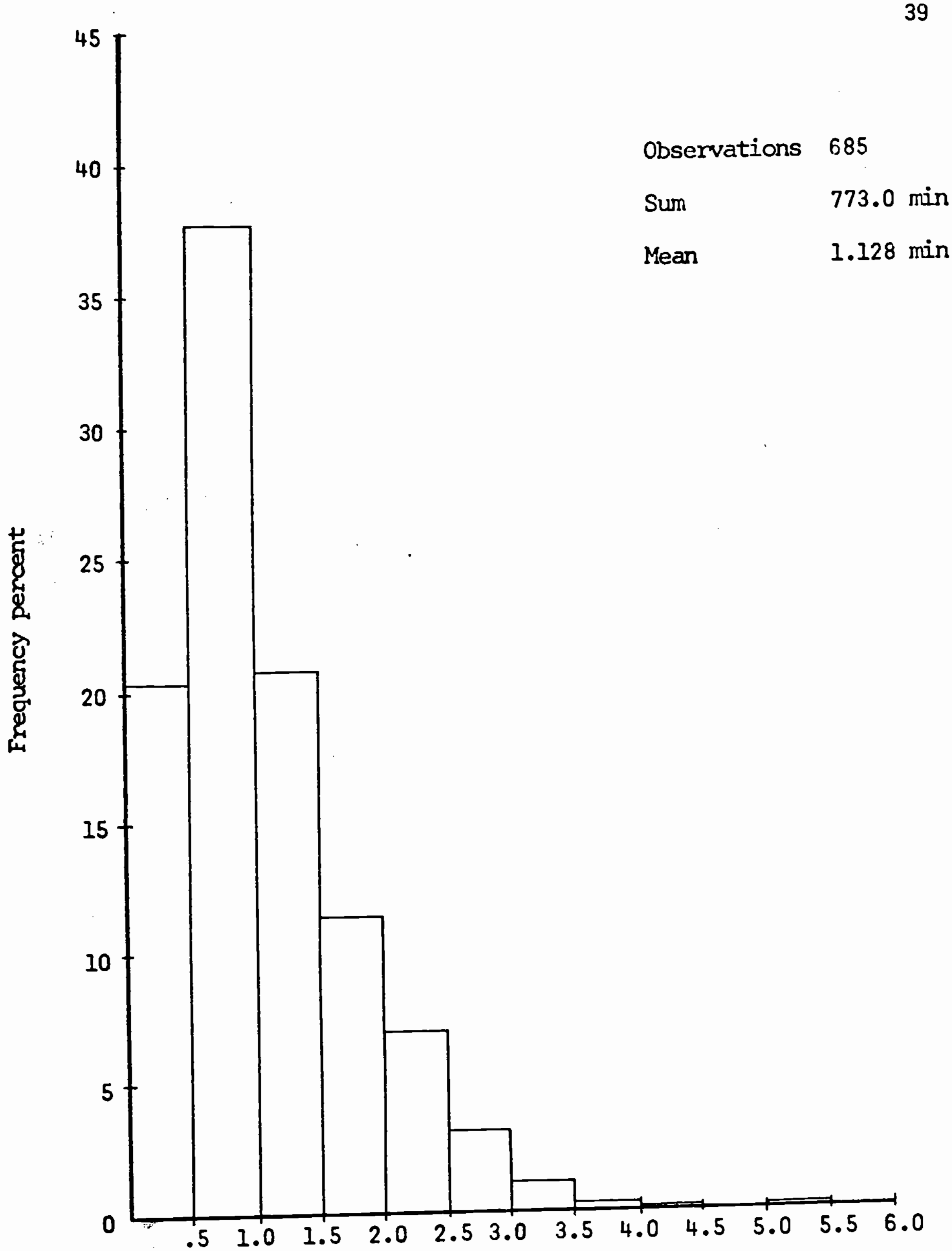

Figure 10. Frequency distribution of hooking time
0.5 minutes intervals

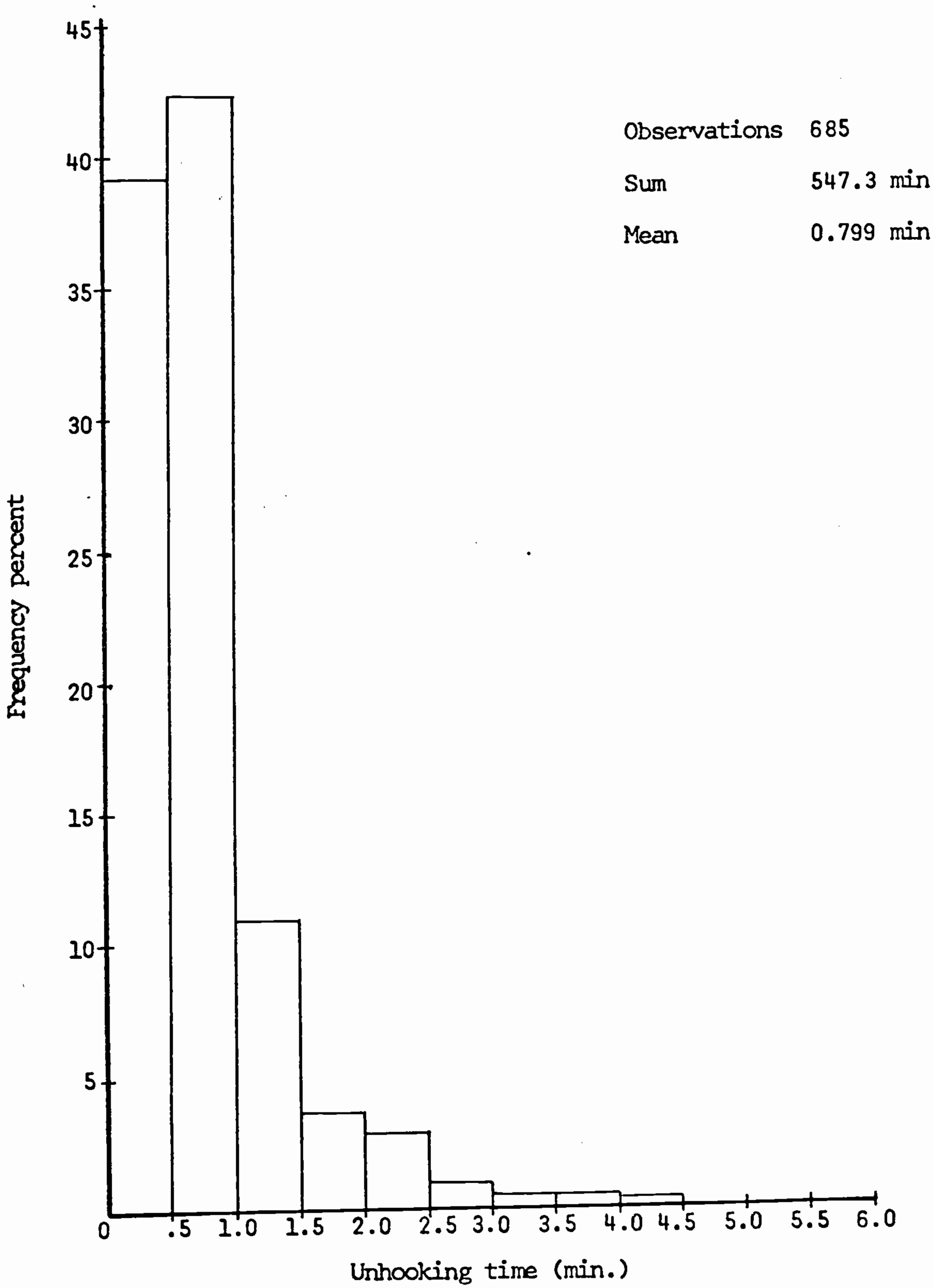

Figure 11. Frequency distribution of unhooking time 0.5 minutes intervals

wrapped tight enough. Also, logs of an incoming turn might be too long to swing from the lateral direction into the skyline road, but would rub standing timber and would be in danger of breaking. The process was interrupted then and chokersetters moved in to reset the chokers. In other turns, the load was pulled backwards by the haulback line to allow for a wide turning radius.

In light thinning with narrow skyline roads and a dense remaining stand, more chances for resets are inherent. The amount of turns in the study requiring resets varied from 34 percent in one heavy cut unit to 57 percent in a light cut unit. Long lateral yardings in light thinnings may have had several resets. Therefore this element does not only occur more frequently, but also requires more time in light cuts:

Unit	Percent of turns requiring resets	Percent of total turn time	Average time per reset (1/10 minutes)
H1	39.2	7.5	13.7
M1	43.7	10.5	16.8
L1	56.9	17.8	19.6
H2	33.7	6.6	12.0
M2	48.7	9.0	16.5
L2	56.4	9.8	17.6
Average	41.6	8.8	15.0

The frequency distribution for reset times in 0.5 minutes intervals fits a negative exponential distribution (Figure 12) at the 0.05 probability level. Its value is:

$$Y_7 = p(X) = 1.45 \times e^{-1.45 \times 0.5}$$

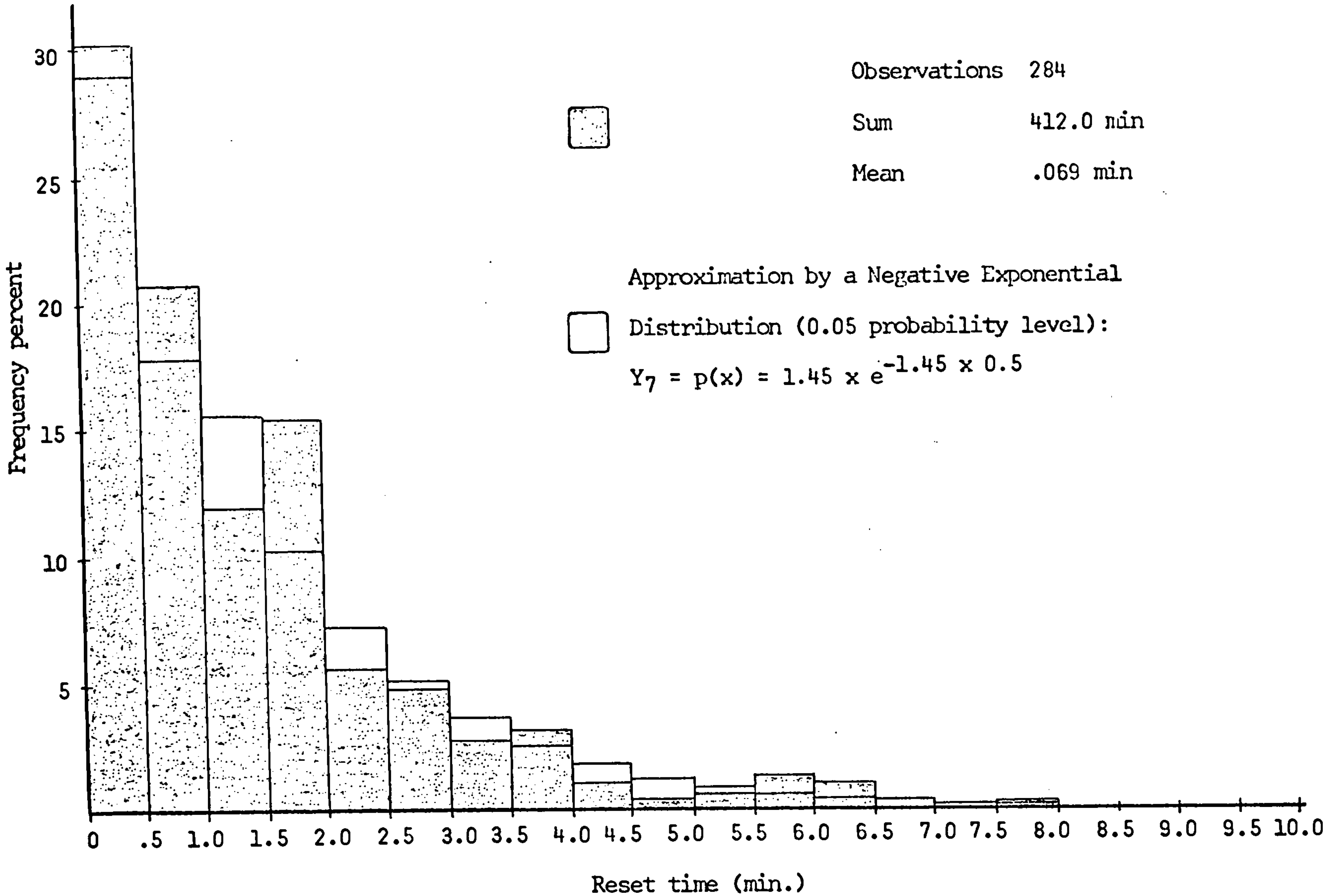

Figure 12. Frequency distribution of reset time - 0.5 minutes intervals

Delay

Throughout the time study I recorded 169 delays, one every four turns. Together, delays consumed 11 percent of all time. This is not entirely true as several longer interruptions ended the observations. The yarder was down for a few days with a broken hydraulic system, preventing any observations. Most of the other downtimes were failures in the cable system as broken or stranded lines, or difficulties with the hydraulic wind friction.

Downtime elements seem to appear at random. They depend on factors like age of the equipment, quality of maintenance, or frequency of overstrain of the machine. These factors are hardly measurable in the time study. I therefore limited the analysis of delay to the values that had been observed during the time studies. The origin of these elements may be human, such as interruption by a supervisor, or a crew not ready at the working place. Other interruptions were caused by the equipment, as short repairs or maintenance periods at the machine. Many of the latter breaks originated in the winch system, if lines were not wound correctly on the cable drums.

A delay averaged 2.65 minutes. Only two observations were longer than 12 minutes, 21 and 26.2 minutes, respectively. The frequency distribution of delays follows closely a negative exponential distribution with the value

$$Y_8 = p(x) = 0.416 \times e^{-0.416 \times 0.5}$$

if the time values are grouped in 0.5 minutes intervals (Figure 13). However, the two frequency distributions did not reach the required conformity at the 0.05 probability level in a chi-square test for goodness of fit. This is mainly due to a peak in the distribution of delays in the 11- and 12-minutes interval (Figure 13).

Moving

Changing the skyline road took between 45 minutes and two hours. The average time was one hour to haul all lines in, move the yarder to a new landing position, pull the cables out again, and tighten the lines. An important factor in moving time is the ground profile of the skyline road. A tail tree was needed on straight or convex slopes to provide for adequate deflection of the skyline and ground clearance of the load. Climbing and rigging a tail tree added 30-45 minutes to moving time.

A Test of the Analysis

A model may fit the data used to build it very well, but it may still not actually reflect the underlying relationships. To test the equations I developed, I took a sample time study on another skyline thinning. The yarding machine and the crew were the same and the stand was 40 year old Douglas-fir with similar characteristics to the original study site. Thinning intensity was 35 percent among the conifers. The slope was 15 percent. The stand was different in one major respect from the original site: it had been thinned once before. Therefore, the average log was slightly larger, about 66

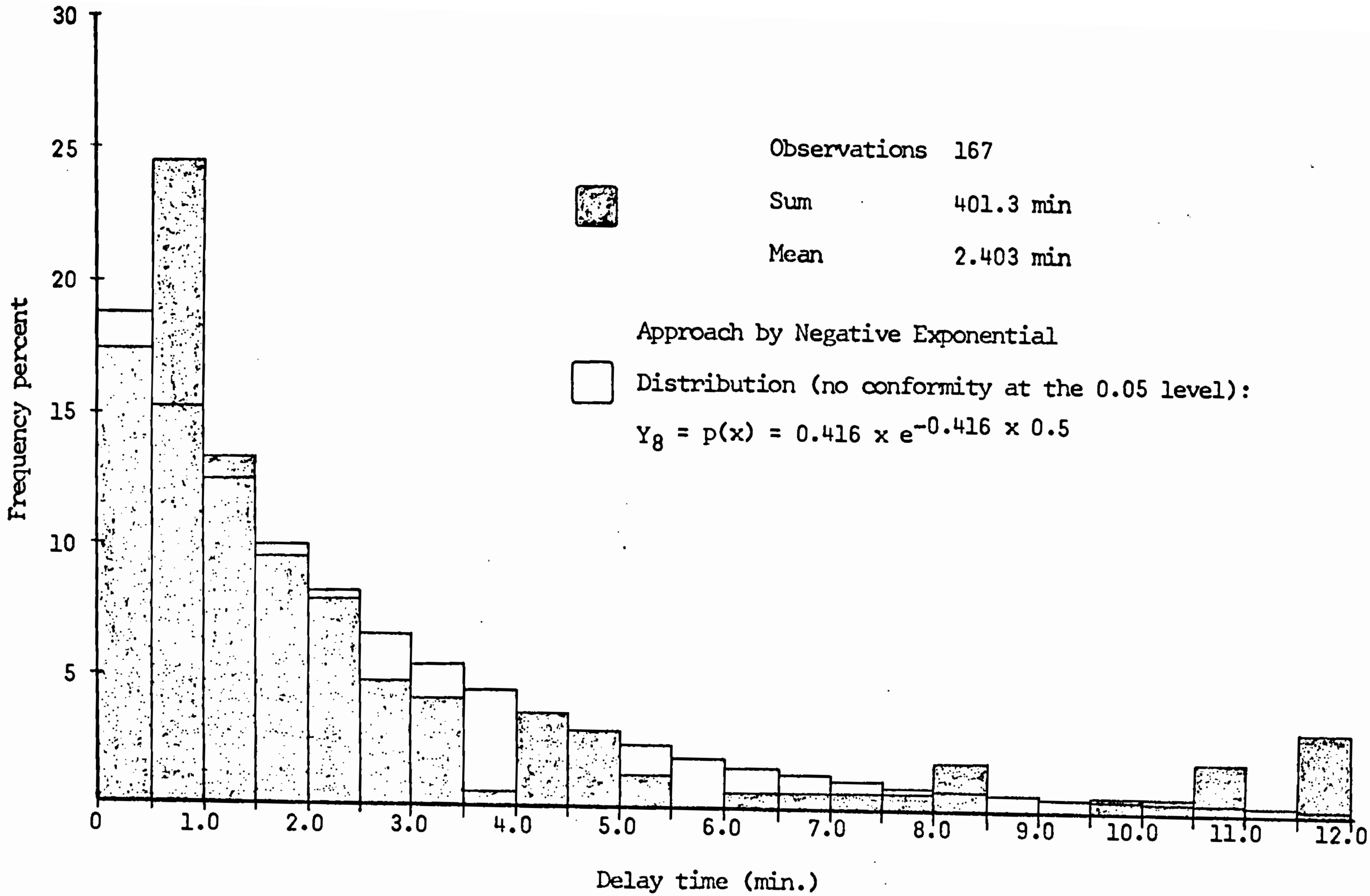

Figure 13. Frequency distribution of delay times - 0.5 minutes intervals

board feet (0.3 cubic meters)[1] [3], and small trees that hamper an initial thinning had been removed.

The purpose of the test was to detect whether my regression models and frequency distributions represent time relationships between variables, or whether they only fit the data of this one study. I used a chi-square test for goodness of fit between a given distribution and a sample at a set probability level. I assumed it was unlikely that the data of a sample would follow the same distribution, if the original regressions had matched the observed data only. For comparison of total yarding times I used a t-test.

I sampled 82 yarding cycles in June 1973. The average characteristics of the sample observations were:

skyline distance	287.8 feet
lateral distance	44.9 feet
load size	2.15 logs

I grouped the elements into the following classes:

Element	Range	Class
Carriage out	0-520 feet	50 feet
Lateral out	10-100 feet	10 feet
Hooking	0-3 minutes	0.5 minutes
Lateral in	10-100 feet	10 feet and load size
Carriage	0-520 feet	50 feet and load size
Unhooking	0-2 minutes	0.5 minutes

Each class should contain at least four observations (Linder, 1960). I combined two classes, if this condition was not accomplished. I

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[1] [3]Estimated volume, the scaling tickets were not available at this time.

computed the mean value for each class and calculated the corresponding predicted mean from the regressions or frequency distributions. These two figures entered the chi-square test for each class:

$$\chi^2 = \frac{(\text{observed - predicted value})^2}{\text{predicted value}}$$

I compared the sum of all chi-square values of an element with the table value of the chi-square distribution at the 0.05 probability level (Linder, 1960). The results show a highly significant correspondence between the models and the sample elements:

Activity	chi-square observed	chi-square table (0.05 level)	degrees of freedom
Carriage out	2.392	16.919	9
Lateral out	14.734	16.919	9
Hooking	7.586	9.482	4
Lateral in, 2 logs	2.257	11.070	5
Lateral in, 3 logs	0.579	7.815	3
Carriage in, 2 logs	4.358	12.592	6
Carriage in, 3 logs	2.941	5.991	2
Unhooking	2.934	5.991	2

For the elements Reset and Delays, I could not observe enough data in this small sample to conduct a chi-square test. There were 20 resets during the 82 observations, 24.41 percent of all turns. Nineteen delays occurred in the sample, for 23.2 percent of the time.

The number of sample data for total yarding time (without resets and delays) was insufficient to conduct a chi-square test. I could not fill the classes with enough data, if I considered all three variables of the total time equation, skyline distance, lateral distance, and load size (thinning intensity and slope steepness were constants). Therefore, I calculated the predicted total time values for all 82 observations with deviations from the observations. I considered both, observed and predicted values, as samples of a statistical total of skyline yarding turns and tested the hypothesis that the mean values of both samples are equal. The statistical method for this examination is Student's t-test (Brandt, 1968):

$$t = \frac{\text{Difference between means}}{\text{Standard deviation of difference}}$$

Results of the comparison were (in 1/10 minutes)

	Observed	Predicted	Difference
Sum	3755	4500.1	-745.1
Mean	45.79	54.88	- 9.09
Std. deviation	14.75	13.56	6.29

The calculated t-value is $\frac{9.09}{6.29} = 1.445$. This is smaller than the table volume $t_{(0.005,162)} = 1.975$. Therefore I accepted the hypothesis.

Most observations are slightly lower than the predicted values. I explain part of this deviation from the fact that the sample was taken in a stand that was thinned for the second time and was stocked with heavier timber. Another reason, which I cannot prove, may be that the crew worked on a quicker pace while I was collecting the sample data. It is a common problem during the initial period of a time study that workers try to work at a pace different from their normal performance (KWF, 1970).

The close correspondence suggests the reliability of my regression equations, at least for this particular yarding machine. To be applicable for a more general use, the model should be tested against observations from several other machines and varying conditions.

VI. SUGGESTIONS FOR SYSTEM MODIFICATIONS

Several suggestions for modifications of the yarding system result from my time study observations and from my analysis of the yarding system. They have to be analyzed and tested in practice before they can be considered as real system improvements.

Hooking

The two chokersetters worked only 40 percent of the total time. If several sets of chokers were used with the system they could preset another turn of logs during the rest of the time. Because the haulback line is led behind standing trees in thinning, it causes no imminent danger to the workers, as in clearcutting. Presetting chokers would reduce hooking times and it could increase the average load size if all chokers were utilized in every turn. Log production per day depends to a great extent on the number of logs per turn. Sometimes it is difficult to obtain a full load in thinning as no logs were cut at a spot. However, I consider it unproductive for the chokersetters to pull the rigging 100 or more feet out to hook only two logs, trying to keep hooking times short, when they could have combined four logs in one turn by presetting part of the chokers. The remaining time should still be sufficient for recuperation from the hard linepulling work.

Unhooking

The system in its present form requires an additional worker, the chaser, to unhook the incoming turns. The chaser is idle for 90 percent of the time, except when he has to buck occasionally a tree that was hung up during felling and then hauled in full length to the landing. Letting the yarder engineer do the unhooking is a possible solution, as shown during some observations in my study, but not adequate over longer periods, as the engineer would be over-stressed. Tree length yarding widely used in Northern Europe (Samset, 1973) might allow a more productive use of the chaser's time. The division of labour is redistributed: the fallers cut and limb the trees and buck the top only, the stems are hauled in full length to the landing, and processed there into logs by a bucker. In thinning, where only two or three sorts of logs occur, the chaser can do this work. He can use a tractor, possibly with grapple to avoid manual resetting of chokers and pull the stems from a landing deck to a working area parallel to the road. There he bucks them and decks the logs into piles at the road separated in classes. In this case, timber felling requires less time, the chaser's work capacity is utilized better, and the tractor is more efficiently used.

Haulback line

A haulback line is necessary if a nonclamping carriage is used in thinning to hold the carriage in place in lateral yarding. The carriage itself would run out from the yarder by gravity on slopes steeper than 15 percent. But it would move up the skyline road, when a load is pulled lateral in an angle to the road. The load line would scrape off the bark from trees along the way. The haulback line itself has disadvantages: it is a high-speed line that works like a saw if it rubs on trees; it slows down lateral yarding if it is laid out close to the skyline road, as incoming turns have to cross under it; it is a possible fire hazard in summer when a cornerblock or tailblock heats up; and it increases moving time as it is an additional line that has to be laid out in each skyline road. Carriages with a clamping device that prevents moving on the skyline could operate without a haulback line on slopes over 15 percent and would simplify the whole skyline system. A different solution are running skylines. There the haulback line runs along the skyline road and haulback and mainline together provide lift and movement to the suspended load.[14]

Winch system

Numerous short delays were caused, as cables jammed on the drum so that they could not be pulled out, as the mainline wound up next to the drum instead on it, or as other lines entangled and had to be cleared. If fairleaders were built in front of mainline- and skyline drums to assist reeling the lines in even layers, most of these interruptions could be avoided. This would not only reduce the delays caused by cable trouble, but also reduce line wear.

Lateral yarding distance

Lateral yarding accounts for almost 30 percent of total yarding time (Table II) and is strongly correlated with lateral distance. Various proposals have been made to reduce the problem of collecting

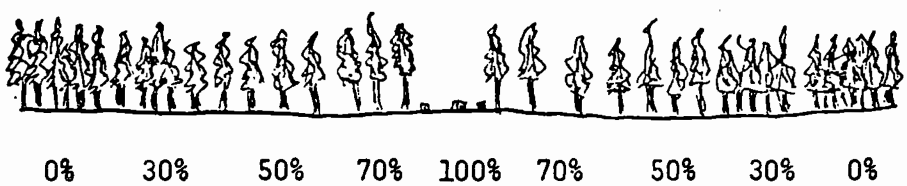
[14]John E. O'Leary, Professor, Forest Engineering Department, OSU: Course FE 560, Logging Methods.

logs scattered over a wide area. A simple approach is to reduce lateral yarding distance. This, however, may result in numerous skyline road changes. A more sophisticated approach has been developed in thinning Western Hemlock (Malmberg, 1969). In this method the loggers cut herringbone-like strips acute angled to the skyline road and leave the adjacent stand untouched. Adamovich (1968) has described the "line thinning" method as still another approach that compromises between the goal of redistributing growth to fewer trees and the goal of low logging costs for harvesting small timber. He has explained the method as follows (Figure 14):

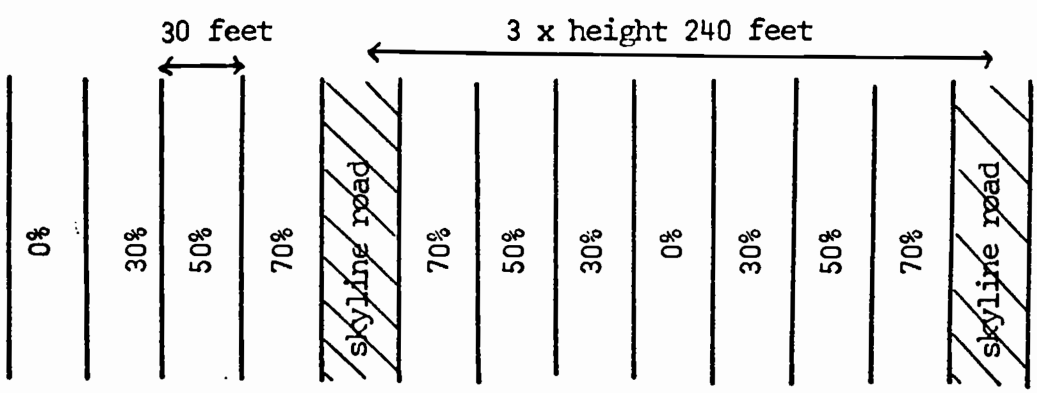
> Frequent lines should be planned no further apart than three times the height of the stand. All trees along this line will be cut regardless of their silvicultural importance. The width of the lines will be dependent on the yarding technology used. After the trees have been removed from the lines the neighbouring trees will be thinned with an above average intensity. Thinning intensity would decrease with increasing distance from the line, having a band of unthinned stand halfway between lines. At the next thinning (in 10 - 15 - 20 years) new lines will be established in the previously unthinned bands, in a similar manner. The third thinning might be based on individual tree selection, leaving the best trees for the final harvest.

I consider reductions of lateral yarding times as the larger opportunity for improvement in skyline thinning. Therefore, I chose lateral yarding distance for a more intense scrutinization. In the following chapter I will describe a simulation model and its use to simulate the effects of reducing lateral yarding distance and using line thinning on total yarding time.

A. Stand profile before thinning



B. Stand profile after first thinning



C. Thinning arrangement and intensities. Each strip is 30 feet wide.

Figure 14. Schematic Diagram of Systematic Line Thinning with 50% Thinning Intensity (According to Adamovich 1968, modified).

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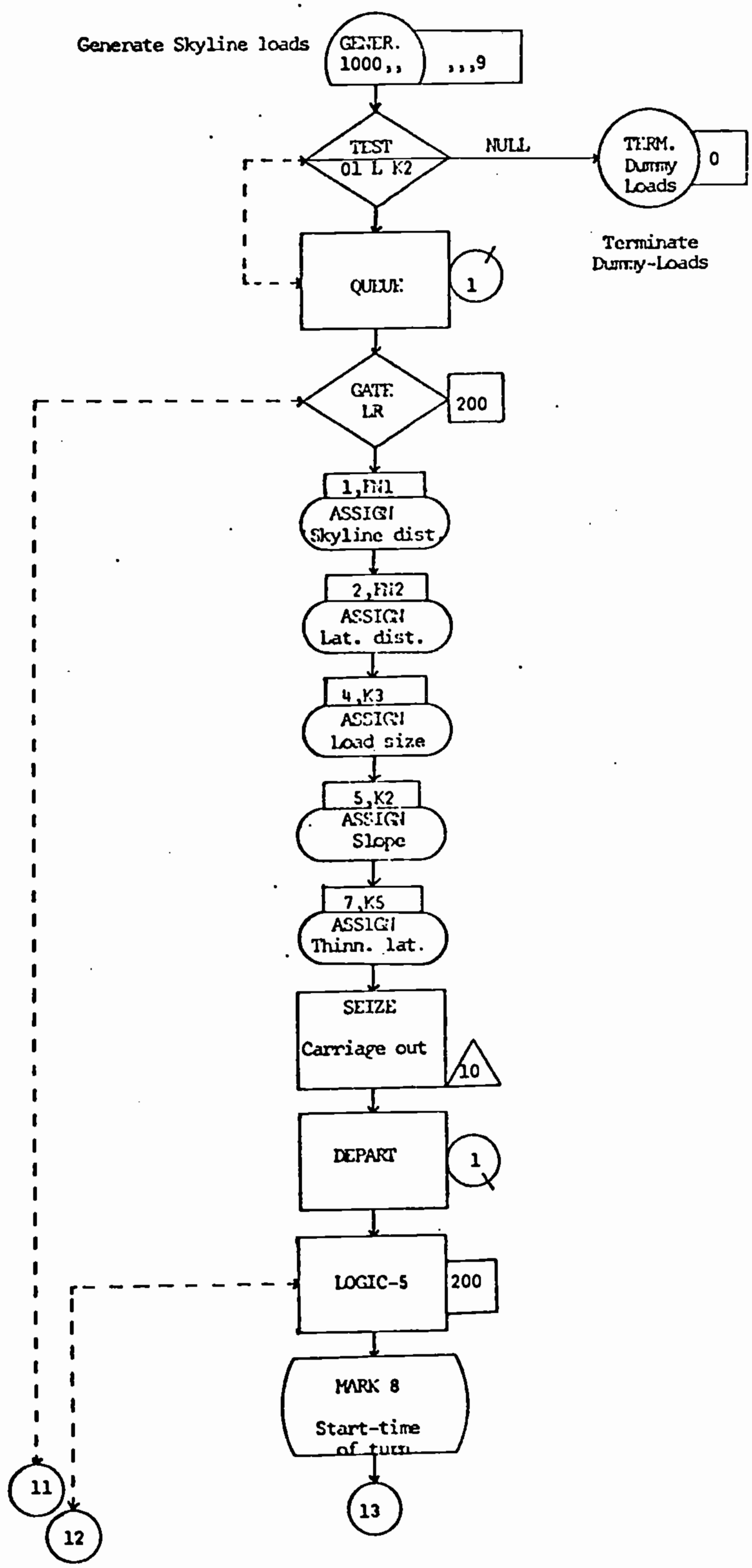

Figure 15. GPSS block diagram - skyline yarding simulation in thinning

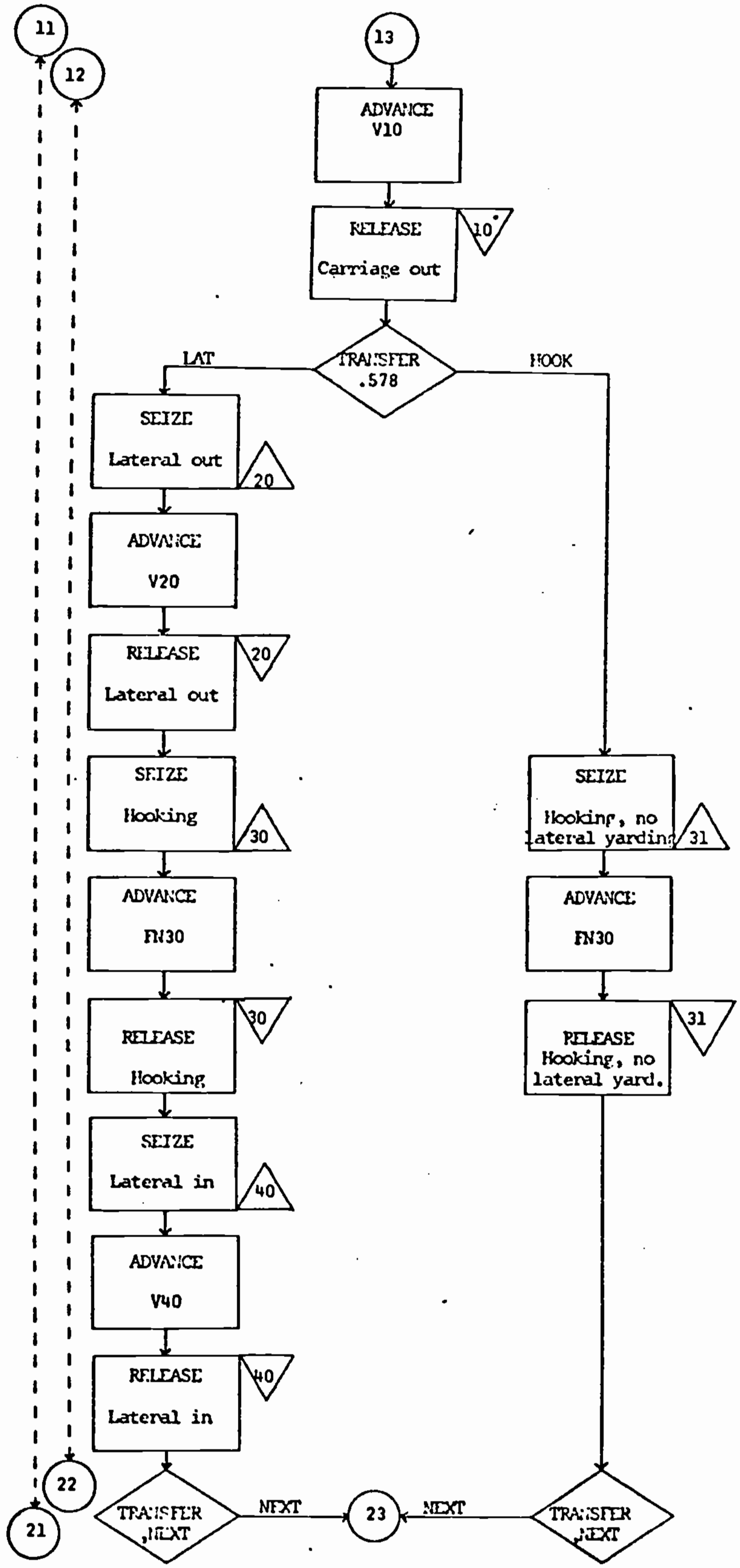

Figure 15 (cont.)

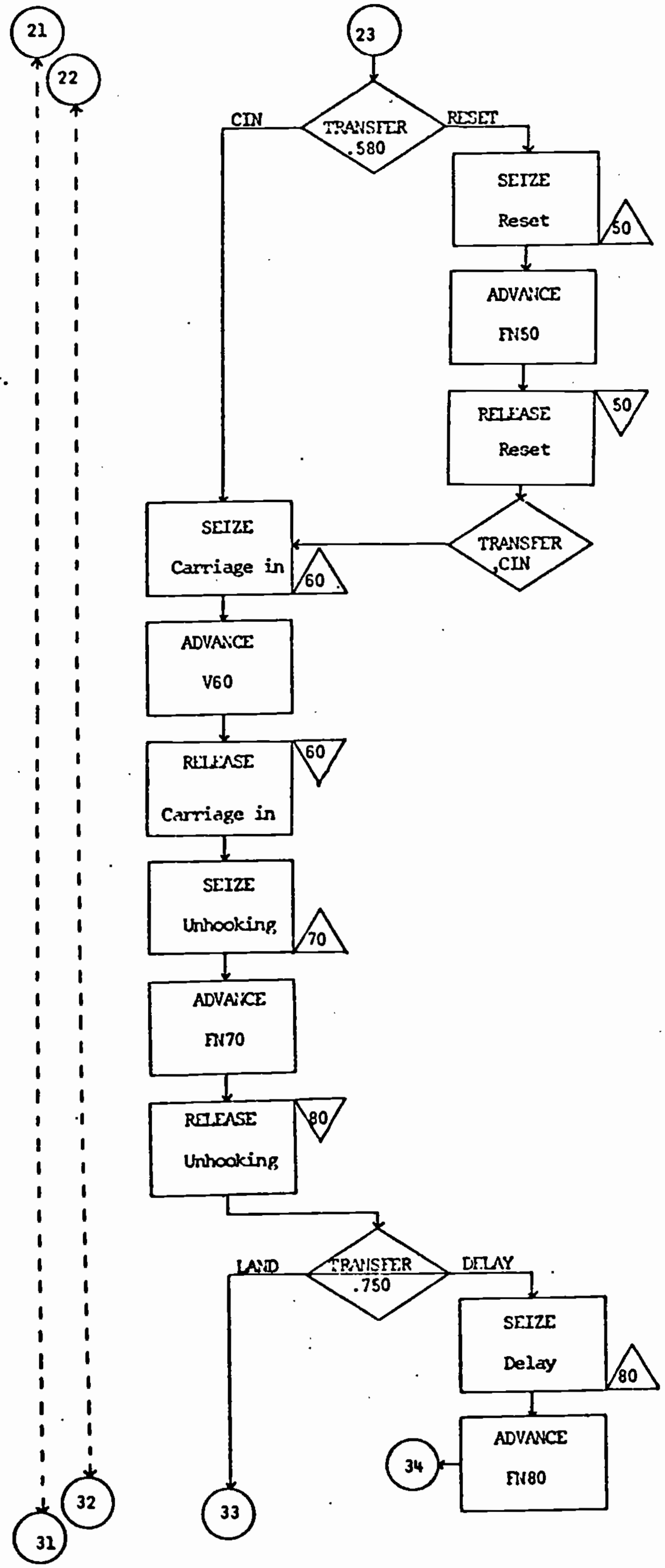

Figure 15 (cont.)

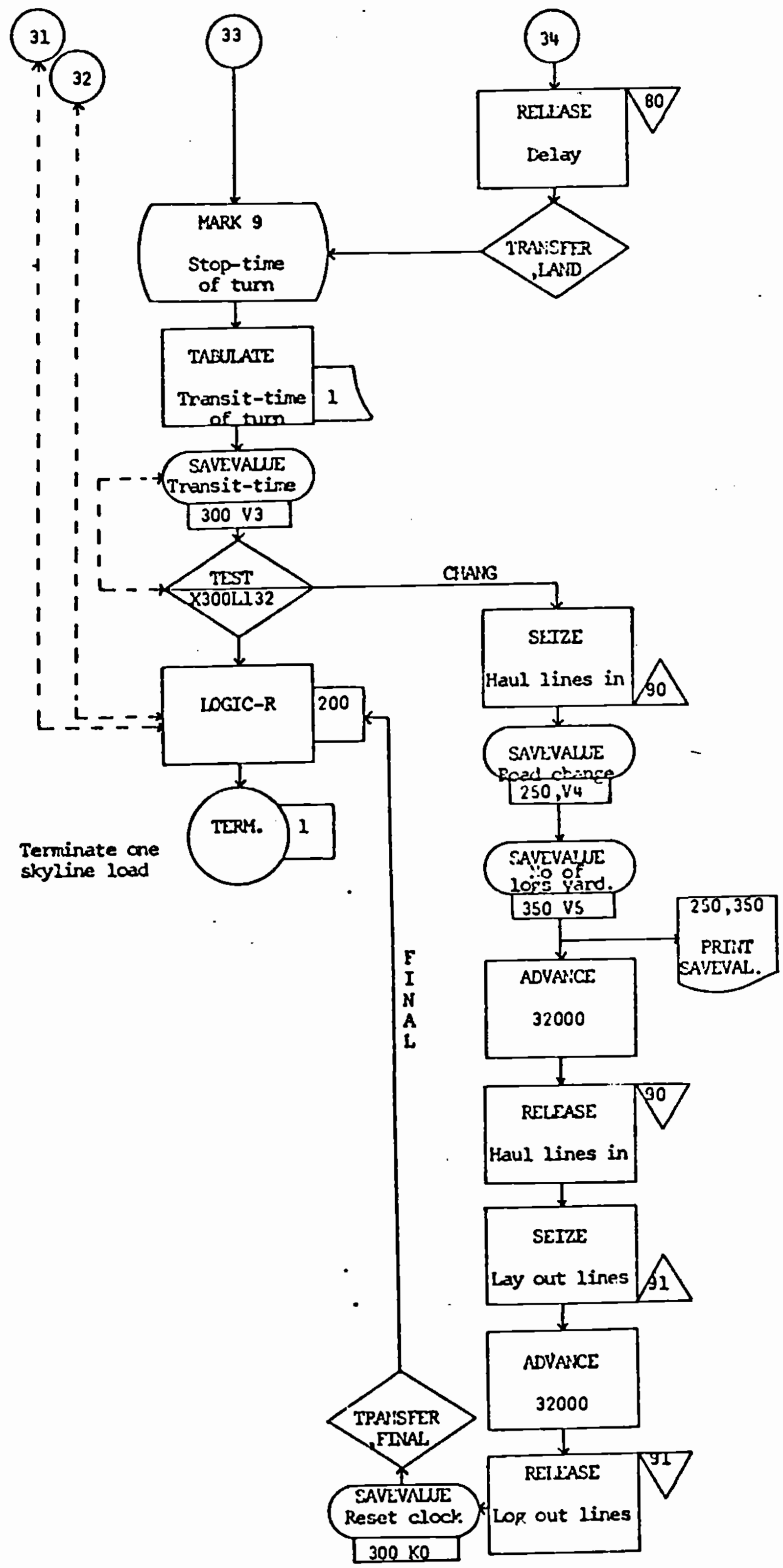

Figure 15 (cont.)

combination.

I simulated thinning of a rectangular stand, 2800 feet long and 700 feet wide (853 x 213 meters), on a 20 percent slope. The rectangular form resembles the usual method of thinning a strip of land from a logging road above without building special landings for the yarder. To simplify the simulation, I assumed that the road was straight for the length of the thinning area and that all skyline roads were parallel to each other. The simulated stand had a density of 230 trees per acre (568 trees per hectare). I assumed a thinning intensity of 50 percent or 115 trees per acre (284 trees per hectare) and one log per cut tree. I kept load size constant at three logs. Each run simulated 1730 skyline turns (5190 logs) as transactions through the system. A change of skyline road required a fixed time of 64 minutes.

The simulation model uses my regression equations and frequency distributions to determine time requirements for each activity. The program assigns five parameters to each transaction:

skyline distance, in ten feet between 0 and 700 feet, randomly selected

lateral distance, in ten feet between 0 and maximum lateral distance, randomly selected

load size per turn, three logs constant

slope steepness, 20 percent

thinning intensity, 50 percent

In order to get integer values in the equations, a requirement of the simulation language, a time unit of 1/1000 minutes was used. Each time a transaction enters an activity block, the program inserts these parameters in equations to calculate the time lag of the transaction in this block.

Simulating Lateral Yarding

To test the influence of lateral yarding distance I kept all factors constant, except this variable. I examined maximum lateral yarding distances of 200, 150, 100, 50, and zero feet. With zero lateral distance only skyline roads were logged and the intermediate stand remained untouched. The roads were 700 feet long and 20 feet wide. Reduced lateral distance increased the number of skyline roads in the area. Each road was a small clearcut, 0.32 acres (0.13 hectares) large and produced 75 logs. To maintain the proposed thinning intensity for the total area, the stand between the skyline roads was thinned less and less. As the number of roads increased, thinning intensity for the stand between the skyline roads decreased from 43 percent at 200 feet lateral distance to zero when only skyline roads were cut (Table IV).

The same simulation model with the same specifications was applied to test the line thinning method. However, skyline roads and all thinning strips were 30 feet wide. I chose thinning intensities of 70, 50, and 30 percent, respectively, for the lines, beginning with the largest intensity at both sides of a skyline road (Figure 14). Unthinned 30 feet wide strips were inserted between each area. Each strip covered an area of 0.482 acres (0.195 hectares). The whole area logged from one skyline road was 3.86 acres (1.56 hectares),

TABLE IV. SPECIFICATIONS OF LATERAL YARDING SIMULATION

Max. lateral distance (feet)	200	150	100	50	0
Distance between skyline roads (feet)	282	212	142	70	40
Area yarded from a skyline road (acres)	4.53	3.41	2.28	1.13	.64
No. of skyline roads	10	13	20	40	70
Total logs cut	5190	5190	5190	5190	5190
Logs cut in skyline roads	750	975	1500	3000	5190
Thinning intensity in stand outside skyline roads	42.8	40.6	35.6	21.1	0
Logs per skyline road	519	402	261	132	75
Percent of logs cut in skyline road	14.5	18.8	28.9	57.8	100.0

including uncut strips (Table V).

The five runs of the regular simulation model with lateral distances between 200 and zero feet require total yarding times between 205 and 240 hours (Table VI). The variant with the shortest requirement, is lateral distance to 50 feet. Cutting skyline roads only had the shortest average turn time with 5.13 minutes, but required 69 changes of skyline roads. Daily log production is based on average turn time including moving time and ranged between 174 and 202 logs per day for the different lateral distances (Table VI).

Line thinning, as a systematic approach to thinning, avoids the regular distribution of logs over the whole thinning area. Most logs are aggregated close to the skyline road, where they are easy to haul. The maximum lateral yarding distances in line thinning is 147 feet, however, 60 percent of all logs are yarded within zero and 60 feet (Table V). This is expressed in a total yarding time of 202 hours, which is shorter than the best results in regular yarding. Line thinning has a daily production of 205 logs (Table VI).

TABLE V. SPECIFICATIONS OF LINE THINNING SIMULATION

Thinning intensity (percent)	100	70	50	30	0
Width of strips (feet)	30	60	60	60	30
Area of strips (acres)	.482	.964	.964	.964	.482
Logs per strip	108	159	111	66	0
Percent of cut	24.33	35.81	25.00	14.86	0
Maximum lateral yarding distance (feet)	21	63	105	147	--

Area yarded from a skyline road (acres)	3.856
No. of skyline roads	12
Total logs cut	5190
Logs per skyline road	444
Percent of logs cut in skyline road	24.3

TABLE VI. RESULTS OF SIMULATION RUNS WITH LATERAL DISTANCE AS VARYING FACTOR

Maximum lateral yarding distance (feet)	No. of required skyline road changes	Required total time (hours)	Average time per turn (minutes)	Average time per turn including moving (min)	Daily log production
200	9	238.5	7.95	8.27	174
150	12	228.4	7.50	7.92	182
100	19	215.2	6.78	7.47	193
50	39	205.3	5.69	7.12	202
0	69	221.3	5.13	7.68	187
Line-Thinning	11	202.6	6.65	7.03	205

VII. Summary and Conclusions

I studied the performance of a small skyline yarder of common design in a thinning operation. The yarder was working under several slope conditions and thinning intensities. I applied the multi-moment time study method to observe the system. The regular work cycle was split into six elements:

Carriage out
Lateral out
Hooking
Lateral in
Carriage in
Unhooking

The irregular elements Reset and Delay interrupted the work cycle at erratic intervals. Moving occurred when a skyline road had been finished. I used regression analysis to examine the influence of variables on time requirements of each element. The following seven variables were considered:

Skyline distance
Lateral distance
Lateral slope
Number of logs per turn
Slope steepness
Thinning intensity
Crew size

Regression equations explain the variation of four elements, carriage out, carriage in, lateral out, lateral in, and of total regular yarding time without resets and delays. For the other elements I developed only frequency distributions. A test of each model showed a low probability of pure chance relationship between the variables and the time study data. The equations and distributions can be used, within range limits, by experts to predict the time requirements for each element in skyline thinning and to estimate total yarding time for a thinning project.

All my analysis is based on one single skyline system and tested against one different sample of the same system. To further test the validity of my data and to improve the results for more general use, more studies should be made in other thinning projects and with different yarding equipment. The studies should include additional variables. Several factors might influence the regression models and should be tested, e.g. skyline deflection, slope of the chord[15], angle to the skyline in which the logs are felled, or volume of the load per turn. Additionally, type and length of breakdowns should be recorded to gather information about the frequency of occurrence and about their influence on the performance of the yarding system.

I developed a simulation model in the GPSS-computer language. It can be used to predict results of an actual thinning project, or to experiment with theoretical situations, like proposals of improved yarding methods, and test their possible practical application. I used this model to examine the influence of lateral yarding distance in skyline thinning and suggested two solutions to reduce lateral

---

[15] A theoretical straight line from the skyline block on the boom of the yarder to the anchorage of the skyline on the tail tree.

yarding time: to limit maximum lateral distance to 50 feet, or to utilize a "line thinning" technique as discussed by Adamovich (1968). I consider both solutions as practicable. They should be further evaluated in consecutive thinning studies.

Several other modifications may improve the skyline system I studied:

1) presetting chokers could reduce hooking times and provide large loads per turn;
2) tree length logging would redistribute the division of work, as bucking would be displaced from the woods to the forest road. It would better utilize the chaser's work capacity in skyline thinning;
3) a clamping carriage or a running skyline would make the haulback line, a possible trouble spot in the present system, unnecessary;
4) the installation of fairleaders that regulate the reeling of skyline and mainline could reduce the number of delays.

These suggestions should be analyzed further before they are applied in practice.

Skyline yarding is an old logging method in the Pacific Northwest, which has advanced technologically over time. However, it has been developed in old-growth logging and was applied to thin second-growth only recently. Further research is essential to advance the capabilities of skyline yarding in thinning.

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APPENDICES

APPENDIX A

ILLUSTRATIONS

Figure 16. Unthinned stand on flat ground (unit H1)

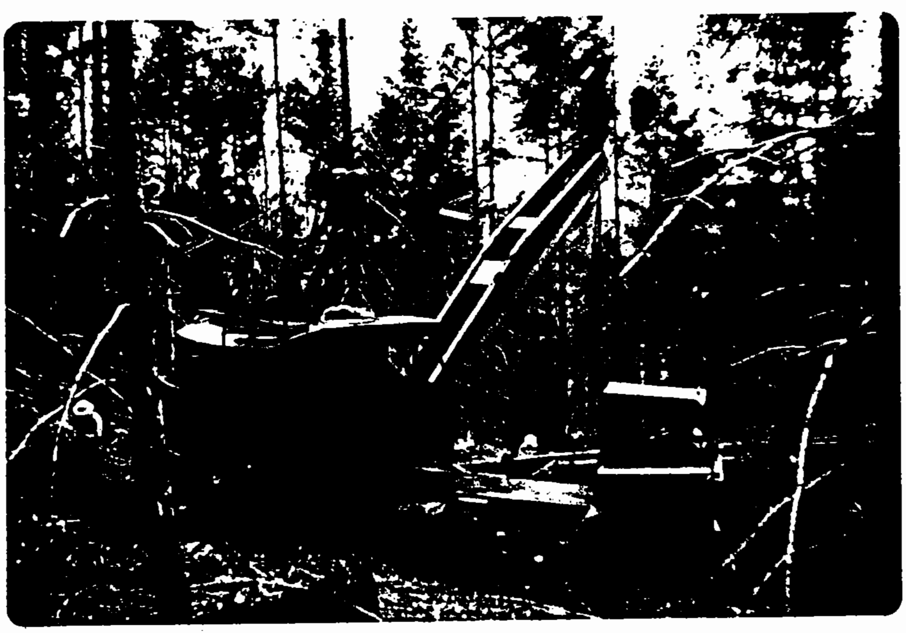
Figure 17. Yarder set up on a spur road (unit H2)

Figure 18. High piled landing deck after a skyline road is finished. The yarder is working in another road (unit M1).

Figure 19. Rigging in lateral. The picutre shows possible damage on standing trees, if the carriage is not positioned exactly on the skyline road (unit H2).

Figure 20.
View of a skyline road from the yarder engineer's seat (unit M2).

Figure 21.
Yarder from the rear, showing drums to tighten guylines on top of gantry.



APPENDIX B

GPSS-SIMULATION PROGRAM

FOR THE SKYLINE THINNING SYSTEM

```
*SKYLINE YARDING SIMULATION
*LATERAL DISTANCE MAX 200 FEET
*TIME=1/1000 MINUTES
*H.U.SINNER
*
      SIMULATE
*
*PARAMETER SKYLINE DISTANCE
    1 FUNCTION     RN1,C8
.125   0     .25    10     .375  20     .5     30     .625  40     .75    50
.875   60    1.0    70
*PARAMETER LATERAL DISTANCE
    2 FUNCTION     RN1,D10
.095   1     .19    3      .285  5      .38    7      .475  9      .57    11
.665   13    .76    15     .855  17     1.0    20
*TIME HOOKING
   30 FUNCTION     RN1,C10
.2029 500    .5795 1000   .7960 1500   .8802 2000   .9503 2500   .9824 3000
.9941 3500   .9970 4000   .9985 4500   1.0   5000
*TIME RESET
   50 FUNCTION     RN1,C16
.272   500   .51    1000   .644  1500   .747   2000   .82   2500   .872   3000
.909   3500  .936   4000   .955  4500   .969   5000   .979  5500   .986   6000
.991   6500  .995   7000   .998  7500   1.0    8000
*TIME UNHOOKING
   70 FUNCTION     RN1,C9
.391   500   .814   1000   .924  1500.   .961   2000   .98    2500   .989   3000
.993   3500  .997   4000   1.0   4500
*TIME DELAY
   80 FUNCTION     RN1,C20
.232   500   .41    1000   .547  1500   .652   2000   .734  2500   .796   3000
.843   3500  .873   4000   .909  4500   .931   5000   .947  5500   .96    6000
.971   6500  .978   7000   .985  7500   .99    8000   .994  8500   .997   9000
.999   9500  1.0    10000
*
      GENERATE     1000,,,,,9         GENERATE SKYLINE LOADS
      TEST L       Q1,K2,NULL         WAIT FOR YARDER
      QUEUE        1                  WAIT FOR YARDER
      GATE LR      200                IS YARDER BUSY^
      ASSIGN       1,FN1              PARAMETER SKYLINE DISTANCE
      ASSIGN       2,FN2              PARAMETER LATERAL DISTANCE
      ASSIGN       4,K3               PARAMETER LOAD SIZE
      ASSIGN       5,K2               PARAMETER SLOPE
      ASSIGN       7,K5               PARAMETER THINNING INTENSITY
*
      SEIZE        10
      DEPART       1                  LEAVE QUEUE
      LOGIC S      200                ENGAGE YARDER - STOP NEXT TURN
      MARK         8                  PARAMETER TRANSIT TIME START
      ADVANCE      V10                TIME CARRIAGE OUT
      RELEASE      10
      TRANSFER     .145,LAT,HOOK      14.5% WITHOUT LATERAL YARDING
 LAT  SEIZE        20
      ADVANCE      V20                TIME LATERAL OUT
      RELEASE      20
      SEIZE        30
      ADVANCE      FN30               TIME HOOKING
      RELEASE      30
      SEIZE        40
      ADVANCE      V40                TIME LATERAL IN
      RELEASE      40
      TRANSFER     ,NEXT              GO TO NEXT
```

```
HOOK  SEIZE      31
      ADVANCE    FN30               TIME HOOKING (NO LATERAL YARDING)
      RELEASE    31
      TRANSFER   ,NEXT
NEXT  TRANSFER   .530,RESET,CIN     42% WITH RESET
RESET SEIZE      50
      ADVANCE    FN50               TIME RESET
      RELEASE    50
      TRANSFER   ,CIN
CIN   SEIZE      60
      ADVANCE    V60                TIME CARRIAGE IN
      RELEASE    60
      SEIZE      70
      ADVANCE    FN70               TIME UNHOOKING
      RELEASE    70
      TRANSFER   .750,DELAY,LAND    25% WITH DELAY
DELAY SEIZE      80
      ADVANCE    FN80               TIME DELAY
      RELEASE    80
      TRANSFER   ,LAND              GO TO LAND
LAND  MARK       9                  PARAMETER TRANSIT TIME STOP
      TABULATE   1
      SAVEVALUE  300,V3
      TEST L     X300,519,CHANG     IF 519 LOGS YARDED, CHANGE ROAD
FINAL LOGIC R    200                DISENGAGE YARDER - START NEXT TURN
      TERMINATE  1
*
*CHANGE OF SKYLINE ROAD
CHANG SEIZE      90
      SAVEVALUE  250,V4             NO. OF SKYLINE ROADS
      SAVEVALUE  350,V5             NO OF LOGS YARDED TOTAL
      SAVEVALUE  400,C1             CLOCK, WHEN ROAD IS FINISHED
      PRINT      250,400,X          PRINT YARDING STATISTICS
      ADVANCE    32000              TIME REMOVING SKYLINE
      RELEASE    90
      SEIZE      91
      ADVANCE    32000              TIME  LAY OUT NEW SKYLINE
      RELEASE    91
      SAVEVALUE  300,K0             RESET NO. OF LOGS YARDED
      TRANSFER   ,FINAL             GO TO FINAL
NULL  TERMINATE  0                  TERMINATE DUMMY LOADS
*
*VARIABLES
    1 VARIABLE   P9-P8
    3 VARIABLE   X300+P4
    4 VARIABLE   X250+1
    5 VARIABLE   X300+X350
   10 VARIABLE   K252+V11*21-P1*P1*13/100+P5*P5*4
   11 VARIABLE   P1+P5
   20 VARIABLE   K551+P2*216-P2*P2*6-P7*P7*11
   40 VARIABLE   P2*177+P4*68+P2*P4*13-P2*P2*5-K53
   60 VARIABLE   K193+P1*26+P4*44+P5*36
*
*TABLES
    1 TABLE      V1,1000,500,50     TIME TOTAL YARDING PER TURN
*
      START      1730
      END
```

APPENDIX C

TIME STUDY RECORD SHEET FILLED WITH FIELD DATA (UNIT H2)

F911 SKYLINE YARDING

CREW: Eng: Keith
Chaser: Gary
Choker: Jay. Boydston

DATE 8/22/72 SHEET 1

START: 08 4 15
STOP:

UNIT NAME H2 [illegible]

TURN NO.	CARR. OUT	LAT. OUT	HOOK	LAT. IN	RESET	CARR. IN	UN-HOOK	DELAY	TOTAL	SL DIST	LAT DIST	LAT SLOPE	NO. LOGS	TAG NO.	COMMENTS
1	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	420 / 350	150	60	–	2		discussion
2	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	500 / 350	150	60	–	2		clear rigging
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		380	130	60	–	2		
4	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	330 / 300	130	70	–	2		discussion
5	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	420 / 360	130	80	–	2		back hangup
6	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		500	130	60	–	2		
7	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		300	130	100	–	2		
8	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		330	140	50	–	2		
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		420	140	70	–	2		
10	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		390	140	70	–	2		
11	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		380	140	100	–	2		
12	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		410	140	100	–	2		
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		720	140	110	–	2		Rig'g landing deck
14	[illegible]		[illegible]			[illegible]	[illegible]		380	250	0		2		. . .
15	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]		1010	260	0		2		reset load slash hauled to landing
16	[illegible]		[illegible]			[illegible]	[illegible]	.	390	270	0		2		
17	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		540	250	30	+	2		
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		420	260	40	+	2		2 resets