AN ANALYSIS OF PRODUCTION AND COSTS IN HIGH-LEAD YARDING

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By

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and

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U. S. Department of Agriculture — Forest Service
Pacific Northwest Forest and Range Experiment Station
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Foreword

This study was planned and conducted by Magnus E. Tennas, a research forester with the Norwegian Forest Research Institute, Division of Logging Engineering, in coöperation with the Pacific Northwest Forest and Range Experiment Station. Mr. Tennas carried out the study during the 1953-54 school year as a part of his graduate work at the School of Forestry, Oregon State College, Corvallis, Oregon. He has been aided in this work by grants from the U. S. State Department under the Smith-Mundt and Fulbright Acts. Robert H. Ruth and Carl M. Berntsen, research foresters at the Cascade Head Experimental Forest, cooperated with Mr. Tennas in collecting data for the analyses and in writing this report.

Modern industrial engineering techniques and statistical methods have been applied in this study to analyze how various factors influence production and costs in high-lead yarding operations.

R. W. Cowlin
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Magnus E. Tennas, Robert H. Ruth, and Carl M. Berntsen [1/]

INTRODUCTION

In recent years loggers and timber owners have needed better information for estimating logging costs in the Douglas-fir region. Brandstrom's comprehensive study, published in 1933 (1), [2/] has long been used as a guide in making cost estimates. But the use of new equipment and techniques and an overall increase in logging costs have made it increasingly difficult to apply Brandstrom's results in analyzing modern logging operations. As a result, the logger has tended to rely on his own experience and such average costs as are known for similar operations. This method is often inadequate and sometimes misleading because average cost records often fail to account for the effect of variations in volume per acre, topography, crew organization, working methods, and other conditions that influence the cost of logging. The need for up-to-date information on production and costs has led to a growing interest in the application of industrial engineering techniques in studies of logging operations.

Of the several techniques used in industrial performance analysis, the production study is probably the most applicable to the logging industry (4). This technique requires continuous timing of each

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1/ The authors wish to express their appreciation to the Neskowin Timber Company, contract loggers for the Publishers' Paper Company, for permitting this study of the logging operation and for furnishing logging cost data. Special thanks are due to logging superintendent C. E. Shultz and his yarding crew for valuable assistance and cooperation during the study. Acknowledgement is made to Clarence W. Richen, chief forester, Crown Zellerbach Corporation, for advice and cost data, and to Edgel C. Skinner, Pacific Northwest Forest and Range Experiment Station, for regression analyses.

2/ Underlined numbers in parentheses refer to Literature Cited, page 37.

operation, delay, or other event associated with a particular job. The time for each operation is noted on the data sheet, and by sorting the separate observations into appropriate categories it is possible to estimate how the performance times are influenced by factors such as topography, volume, and distance. The production study may also be employed to obtain distribution of machine time and manual time and to estimate amount and types of delays in performing special jobs.

This paper presents the results of a production and cost study of a high-lead yarding operation. Yarding costs average 10 to 15 percent of total logging costs, about the same share as falling and bucking combined. But yarding usually is the "bottleneck" that controls the flow of logs to other activities and is subject to widely varying costs.

The objective was to determine how high-lead yarding production and costs per thousand board feet vary with factors such as crew organization, haul-in distance, volume per turn, and slope. An analysis of delay time was included to determine amount and types of delays.

SCOPE

The study was made in a 100-year-old stand on the Cascade Head Experimental Forest near Otis, Oregon. Stand composition was 55 percent Sitka spruce, 35 percent Douglas-fir, and 10 percent western hemlock. Volume per acre averaged 65 thousand board feet. Results are directly applicable to high-lead settings in similar stands if equipment and crew organization are approximately the same.

Falling was done by an experienced crew. Trees were felled to the lead of the mainline wherever possible, but those near the perimeter of the setting were felled on the side hill to avoid the truck road or the standing timber outside the clear-cut boundary. Stumps were cut as low as operation of power saws would permit. Losses due to breakage were minor. Logs were generally cut in 40- to 48-foot lengths; but shorter logs, down to 12 feet long, were cut when necessary.

Distribution of logs on yarding roads ranged from 76 to 353 logs per acre. There was an average of 2.08 logs yarded per turn for an average volume of 735 board feet. Height of spar tree was 95 feet and height of mainline block 80 feet. A total of 1,110 turns was timed with a stopwatch. This involved the yarding of 2,304 logs for a gross volume of 815,440 board feet, Scribner Decimal C.

The yarding show was a good one with no downhill yarding, no excessive haul-in distances, and a good landing. Yarding roads ranged in length from 300 to 900 feet with volume variations from 40 to 3,000 board feet per turn. Average slope of yarding roads ranged from level to 50 percent.

Weather during the yarding operation was generally good with only occasional showers during the first two and one-half weeks. The last week was mostly stormy with frequent heavy rain, strong winds, and occasional hail or sleet.

The yarding machine was a 130 drawbar horsepower crawler tractor equipped with a triple-drum winch (table 1 and fig. 1). The butt rigging had two chokers.

The yarding crew consisted of a hook tender, machine operator, head rigger, one or two choker setters, a chaser, and a signal man. The first half of the study was carried out using one choker setter and the last half with two choker setters to determine the production and costs using both a 6-man and 7-man crew. Yarding was to a "hot" landing, with the logs loaded out about as fast as they were hauled in.

PROCEDURE

Total productive time was broken down into basic elements to facilitate analysis and interpretation of data (fig. 2). The elements that contributed directly to output, such as haul-in, haul-back, choker-set, and unhook times, were grouped together as maintime. Elements not directly productive, but essential to production, such as changing yarding roads and swinging blocks on the spar tree were grouped together as supplementary time. Maintime and supplementary time were combined and called basic time. Necessary delays, such as starting the yarding machine and hang-ups, were added to basic time to obtain total productive time. Unnecessary delays were those that should not have occurred, such as waiting on the loading operation at the landing. They are not included in the analysis. Each element of the yarding operation was timed separately by hundredths of minutes, using the "snapback" method. The stopwatch was read at the end of each element and the hand was then snapped back to zero (3). Recording of element times was checked each 9 turns. When the difference between sum of element times and elapsed time exceeded 3 percent of the elapsed time, data were excluded in the analysis.

Independent variables such as haul-in distance, volume of turn, slope, and number of logs per turn were recorded along with time

Table 1.--Equipment specifications: 1/ Triple-drum winch mounted on a 130 drawbar horsepower crawler tractor

Item	Main drum	Haul-back drum	Straw drum
Drum size	12 inches	12 inches	8-5/8 inches
Cable capacity (feet and wire size)	1,000 ft. 1-1/8" 1,250 ft. 1"	2,600 ft. 5/8" 3,200 ft. 9/16"	3,000 ft. 3/8" 4,000 ft. 5/16"
Capacity factor "F" 2/	4,755	3,890	1,635

Drum	Line pull (pounds) 3/			Line speed 3/ (ft. per min.)		
	Bare	Average	Full	Bare	Average	Full
MAIN DRUM						
Low gear	62,000	47,500	32,800	78	114	149
Second gear	43,500	33,000	23,000	112	162	212
Third gear	30,900	23,500	16,300	158	229	300
High gear	21,600	16,500	11,400	226	327	428
HAUL-BACK DRUM						
Low gear	16,100	12,500	8,800	303	431	560
Second gear	11,300	8,500	6,100	432	616	800
Third gear	8,000	6,000	4,400	612	871	1,130
High gear	5,600	4,500	3,100	874	1,244	1,615
STRAW DRUM						
Low gear	23,500	15,500	7,700	207	423	640
Second gear	16,500	11,000	5,400	296	605	914
Third gear	11,700	8,000	4,100	418	854	1,290
High gear	8,200	5,500	2,700	597	1,221	1,845

Weight, net (without cable)	8,050 pounds

1/ Equipment specifications are from manufacturer's catalog.

2/ Capacity factor "F" is used to compute the cable capacity of the drums. The formula is: (Capacity Factor "F") x (Line Factor "G" - obtain from wire rope manufacturer's manuals) = (Cable Capacity of Drum).

3/ Line pulls and speeds based on 148 h.p. (belt) tractor at 1,000 r.p.m., and using line sizes--mainline 1-1/8", haul-back line 5/8", and strawline 3/8".

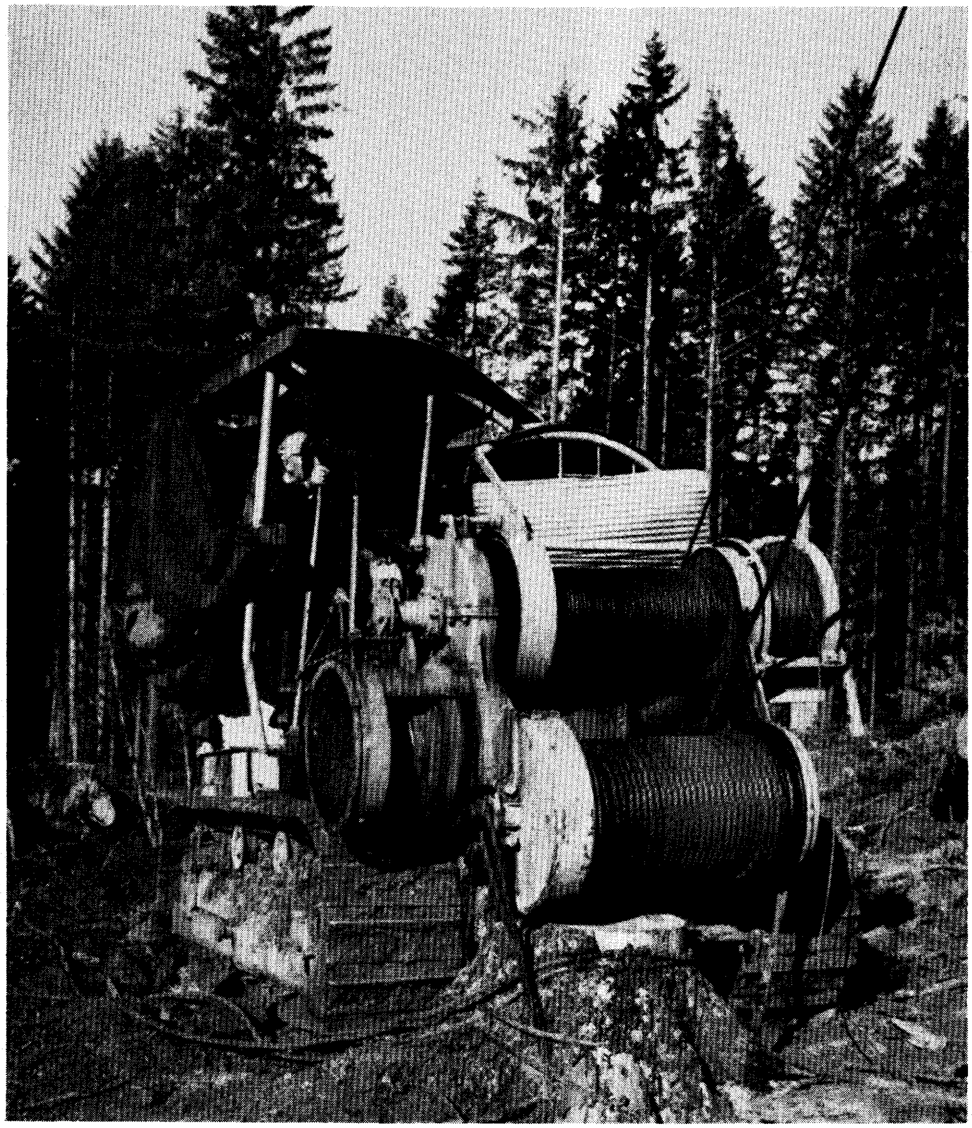

Figure 1.--The yarding machine was a crawler tractor with a triple-drum winch.

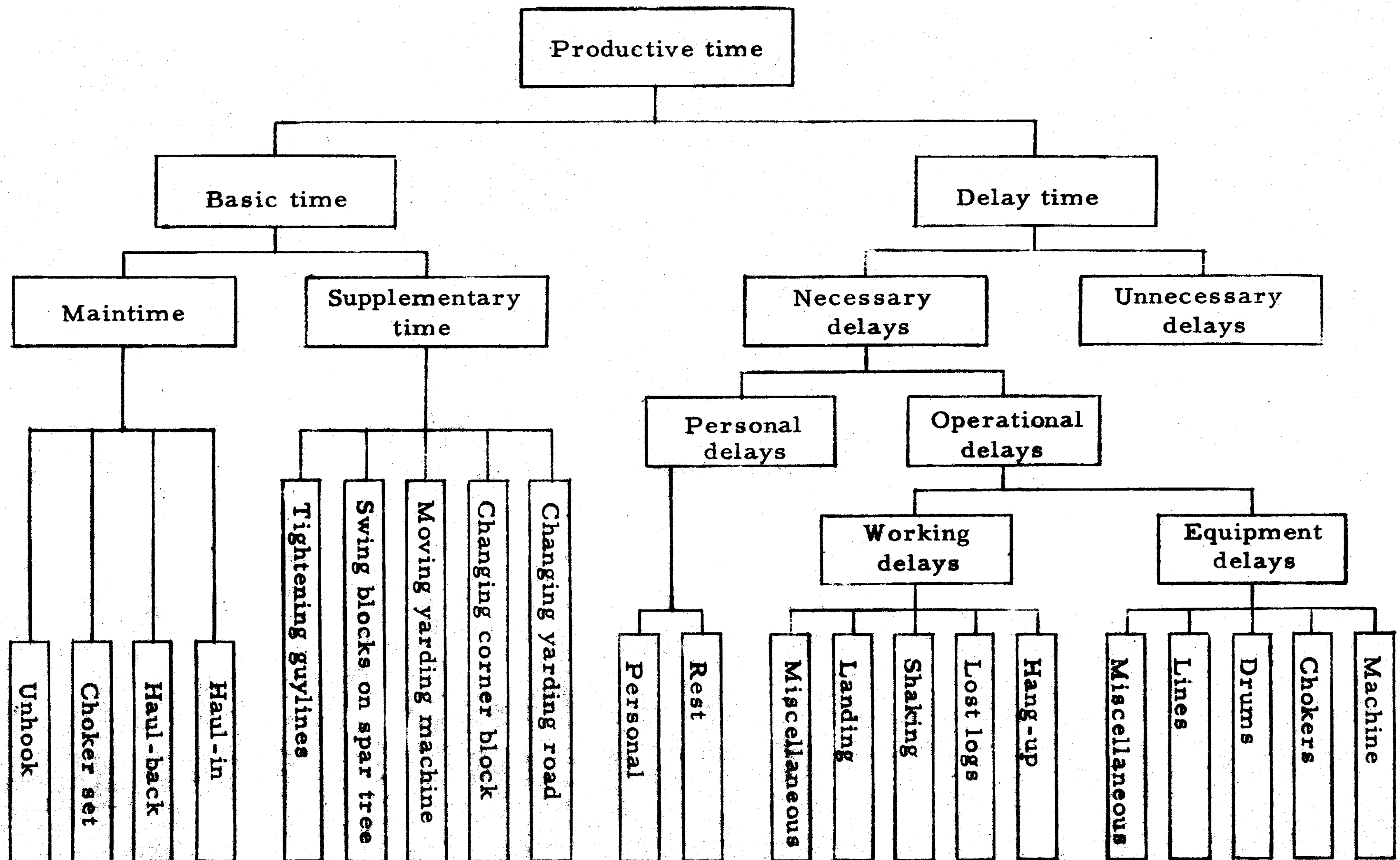

Figure 2.--Production study chart for high-lead yarding.

observations. A contour map of the setting was prepared to show topography, layout of yarding roads, and to determine area of each yarding road (fig. 3). In compiling data, each yarding road was regarded as a unit.

The following procedure, described by Samset (5), was used to determine which independent variables affected basic time elements and to determine the types of functions that should be used in the regression analyses.

The first step was to sort all time data for an individual element. For example, all haul-in times were separated into groups according to haul-in distance. Each group was then divided into subgroups corresponding to volume per turn classes and again into sub-subgroups by slope classes. Average times were calculated from all observations for the sub-subgroup and plotted over corresponding average class values for the independent variable. Thus, average haul-in times for a given distance class were plotted over average volumes per turn. A series of freehand curves were then drawn, each for a separate slope class. Following this, data were re-sorted with slope as the subgroup and volume per turn as the sub-subgroup. New averages resulted in another series of curves of haul-in time over slope with one curve for each distance class.

Freehand curves such as these, together with a knowledge of fundamental factors that might be presumed to have an effect on individual operating times, led to the selection of independent variables for formal multiple-regression analyses using the method of least squares (6). Any independent variable whose influence was doubtful was included in the regression analysis.

Each independent variable in every regression was tested to determine if its effect on the time required for a particular phase of the yarding operation was real or possibly only a chance occurrence. The functions of each time element were accepted only if the regression coefficients were significant at the 5-percent level of fiducial probability.

RESULTS

A formula for total productive time per turn is the end result of this study. Different values may be substituted for variables in this formula to estimate total productive time per turn for various combinations of factors. Maintime, supplementary time, and delay time will be discussed separately since each contributes to total productive

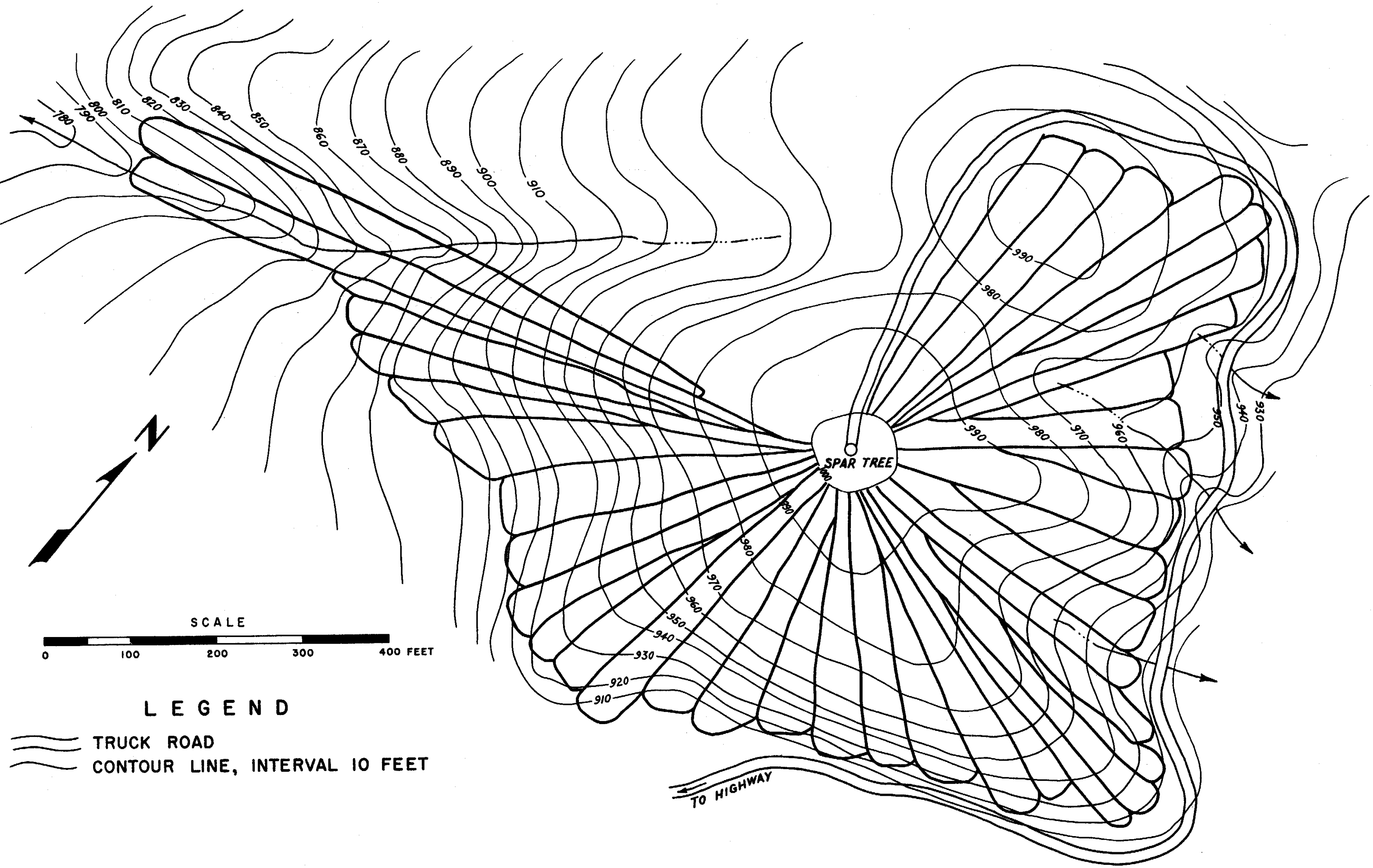

Figure 3.--Contour map of high-lead setting showing yarding roads.

time per turn. Formulas for daily production in thousand board feet and for cost per thousand board feet follow directly from estimates of total productive time per turn.

The following symbols are used in presenting the basic time formulas:

Y = Time per turn in 1/100 minute.
D = Haul-in distance in feet.
V = Volume per turn in board feet by the Scribner rule.
S = Slope in percent.
C = Number of choker setters (including head rigger).
N = Number of logs per turn.
Z = Number of turns per yarding road.
T = Density of timber (number of logs per acre).
L = Length of yarding road in feet (external yarding distance).

Maintime

Regression equations were developed for each of the four maintime elements, and a formula for total maintime was obtained by combining the four equations.

Haul-back Time

Haul-back time per turn is the time required to move the butt rigging from spar tree to yarding area in preparation for the next turn. For a given line speed, the time required for this typical machine operation is determined largely by haul-in distance (fig. 4). Haul-back time per turn was as follows:

$$Y = 16.99 + 0.089\ D$$

Average speed of butt rigging during the haul-back operation was calculated to be 1,124 feet per minute. This is lower than the line speed specified for high gear (1,244 feet per minute), probably owing to slower speed when the butt rigging starts from the spar tree and again when it slows to a stop at the yarding area.

Choker-set Time

Choker-set time per turn begins when the butt rigging is signalled to stop at the yarding area and ends when the signal is given to start the turn on its way to the landing. A head rigger with one choker setter was used during the first part of this study, and a

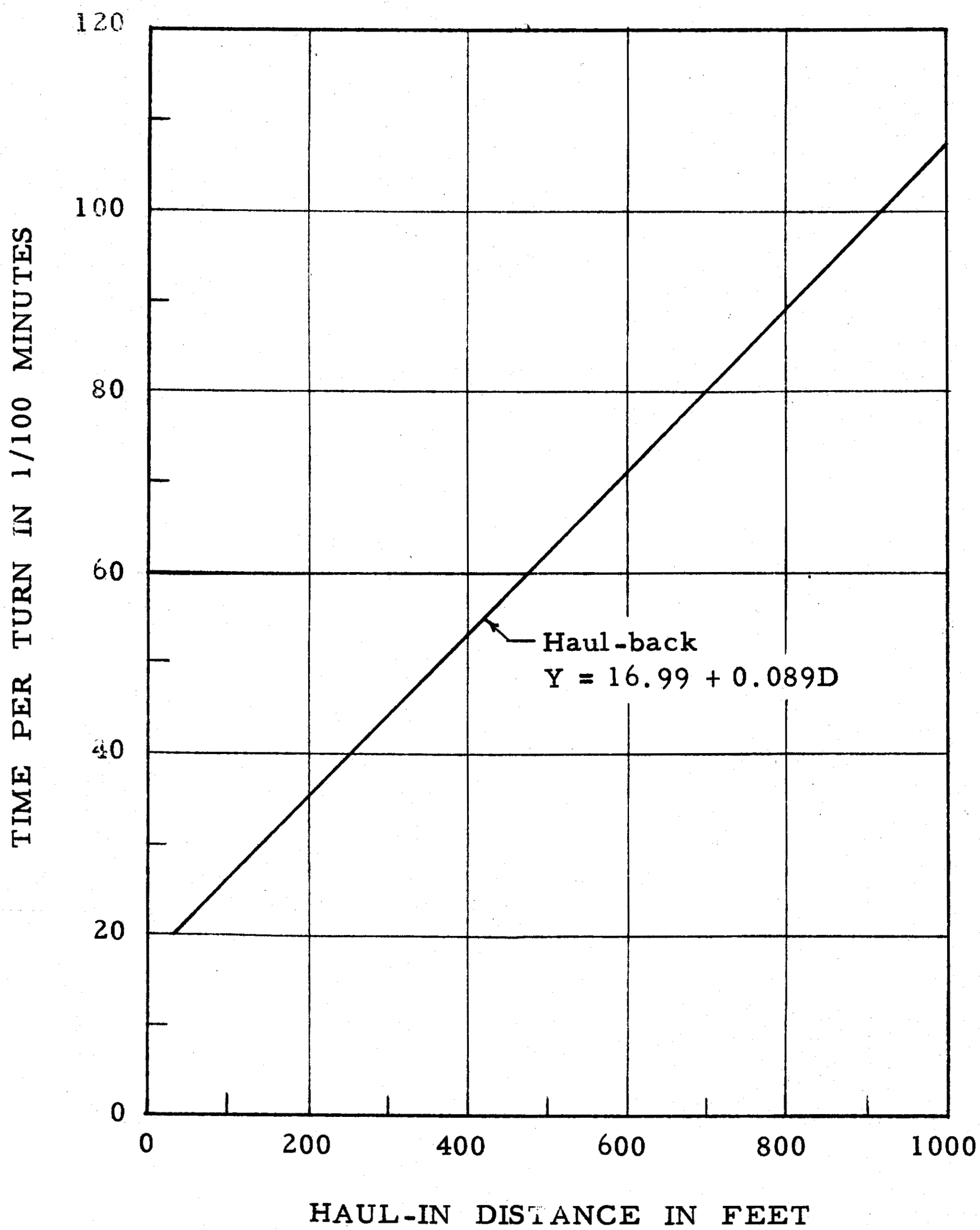

Figure 4.--Haul-back time per turn for various haul-in distances.

head rigger with two choker setters (fig. 5) during the last part to provide information on effect of crew size on production and costs.

Choker-set time increased as distance from the spar tree increased (fig. 6). Number of logs per turn and volume in board feet per turn had no significant effect; but as would be expected, choker-set time was less with two choker setters than with one. Regression analysis showed the following relationship: 3/

$$Y = 271.6 + 0.195\,D - 49.25\,C$$

Choker-set time per turn averaged 0.49 minute less with the larger crew. The two regression lines in figure 6 were assumed parallel since their regression coefficients were not significantly different.

The shorter time per turn with two choker setters was a considerable saving at short haul-in distances. For a 100-foot haul-in distance choker-set time was reduced 26 percent when two choker setters were used. At longer haul-in distances where choker-set time was greater, the 0.49 minute saving per turn became less important. At 800-foot haul-in distance the extra man reduced the choker-set time by 16 percent.

The formula for choker-set time is based on records taken throughout the study and, therefore, represents average ground conditions on the setting studied. A relatively low correlation coefficient ($R = 0.46$) and a high standard error of estimate ($S = 31.81$ percent) are due to rather wide variations in time for individual turns. These variations resulted from differences in brush and slash concentrations, density of timber, and ground conditions. If these factors had been classified at each choker setting, it would have been possible to estimate choker-set time for each class. This refinement, however, would have complicated the analysis, and it was not considered of enough practical importance to warrant the additional effort. Choker-set time as used in this study also includes the preparatory time for untangling chokers and moving butt rigging when necessary. These preparatory steps probably account in large measure for the increase in choker-set time with increasing distance from the spar tree. Topography made it difficult to keep the butt rigging off the ground at the greater distances and slowed up choker setting.

3/ The symbol C in the formula designates number of choker setters including the head rigger. Thus, C is 2 for 1 choker setter and 3 for 2 choker setters.

Figure 5.--A head rigger and two choker setters were used in the last part of the study.

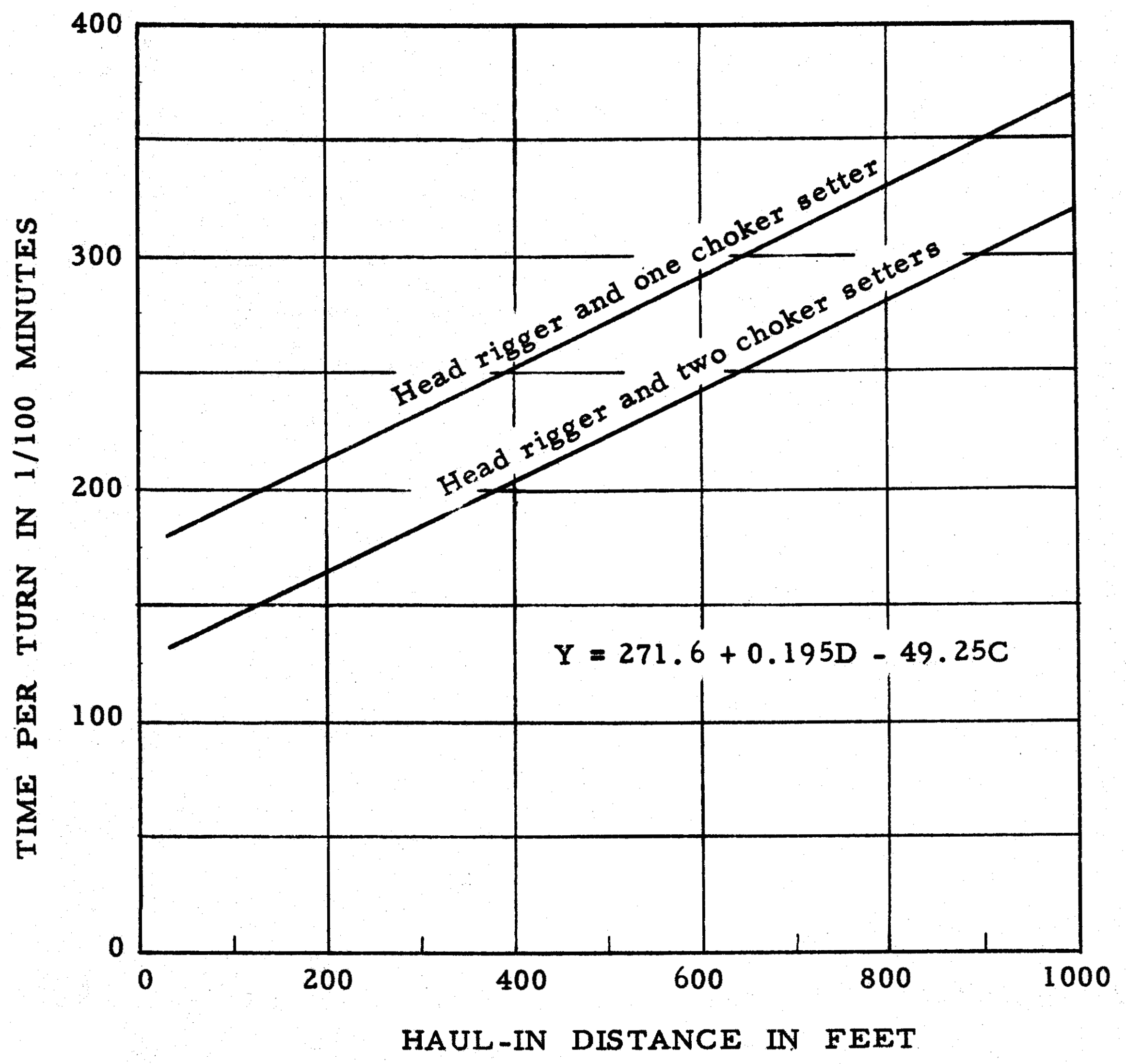

Figure 6.--Choker-set time per turn for various haul-in distances.

Haul-in Time

Haul-in time per turn is the time required to move a turn of logs from yarding area to landing. It begins with the "mainline ahead" signal and ends with the "stop" signal when logs reach the landing. All yarding in this study was uphill. Regression analysis indicated the following relationship:

$$Y = 34.76 + 0.167D + 0.000265D^2 + 0.0000485\,DV + 0.00072\,VS$$

Haul-in distance was by far the most important factor affecting haul-in time. In the case of a 1,000-board-foot turn on a 20-percent slope, haul-in time increased 275 percent when distance increased from 100 to 600 feet. However, volume per turn also had a significant effect on haul-in time (fig. 7). For a 100-foot distance on a 20-percent slope, an increase in volume per turn from 500 to 3,000 board feet increased the haul-in time by 75 percent. For a 600-foot distance, the same increase in volume increased haul-in time 43 percent. Steepness of ground affected time in much the same way as volume per turn. For a 1,000-board-foot turn at 300-foot distance, an increase in slope from level to 40 percent increased haul-in time by 23 percent (fig. 8). Effect of slope became greater for greater volumes per turn (fig. 9). In the above example if volume per turn had been increased from 1,000 board feet to 3,000 board feet, haul-in time would have increased 57 percent.

Unhook Time

Unhook time is the time required to unhook logs at the landing. It varies with number of logs per turn, as follows:

$$Y = 43.08 + 8.60\,N$$

Volume per turn in board feet had no significant effect on unhook time indicating that it took about as long to unhook a small log as a large log. Number of logs per turn ranged from one to five, but 76 percent of the turns consisted of two logs.

Total Maintime

Equations for the 4 maintime elements are grouped and combined in table 2. Standard errors of regression coefficients, correlation coefficients, and standard errors of estimate are also presented.

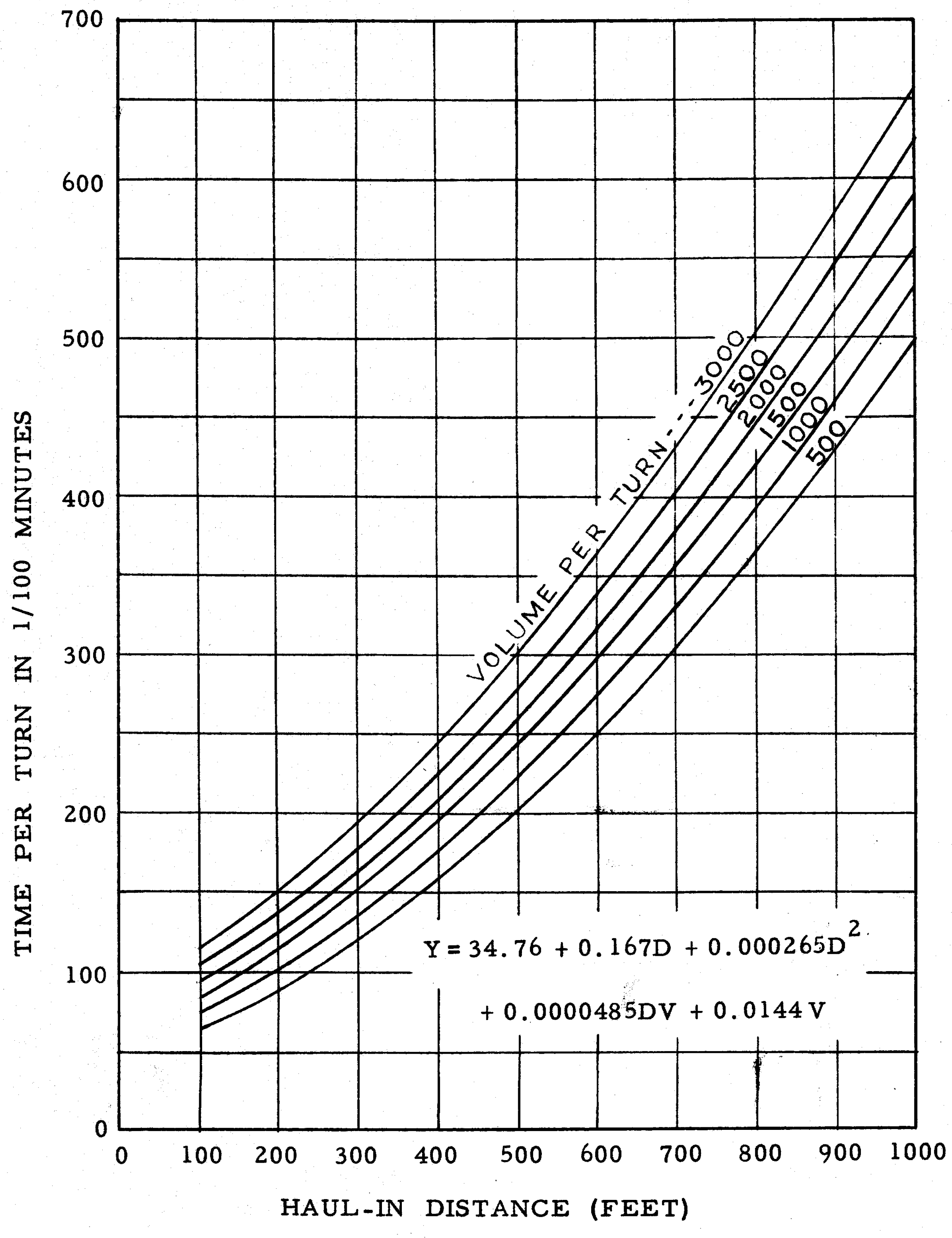

Figure 7.--Relationship of haul-in time to haul-in distance and volume per turn (slope 20 percent).

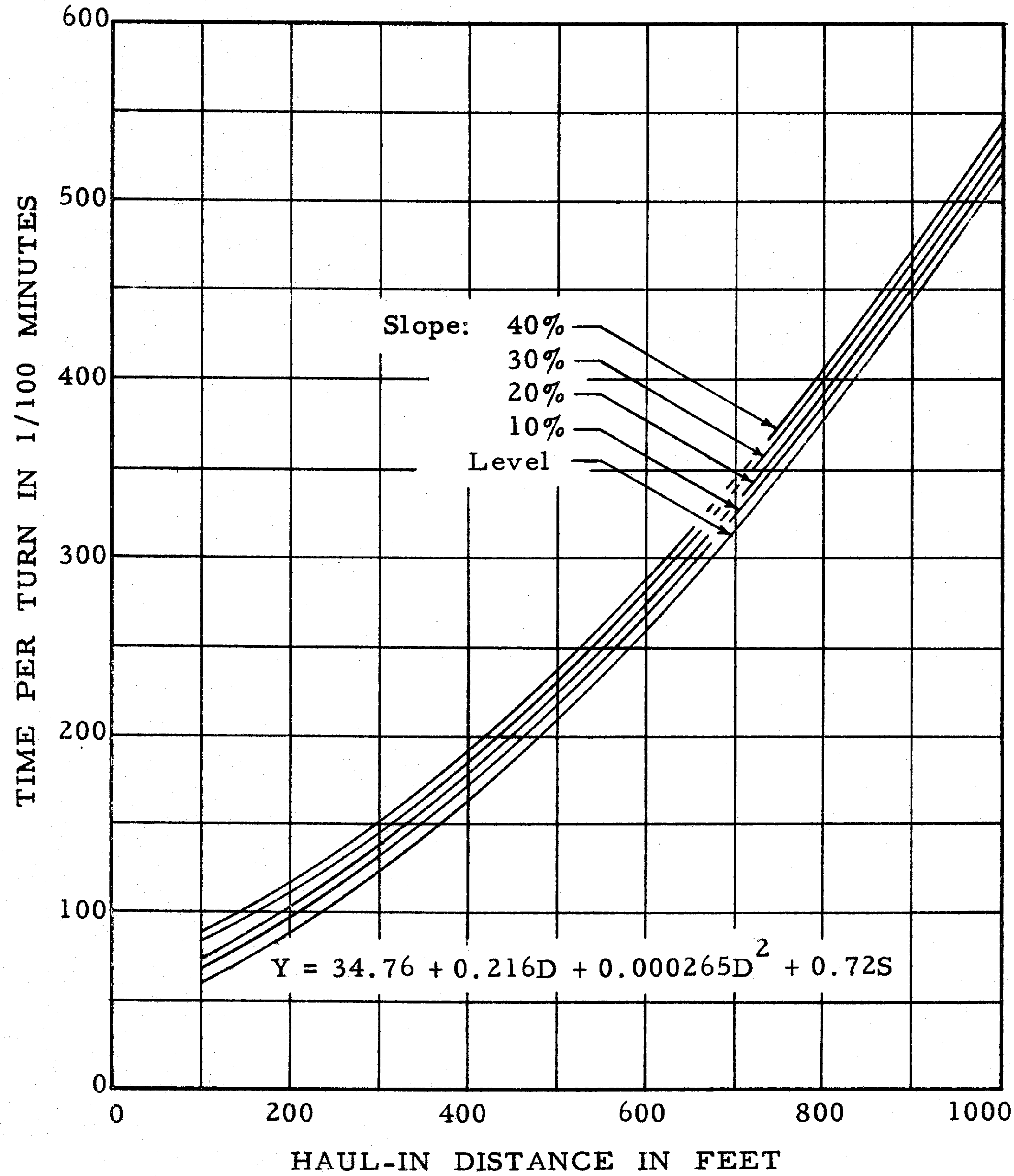

Figure 8.--Relationship of haul-in time to haul-in distance and slope (volume per turn, 1,000 board feet)

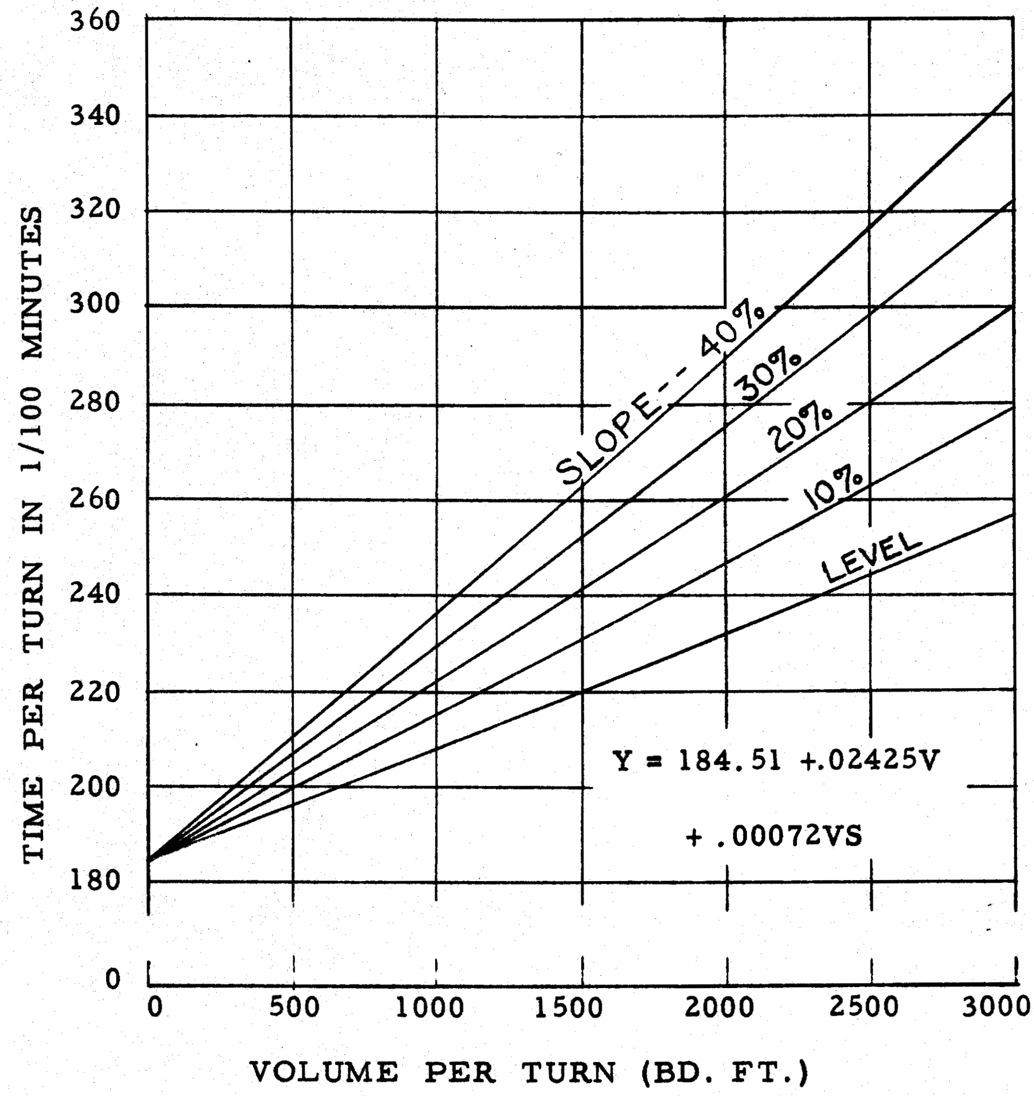

Figure 9.--Relationship of haul-in time to volume per turn and slope (haul-in distance 500 feet).

Table 2.--Summary of equations for maintime elements including standard errors in percent

Item	Haul-back	Choker-set	Haul-in	Unhook	Total maintime
Constant	16.99	271.60	34.76	43.08	366.43
Regression coefficient and percent error					
D	0.089 ± 1.0%	0.195 ± 7.7%	.167 ± 9.0%	--	.451
D^2	--	--	.000265 ± 8.7%	--	.000265
DV	--	--	.0000485 ± 21.0%	--	.0000485
VS	--	--	.00072 ± 23.6%	--	.00072
C	--	-49.25 ± 8.8%	--	--	-49.25
N	--	--	--	8.60 ± 0.4%	8.60
Correlation coefficient	.99	.46	.94	.60	
Standard error of estimate in percent	2.57	31.81	12.25	8.27	

Maintime per turn is the sum of haul-back and haul-in times when the yarding machine is doing most of the productive work plus choker-set and unhook times when the yarding crew is doing most of the productive work. Percentage of maintime required for each of these elements varies with haul-in distance and number of choker setters (table 3). For example, using one choker setter, machine time (haul-back and haul-in) was 28 percent of maintime at 100 feet haul-in distance, assuming 1,000 board feet per turn and 20-percent slope. Manual time (choker-set and unhook) was 72 percent. At 900 feet haul-in distance, machine time was 58 percent and manual time 42 percent.

Table 3.--Relative distribution of element times, by haul-in distances assuming volume 1,000 board feet per turn and slope 20 percent

Element	Haul-in distance									
	100		300		500		700		900	
	Number of choker setters									
	1	2	1	2	1	2	1	2	1	2
	Percent									
Haul-back	7.4	8.6	9.3	10.4	9.9	10.8	10.1	10.8	10.1	10.6
Choker-set	55.0	47.6	48.9	42.9	44.1	39.1	39.8	35.7	36.2	32.7
Haul-in	20.5	23.9	29.1	32.5	36.3	39.5	42.4	45.3	47.5	50.1
Unhook	17.1	19.9	12.7	14.2	9.7	10.6	7.7	8.2	6.2	6.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Supplementary Time

Supplementary time is not directly productive but is necessary to completion of the yarding operation. It includes time for changing yarding roads, changing corner block, moving yarding machine, swinging blocks on the spar tree, and tightening guylines. Times for changing yarding roads and corner block are fixed times per road. Number of choker setters made no significant difference in time required for these jobs.

For analysis purposes it was necessary to estimate supplementary time for a single turn, and this was influenced by number of turns per yarding road. A regression analysis shows that number of turns per yarding road was dependent on length of road and density of timber expressed in number of logs per acre. The equation [4/] is:

$$Z = 0.851 + 0.033\,L + 0.00024L \cdot T$$

Average time for changing yarding roads was 11.50 minutes per road. Changing the corner block took 15.16 minutes, but the block was not moved every time the yarding road was changed. Need for changing the corner block depended upon cable capacity of the haul-back drum and ground conditions. In this study the corner block was changed each 6.6 roads. Using this figure, time per turn for changing roads and corner block becomes:

$$Y = \frac{\left(11.50 + \frac{15.16}{6.6}\right) 100}{0.851 + 0.033L + 0.00024L \cdot T} = \frac{1380}{0.851 + 0.033L + 0.00024L \cdot T}$$

This equation shows that time per turn for changing both roads and corner block decreases when length of yarding road increases. It also shows that for a given length of road time per turn decreases when number of logs per acre increases. Number of logs per acre exerts greater influence on time per turn when yarding roads are short (fig. 10).

Other supplementary times on the setting studied were as follows:

	Minutes
Moving yarder	125
Swing blocks	60
Tightening guylines	145
Total	330

These additional supplementary times could be expected to differ on other settings, depending on topography, ground conditions, and skill and efficiency of the yarding crew. They were not, therefore, included as part of total supplementary time for this study.

4/ Standard error of regression coefficient for L is 31 percent and $\bar{L} \cdot T$, 15 percent. Correlation coefficient is 0.86 and standard error of estimate is 23 percent.

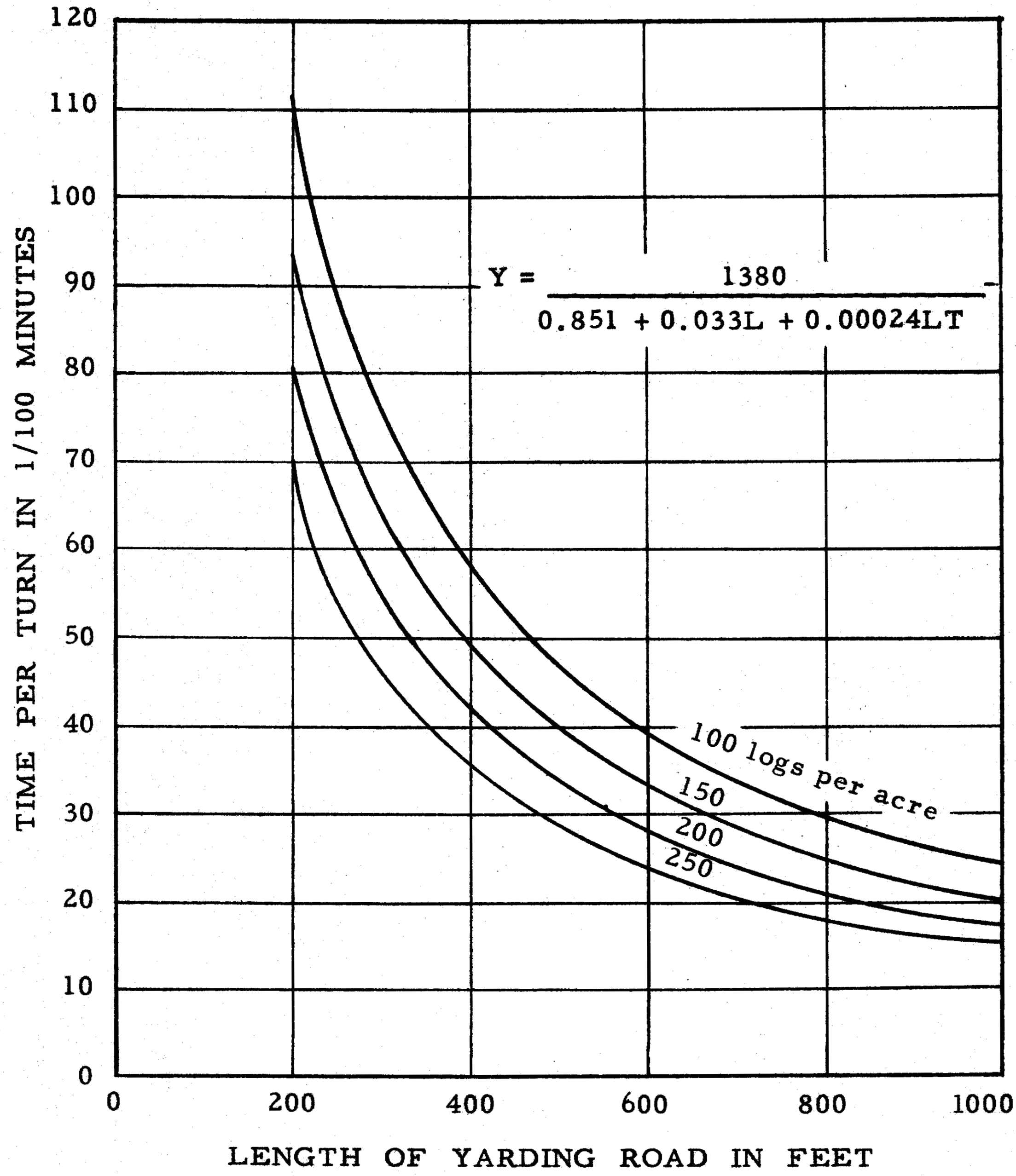

Figure 10.--Supplementary time per turn for various lengths of yarding road and densities of timber (number of logs per acre).

Delay Time

Delay times were divided into two primary classes--necessary and unnecessary (fig. 2).

Unnecessary delays are those due to poor supervision, faulty organization, careless placement of tools, and overly long rest periods. In this study, the only unnecessary delay occurred when the loading of trucks at the landing interrupted yarding. This delay amounted to 2.46 percent of basic time. However, this figure is not used in developing later estimates of production and costs, first, because it may not be typical, and second, because unnecessary delays can be avoided through efficient management.

Necessary delays are classed as personal or operational.

No personal delays occurred, and they are apparently not common in high-lead yarding. No member of the yarding crew works continuously. A choker setter, for example, can be free during haul-in, unhook, and haul-back.

Two types of operational delays occurred: equipment delays and working delays (table 4). Together they totalled 15.24 percent of basic time. Total necessary delay time is likewise assumed to be a constant percent of basic time.

Productive Time

Total productive time per turn is determined by combining maintime (table 2), supplementary time (page 19), 5/ and delay time (this page). The formula for total productive time then becomes:

$$Y = 1.1524 \left[366.43 + 0.451D + 0.000265D^2 + 0.0000485DV + 0.00072VS - 49.25C + 8.60N + \frac{1380}{0.851 + 0.033\,L + 0.00024L \cdot T}\right]$$

To simplify calculations maintime per turn has been tabulated for 2-log turns on level ground (table 5). Thus, maintime per turn for level ground can be read directly for different haul-in distances, volumes per turn, and crew sizes. Effect of slope is tabulated separately (table 6), and the slope allowance should be added to the time obtained from table 5. The next step is to add supplementary time, which can be read from table 7. The final step is to add the delay time allowance

5/ Exclusive of time for moving yarder, swinging blocks, and tightening guylines. These elements are discussed further on page 31.

Table 4.--Equipment and working delays in percent of basic time

Equipment delays		Working delays 1/	
Cause	Percent	Cause	Percent
Machine	3.88	Hang-ups	4.37
Drums	0.89	Lost logs	2.23
Lines	0.59	Shaking	1.33
Chokers	0.92	Landing	0.46
Miscellaneous	0.35	Miscellaneous	0.22
Total	6.63		8.61

1/ Working delays are defined as follows:

Hang-up: Time required to free a turn of logs stopped by a stump or other obstruction.

Lost log: Time required to pick up a log that has slipped out of the choker.

Shaking: Time required to shake limbs or other debris from a turn of logs.

Landing: Time required to arrange logs at the landing when they do not fall into proper place.

Table 5. --Maintime per turn in minutes for haul-in distance, volume per turn, and number of choker setters

Slope: level
Logs per turn: 2

Haul-in distance (feet)	Volume per turn in board feet							
	100	200	500	1,000	1,500	2,000	2,500	3,000
				One choker setter				
100	3.33	3.34	3.35	3.38	3.40	3.42	3.45	3.47
200	3.87	3.88	3.91	3.96	4.00	4.05	4.10	4.15
300	4.46	4.47	4.51	4.59	4.66	4.73	4.80	4.88
400	5.10	5.12	5.17	5.27	5.37	5.47	5.56	5.66
500	5.79	5.82	5.89	6.01	6.13	6.25	6.37	6.49
600	6.54	6.57	6.66	6.80	6.95	7.09	7.24	7.38
700	7.34	7.38	7.47	7.64	7.81	7.98	8.15	8.32
800	8.19	8.23	8.35	8.54	8.74	8.93	9.12	9.32
900	9.10	9.15	9.27	9.49	9.71	9.93	10.15	10.36
				Two choker setters				
100	2.84	2.85	2.86	2.89	2.91	2.93	2.96	2.98
200	3.38	3.39	3.42	3.47	3.51	3.56	3.61	3.66
300	3.97	3.98	4.02	4.10	4.17	4.24	4.31	4.39
400	4.61	4.63	4.68	4.78	4.88	4.98	5.07	5.17
500	5.30	5.33	5.40	5.52	5.64	5.76	5.88	6.00
600	6.05	6.08	6.17	6.31	6.46	6.60	6.76	6.89
700	6.85	6.89	6.98	7.15	7.32	7.49	7.66	7.83
800	7.70	7.74	7.86	8.05	8.25	8.44	8.63	8.83
900	8.61	8.66	8.78	9.00	9.22	9.44	9.66	9.87

Table 6.--Additional time per turn when yarding uphill by percent slope and volume per turn

Slope, percent	Volume per turn, in board feet							
	100	200	500	1,000	1,500	2,000	2,500	3,000
	Minutes							
10	.01	.01	.04	.07	.11	.14	.18	.22
20	.01	.03	.07	.14	.22	.29	.36	.43
30	.02	.04	.11	.22	.32	.43	.54	.65
40	.03	.06	.14	.29	.43	.58	.72	.86
50	.04	.07	.18	.36	.54	.72	.90	1.08

Table 7.--Supplementary time allowance per turn for changing road and corner block

Total length of yarding road, feet	Number of logs per acre			
	100	150	200	250
	Minutes			
300	.76	.63	.54	.47
400	.58	.48	.41	.36
500	.47	.39	.33	.29
600	.39	.32	.28	.24
700	.34	.28	.24	.21
800	.29	.24	.21	.18
900	.26	.22	.19	.16

of 15.24 percent. This procedure for obtaining total productive time per turn for a given setting is illustrated by the following example:

Estimated Conditions on Setting

Length of yarding road	700 feet
Haul-in distance 1/	495 feet
Volume per turn	1,000 board feet
Slope	30 percent
Number of logs per turn	2
Number of choker setters	1
Number of logs per acre	200

Solution	Time in minutes
Maintime per turn for level ground (table 5)	5.97
Allowance for slope (table 6)	.22
Supplementary time for changing road and corner block (table 7)	.24
Total basic time	6.43
Delay allowance, 15.24 percent of basic time	.98
Total productive time per turn	7.41

1/ For settings that approximate circles or segments of circles average distance equals .707 times length of yarding road (2).

Production

When total productive time per turn is estimated, production in thousand board feet per 8-hour day under various conditions can be calculated using the following formula:

$$B = \frac{8 \times 60}{Y}\left(\frac{V}{1,000}\right) = B = \frac{0.48\,V}{Y}$$

where:

B = production per 8-hour day in thousand board feet

V = volume per turn in board feet

Y = productive time per turn in minutes

For the above example in which total productive time per turn was 7.41 minutes, production in thousand board feet per 8-hour day will be:

$$B = \frac{.48 \times 1,000}{7.41} = 64.8 \text{ M board feet}$$

Similar production calculations can be made for varying haul-in distances, both crew sizes, various volumes per turn, and different slopes.

Both haul-in distance and volume per turn affect production to a high degree (fig. 11). The relatively minor effect of slope on production is illustrated in figure 12 for a 500-foot haul-in distance.

Adding a second choker-setter to the crew increased production. The increase was greatest at short haul-in distances and with high volumes per turn (fig. 13).

None of the tables and curves given in this paper include time allowance for rigging spar tree, moving yarder, swinging blocks, or tightening guylines. Time for these jobs differs widely from setting to setting. The reader should therefore estimate these additional supplementary times from his own experience and knowledge of ground conditions on the setting.

Costs

When production rate per day has been estimated, costs per thousand board feet can be calculated by dividing daily production into total operating costs as follows:

$$UC = \frac{M}{B}$$

where: UC = unit costs, i.e., costs per thousand board feet.

M = total operating costs, i.e., daily costs of labor, supplies, equipment, etc.

B = production in thousand board feet per 8-hour day.

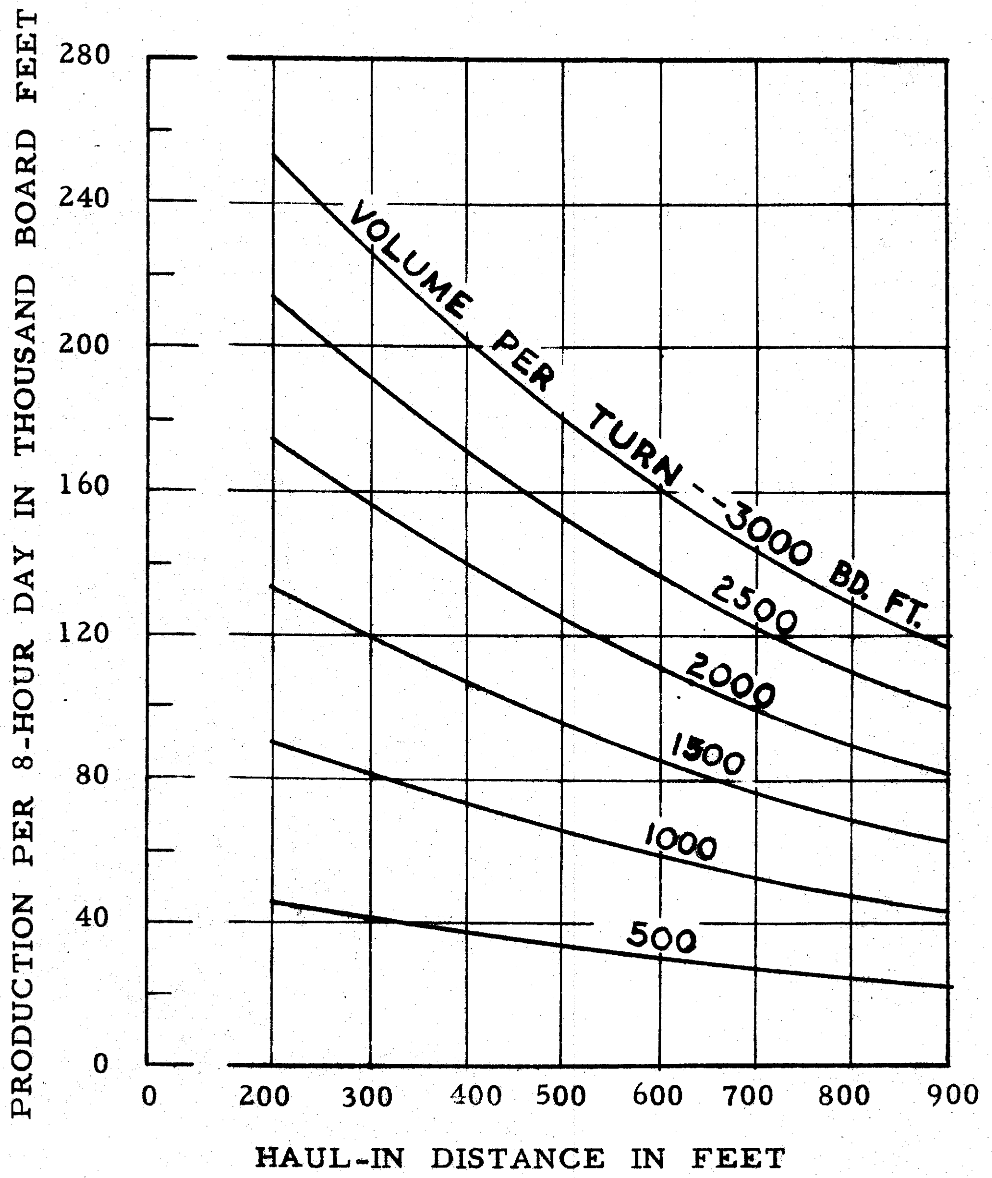

Figure 11.--Production in thousand board feet per 8-hour day by haul-in distance and volume per turn.

No. of choker setters:	1
Logs per turn:	2
Slope:	10 percent
Logs per acre:	200

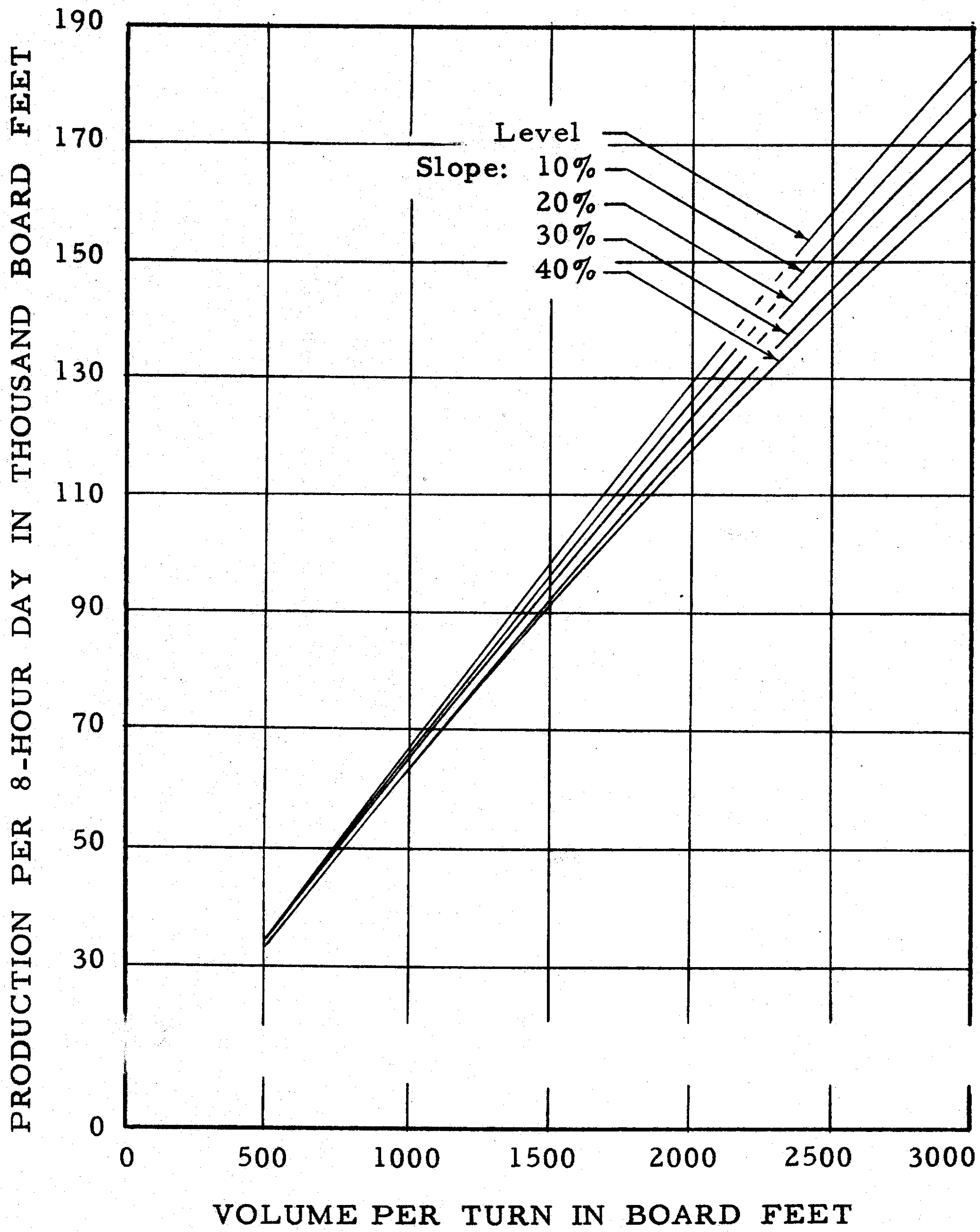

Figure 12.--Production in thousand board feet per 8-hour day by volume per turn and slope.

No. of choker setters:	1
Haul-in distance:	500 feet
Logs per turn:	2
Logs per acre:	200

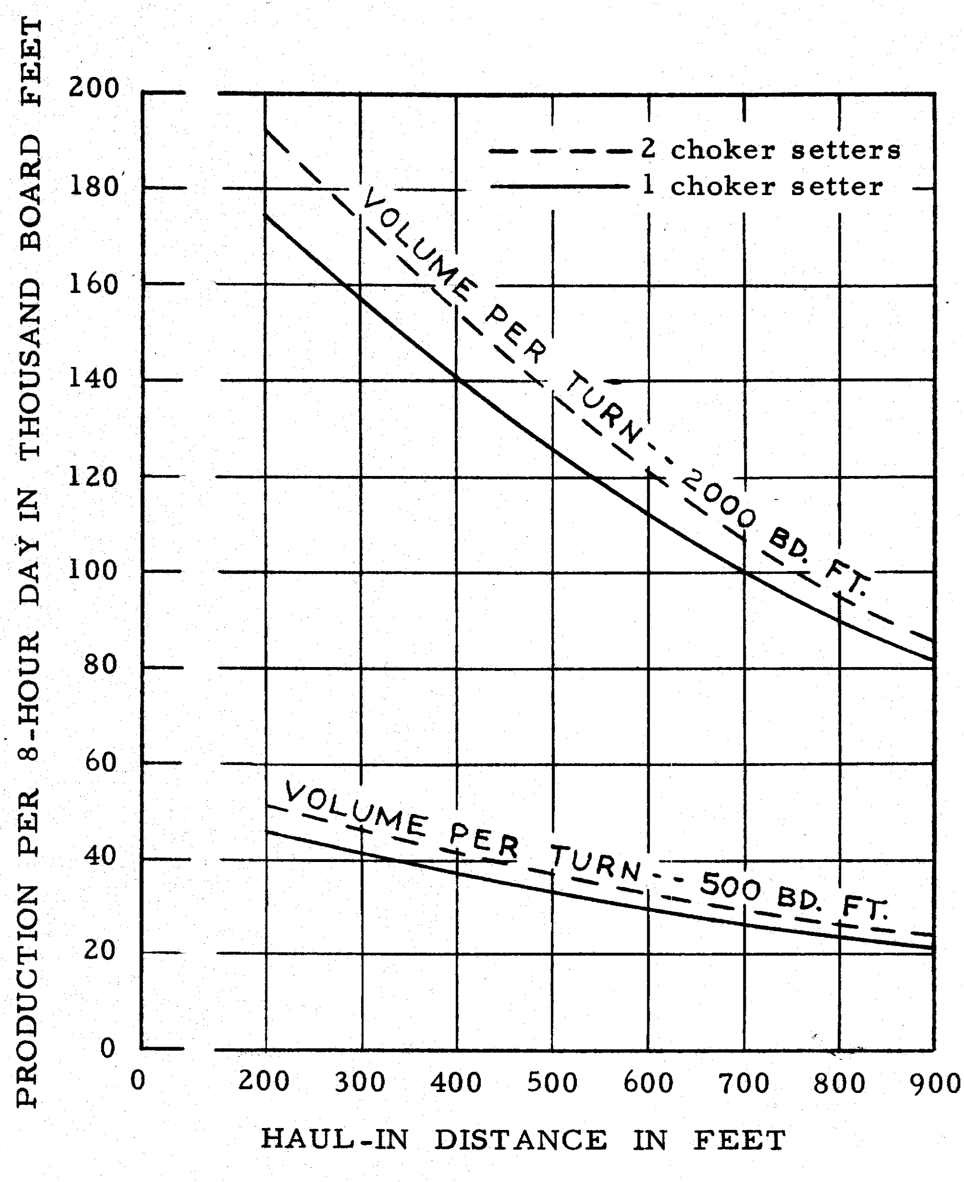

Figure 13.--Production in thousand board feet per 8-hour day by haul-in distance and crew size.

Slope:	10 percent
Logs per turn:	2
Logs per acre:	200

The average operating costs calculated in the following examples are based on current cost figures from Pacific Northwest logging companies using equipment similar to that used in the Cascade Head study (table 8). Costs can be expected to vary with economic conditions, and a current rate should always be used. Basic production data, however, can be used as long as equipment specifications remain essentially the same.

Using the above example for which production was estimated at 64.8 thousand board feet per 8 hours and substituting total operating costs from table 8:

$$UC = \frac{\$241.05}{64.8} = \$3.72 \text{ per M board feet}$$

By adding cost estimates for rigging spar tree, moving yarder, swinging blocks, and tightening guylines, and perhaps an allowance for unnecessary delays, we would obtain an estimate of total yarding costs per 1,000 board feet.

Costs of these supplementary elements can be expected to exert a pronounced effect on the relationships brought out in this study. For example, the advantage of short yarding roads might be offset by the cost of rigging more spar trees. More spar trees, in turn, would require additional miles of truck road.

Haul-in distance and volume per turn are major factors affecting yarding costs (fig. 14). Cost increases as haul-in distance increases. This trend is most pronounced when yarding with low volumes per turn.

Costs are about the same for both crew sizes at a haul-in distance of 700 feet and a volume per turn of 500 board feet (fig. 15). For shorter haul-in distances two choker setters were more efficient and for longer haul-in distances one choker setter was more efficient. There was a tendency for the break-even point to occur at shorter haul-in distances as volume per turn increased.

Table 8.--Total operating costs--triple-drum winch mounted on 130 drawbar horsepower crawler tractor 1/

Item	Charge per 8-hr. day 2/	Machine rate
		Percent
Current operating costs		
Labor:		
1 hooktender	$ 21.00	
1 head rigger	18.50	
1 engineer	20.00	
1 choker setter	16.50	
1 signalman	16.50	
1 chaser (including extra labor)	16.70	
Holiday pay and vacation pay	11.47	
Industrial insurance)		
Payroll taxes)	13.88	
Total labor	134.55	55.8
Supplies:		
Fuel	3.42	
Grease, oil, waste, etc.	2.00	
Wire rope and rigging	15.97	
Miscellaneous	4.33	
Total supplies	25.72	10.7
Maintenance	11.00	4.6
Ownership costs:		
Supervision	7.35	3.0
Initial costs $30,000		
Depreciation		
5,000 hours--1,000 hours per year	48.00	19.9
Interest, rate 6% of average value (2)		
$\frac{30,000 \times 6}{10} \times 0.06 = 1,080$	8.64	3.6
Fire insurance, rate 1.25% of average value	1.44	0.6
Taxes	4.35	1.8
Total ownership costs	69.78	28.9
Total operating costs	241.05	100.0

1/ Specifications in table 1, page 4.

2/ Charge per day is derived from season costs (1,000 hours) for all except labor items.

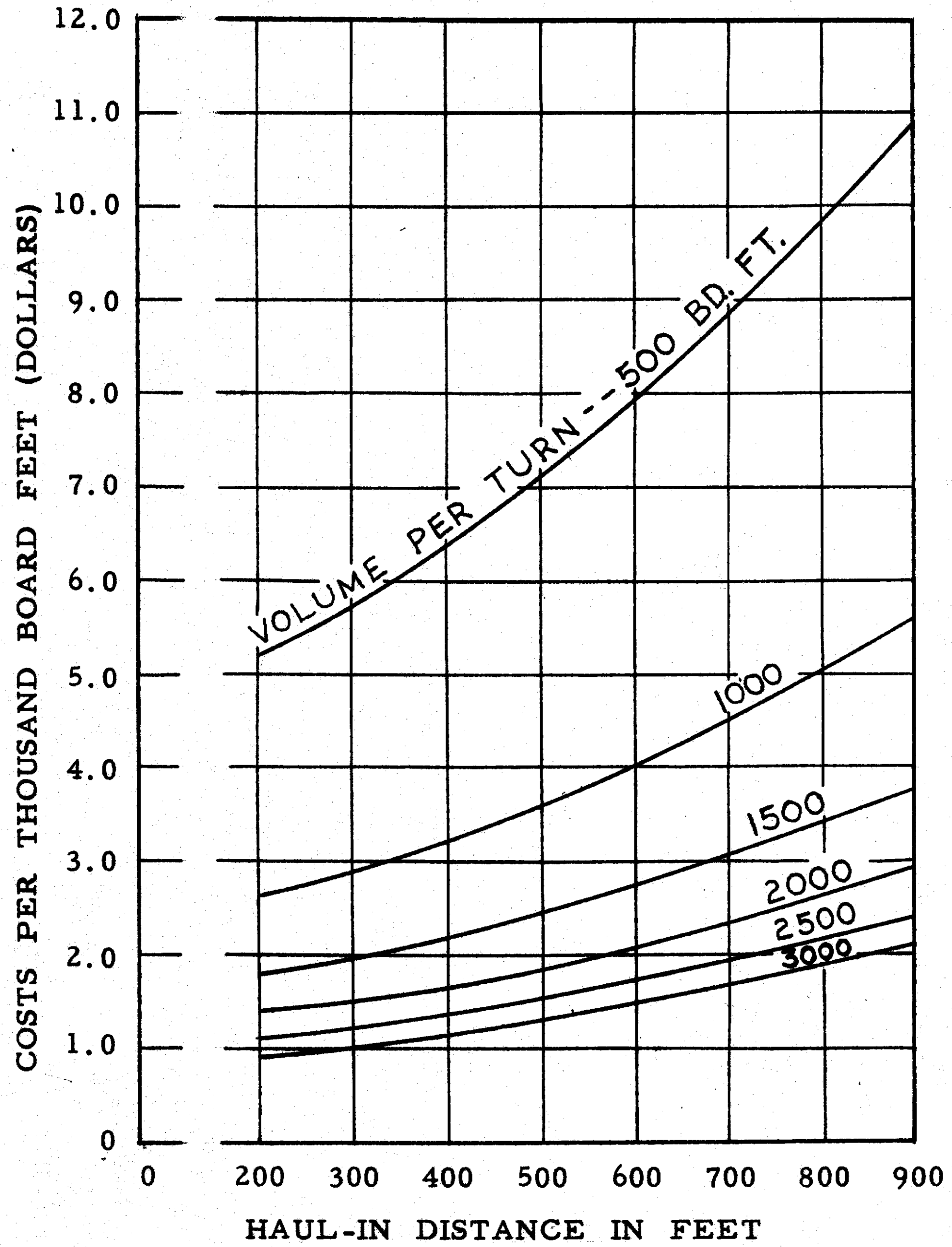

Figure 14.--Costs per thousand board feet by haul-in distance and volume per turn.

No. of choker setters:	1
Logs per turn:	2
Slope:	10 percent
Logs per acre:	200

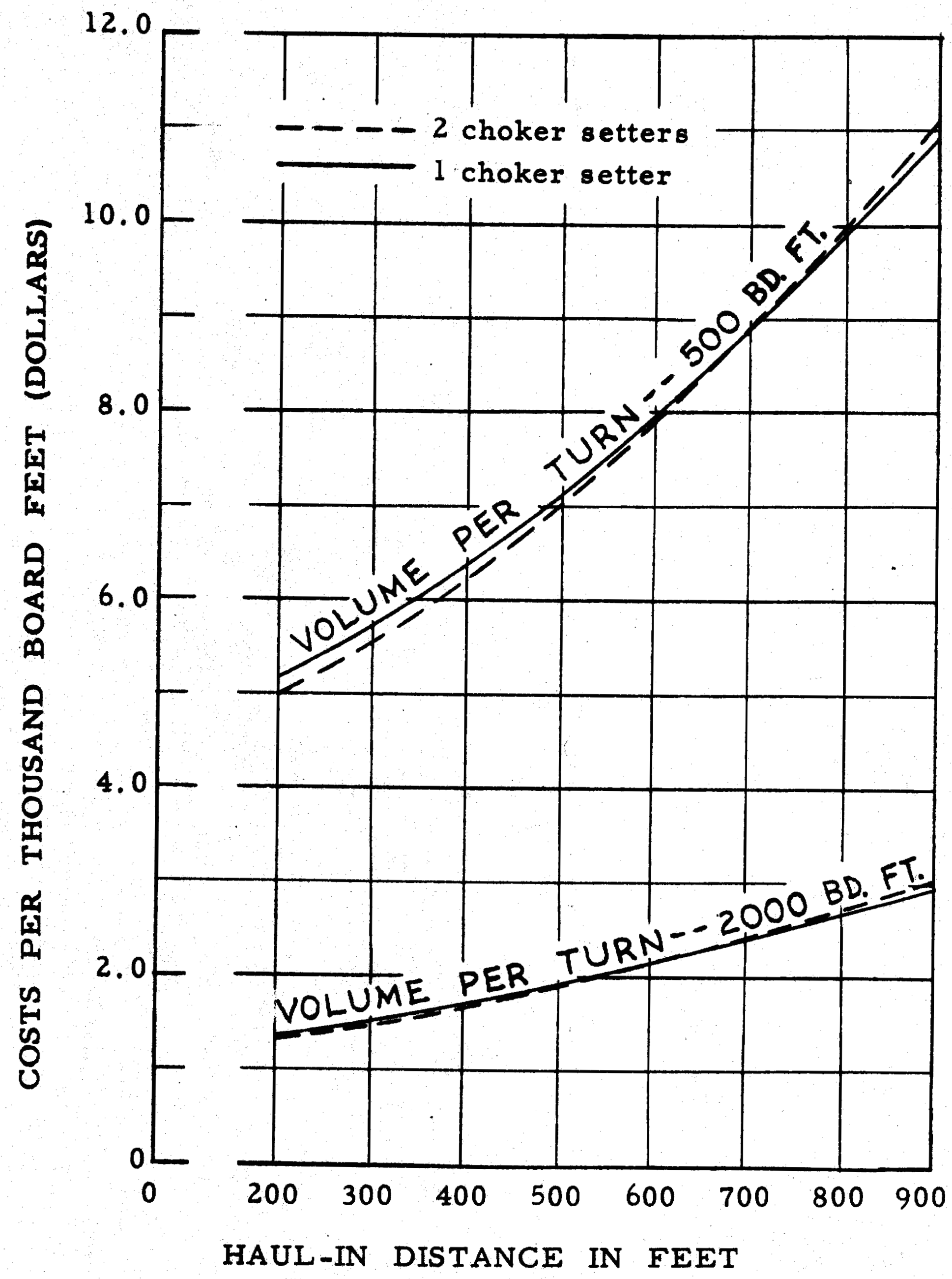

Figure 15.--Costs per thousand board feet by haul-in distance and crew size.

Slope:	10 percent
Logs per turn:	2
Logs per acre:	200

SUMMARY

Factors influencing production and costs on a high-lead yarding operation in a 100-year-old stand on the Cascade Head Experimental Forest near Otis, Oregon, were isolated and analyzed. The yarding machine was a 130 drawbar horsepower crawler tractor equipped with triple-drum winch.

Industrial engineering techniques and statistical analyses were used to estimate how crew size, haul-in distance, volume per turn, slope, length of yarding road, and number of logs per acre affected production and costs. The influence of these variables is illustrated by a series of curves. Formulas and tables are presented for estimating production rates for various combinations of conditions. Total operating costs are then calculated from production figures to obtain costs per thousand board feet.

Examples are given to illustrate how loggers and timber owners can use the formulas and tables to make yarding cost estimates for high-lead settings when using similar equipment and working within the range of conditions encountered in this study.

Choker-set time was found to increase with increasing distance from the spar tree, probably because at greater distances the butt rigging was on the ground and more difficult to arrange. Choker-set time per turn averaged 0.49 minute less when two choker setters were used than when only one choker setter was used.

Haul-in time per turn was closely related to haul-in distance, and volume per turn also had a significant effect, particularly at greater yarding distances. The effect of steepness of slope was minor but became more pronounced with high volumes per turn.

Unhook time was dependent on number of logs per turn. Volume per turn had no significant effect on unhook time indicating that it took about as much time to unhook a small log as a large log.

Haul-back was a typical machine operation with time influenced mainly by line speed and distance.

Average time for changing yarding roads was 11.50 minutes per road. Changing the corner block took 15.16 minutes. The corner block was changed each 6.6 yarding roads in the operation studied.

LITERATURE CITED

(1) Brandstrom, Axel J. F.
1933. Analysis of logging costs and operating methods in the Douglas-fir region. Washington, D. C. Charles Lathrop Pack Forestry Foundation. 117 pp., illus.

(2) Matthews, Donald Maxwell.
1942. Cost control in the logging industry. New York. McGraw-Hill Book Company, Inc. 374 pp., illus.

(3) Morrow, R. L.
1946. Time study and motion economy. New York. Ronald Press. 338 pp.

(4) Sammet, L. L. and Hassler, J. B.
1951. Use of the ratio-delay method in processing plant operations. Agric. Econ. Res. 3(4): 124-134. Oct. 1951.

(5) Samset, Ivar.
1950. Cutting studies in Norwegian spruce forest. Norwegian Forest Research Institute Report No. 37. Oslo, Norway. (In Norwegian with English summary.)

(6) Snedecor, George W.
1948. Statistical methods. Ames, Iowa. The Iowa State College Press. Ed. 4, 485 pp.