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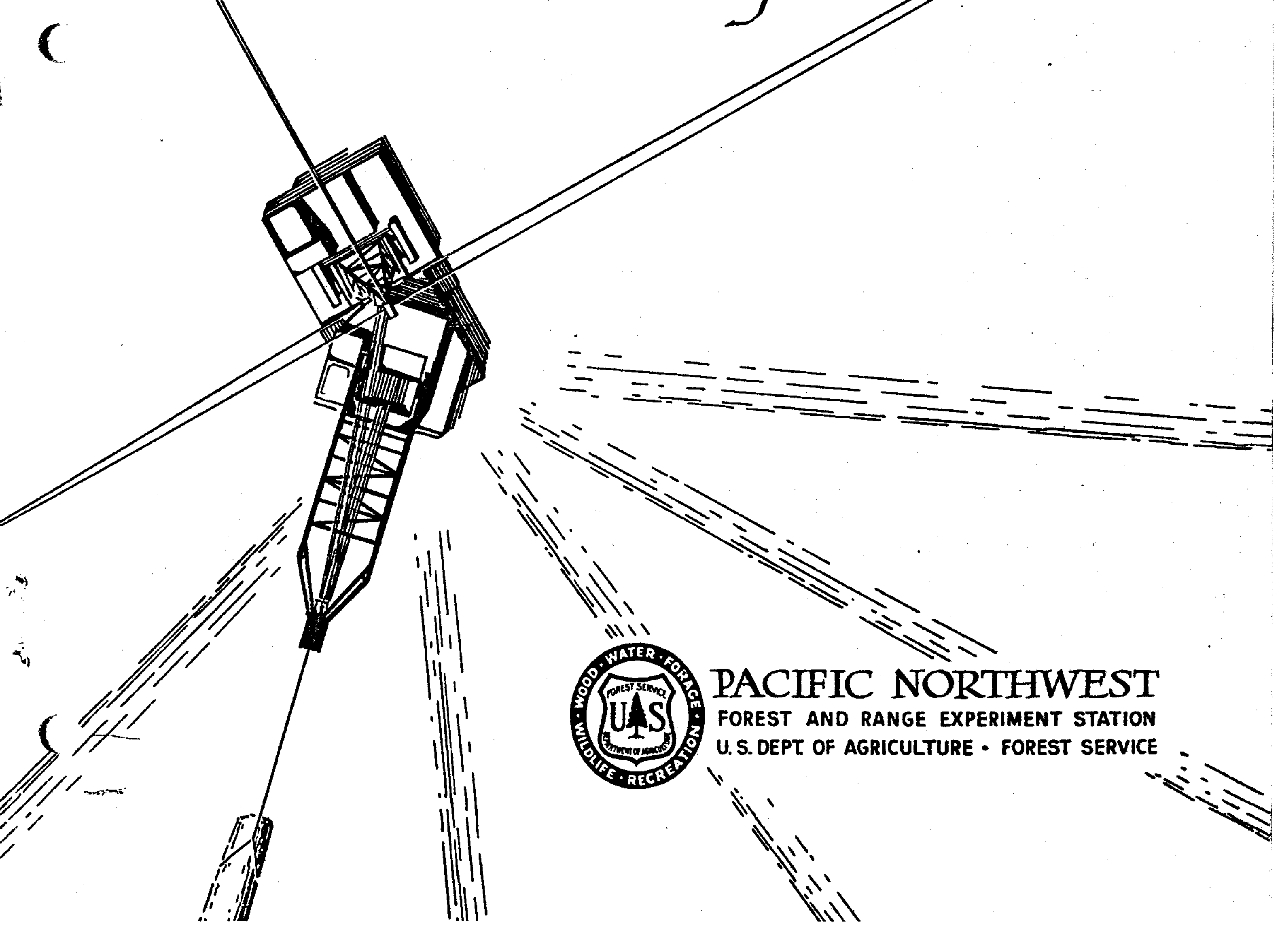
YARDING and LOADING COSTS

for salvaging in old-growth Douglas-fir with a mobile high-lead yarder

by JOHN CAROW



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This study was planned and conducted by John Carow, Associate Professor of Forest Management, School of Natural Resources, University of Michigan. Field work was carried out during the summer of 1955 while Professor Carow was employed by the Pacific Northwest Forest and Range Experiment Station. Analysis of data and preparation of this report were accomplished after he returned to teaching duties at the University of Michigan. Robert F. Keniston of the School of Forestry, Oregon State College, assisted on field phases of the study. Financial assistance was provided by a grant-in-aid from the Skagit Steel and Iron Works, Sedro Woolley, Wash.

SUMMARY

This report describes the use of a mobile high-lead yarder to salvage dead and down timber in old-growth stands reserved for future cutting under the staggered-setting system of management.

A time and production study of the yarding operation, and regression analyses of the data revealed the factors affecting each step in the yarding sequence. Results of the analyses permit prediction of yarding time per turn for different yarding distances and log sizes under conditions similar to those encountered on the study area. Also, an equation was developed to relate loading time to the number of logs per load.

Data on yarding costs were obtained by application of the yarder operating-cost rate to yarding times. A consideration of the geometry involved in yarding to landings along contour roads brought in other related logging costs--cable-road changing, moving and rig-up, and truck road construction--so that cost data from both the time study and the operator's records could be used to analyze problems of efficient planning.

Results indicate limits of volume per acre and log size within which efficient high-lead salvage operations can be planned. A formula is given for evaluating the effect of these and other variables in determining total yarding, moving, and road costs.

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CONTENTS

INTRODUCTION

The planned salvage of dead and down timber in old-growth Douglas-fir forests before the final cut is of particular interest where stands are being harvested by the staggered-setting system of clear cutting. Under this system, the whole forest is made accessible within a relatively few years by a network of high-standard roads. When areas are clear cut, all merchantable dead trees are harvested with the green timber. This material should also be salvaged periodically from the reserve settings--which may not be harvested for many years--if it can be done economically and without serious damage to the residual stand and the soil. Some material has been salvaged from reserve stands along existing roads and on favorable slopes, but the operation has often been piecemeal rather than part of a planned forestry-logging program.

Beginning in 1951, a series of experimental sales[1/] aimed at developing new salvage methods were made on the H. J. Andrews Experimental Forest, a 15,000-acre tract east of Eugene, Oreg., within the Willamette National Forest. These experiments sought to extend salvage operations to steep ground and systematically cover all reserve settings. Successful trials with high-lead equipment on steep topography were first made in 1953, when about 100 acres along existing roads were salvage logged with light, rubber-tired donkeys.

A later experimental sale was carried out during 1954-55 by the Tuff Luck Logging Co. of Blue River, Oreg. Objective of the sale was to investigate the feasibility of completely removing all useful dead and down timber from reserve units by means of a planned system of low-standard salvage roads to augment the primary road network. To further study objectives, high-lead yarding was required on the entire study area, even though parts of the tract were suitable for tractor yarding. As one of the major features of the

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1/ This series of sales was conceived and laid out by Roy R. Silen, assisted by H. J. Gratkowski and working in close cooperation with Salvage Loggers Robert Kenady and Robert Drury.

Because of low moving costs, it was feasible to yard areas having as few as 20 logs. Once rigged at a new setting, the mobile logger was used alternately for yarding and loading (fig. 2). Yarding proceeded

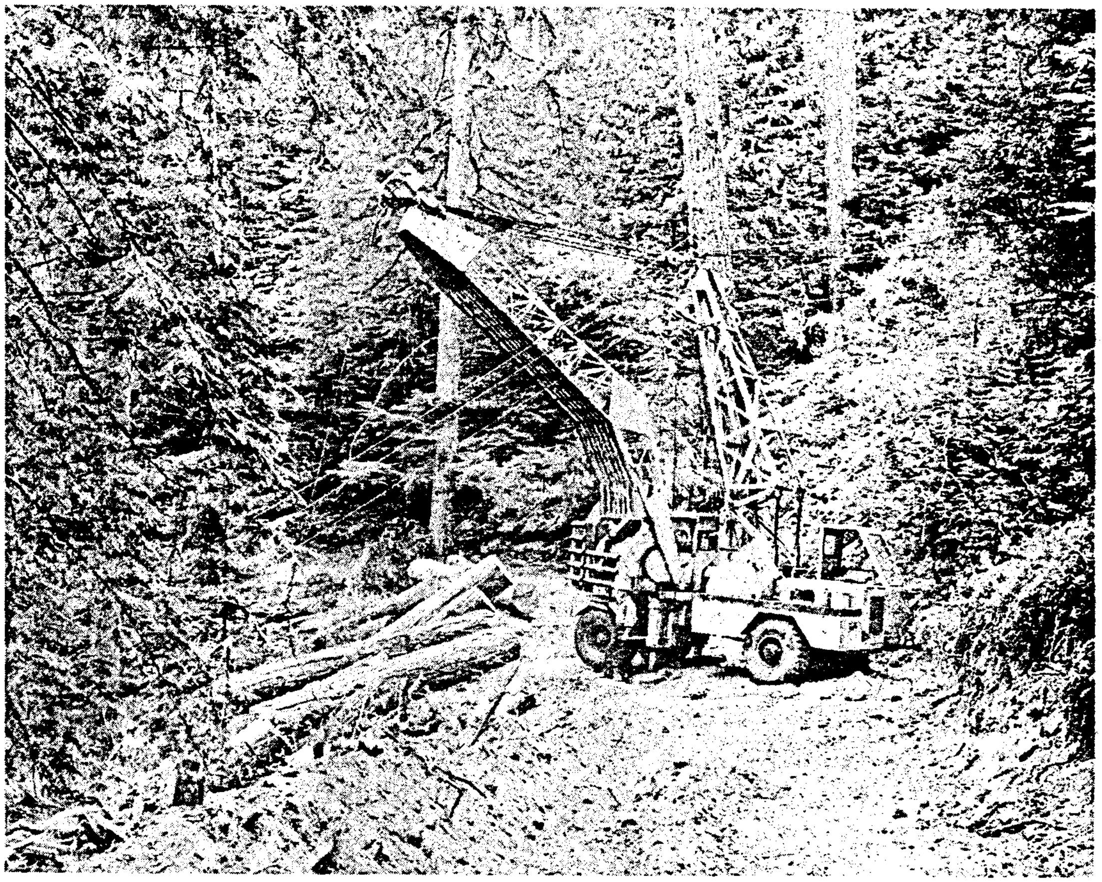

Figure 2.--A Skagit SJ-4 mobile yarder-loader at work on a setting along a contour road.

until at least a truckload of logs was on the deck and a truck was on hand. The boom was then lowered, tongs were attached to the main line in place of the butt rigging, and loading was begun. The reverse change was equally easy. Yarding took 65 percent of the working time; loading, 22 percent; moving and rigging, 9 percent; and cleanup and delays, 4 percent.

A crew of five men was normally employed. It consisted of a hook tender who acted as foreman, a choker setter, an unhooker, a machine operator, and a signalman. Often a four-man crew did the job without apparent loss in efficiency, but the hook tender had to work harder. The same crew did the loading.

RECORDS AND METHODS OF ANALYSIS

The time study was primarily concerned with the yarding phase of the operation, although data were also collected on loading time and production. A number of turns were studied in detail so that variables affecting each step, such as haul-in distance and log volume, could be isolated and better understood. Production time and cost were then estimated for different combinations of these variables, and total operating time was broken down into its essential parts (fig. 3).

The variables that were considered to affect elapsed time were haul-in yarding distance, slope (in percent), direction of slope (uphill or downhill), and log size as measured by gross log scale in board feet, Scribner rule. Data on other factors affecting total cost

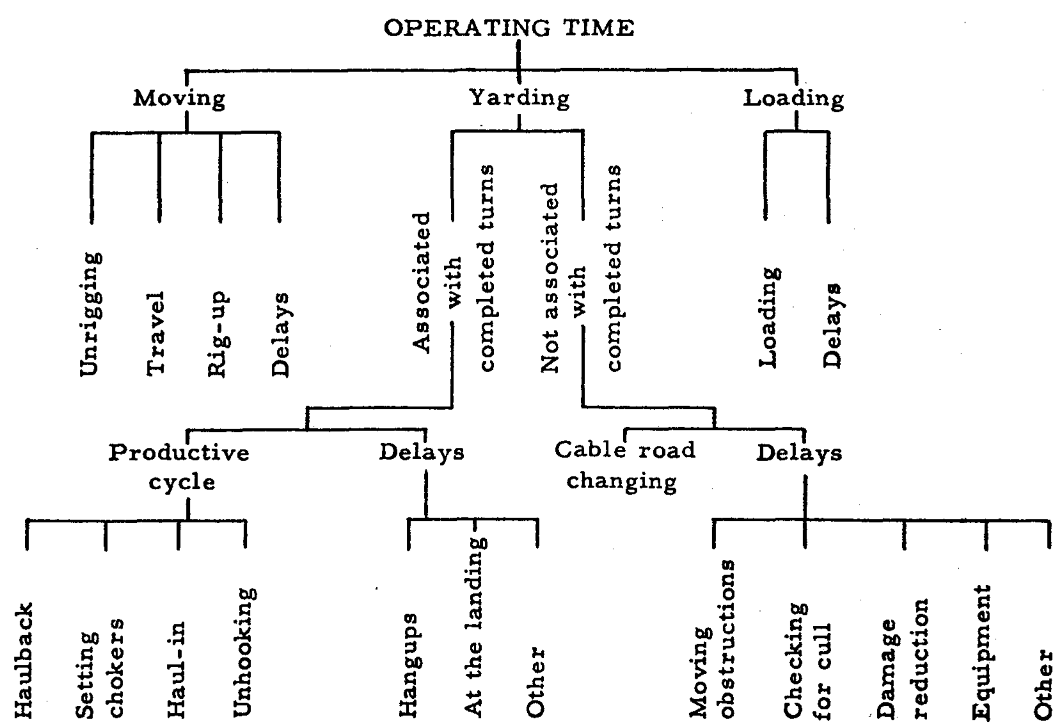

Figure 3.--Breakdown of operating time for the mobile yarder-loader.

per thousand board feet--such as volume per acre, road construction costs, and costs of moving and rig-up--were obtained from records kept by the operator.

Field work was done by a crew of two. One man observed the yarding process from a vantage point and recorded the time for each step to the nearest one-tenth minute. The other observer worked near the choker setters and recorded the distance each turn was yarded and the gross diameter, length, and scale of each log. Since only one log was taken on each turn, he was able to keep up with the yarding and coordinate his records with those of the timer. Yarding distances were estimated to the nearest 10 feet by observing the position of the log with respect to markings made in advance of yarding at 50-foot intervals along prospective cable roads.

The yarding cycle involved four basic, productive steps common to moving many types of materials: (1) haulback--taking the rigging out to the log; (2) choker setting, or attachment; (3) haul-in--transporting the log to the landing; and (4) unhooking at the landing. During this cycle there were often delays that caused considerable difference between turn times, even at comparable log locations.

Delays were timed where possible and identified as to cause. Results are shown in the following summary:

	Delay	
	(Minutes)	(Percent)
Hangups	522	56
At the landing	50	5
Moving obstructions	153	16
Checking for cull	89	10
Damage reduction	41	4
Equipment	34	4
Cutting snags	11	1
Cutting through logs	16	2
Cleanup	14	2
	930	100

Some delays occurred during turns, and the rest took place between turns. Hangup was the most important cause, since the lines had to be stopped to free the incoming log from obstructing trees, logs, or debris. When high-lead is used, hangups are much more frequent on a salvage operation than on a clear cutting operation, not only because the residual stand is obstructive but also because extreme care is required to avoid serious damage to it. Often, time must be spent in clearing debris from cable roads and placing fender logs at strategic places to guide incoming turns. Occasionally, too, time must be spent pulling out partially buried logs to see if their soundness warrants salvage. Other delays involve equipment troubles and straightening the log deck.

When the mobile logger was used for loading, beginning and completion times were noted on a loading form along with truck arrival and departure times and a tally of number of logs. Later the diameter, length, and net scale of each log was copied from the scale book.

Data were obtained for 386 completed turns. This information was transcribed onto cards, sorted, tabulated, and analyzed graphically to determine the nature of various relationships, and to see which were worth a more objective regression analysis. Graphical analyses showed that the data were inadequate to justify using steepness of slope or direction of slope (uphill or downhill) as important variables in any of the regressions. Regression equations were developed for each of the four yarding steps and for delays occurring on completed turns. By combining these five equations, an equation for total turn time was obtained. In the regression analyses, only those variables that were significant at the 5-percent level were retained in the final equations.

RESULTS

For the 386 completed turns that were studied, log and turn gross volumes ranged from 60 to 1,730 board feet, Scribner scale, and averaged 620 board feet. Haul-in distances ranged from 50 to 470 feet and averaged 220 feet. Most turns were yarded uphill on slopes ranging up to 50 percent.

Haulback Time

Haulback is the machine operation of sending the empty choker from the landing back to the choker setter. Generally, haulback takes place at a constant line speed and is related directly to distance traveled (fig. 4). On this operation, average haulback time was 0.45 minute, representing 9 percent of average turn time.

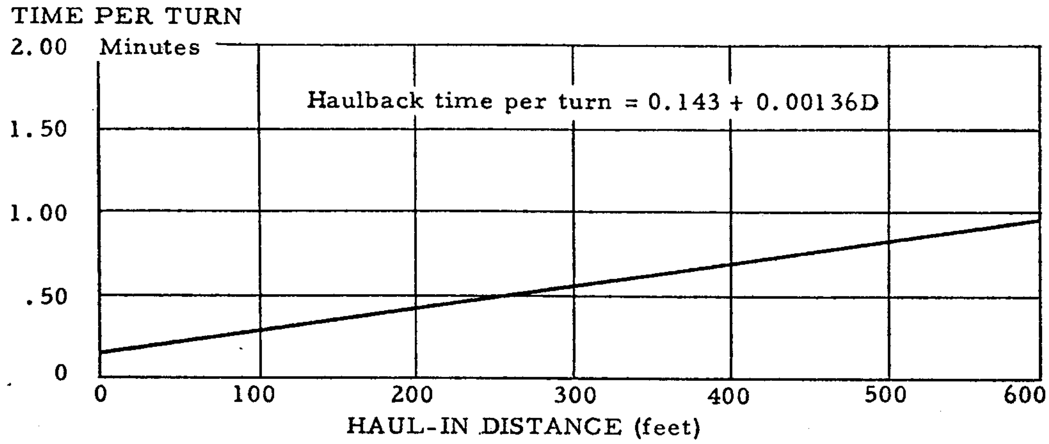

Figure 4.--Relation of haulback time to haul-in distance.

Choker-Setting Time

In terms of time, choker setting was the most variable step in the yarding operation. The regression analysis (illustrated in figure 5) showed that choker-setting time is related to log volume and yarding distance. The standard error of estimate was high, and the multiple correlation coefficient was low. Choker-setting time is related to log volume because it is more difficult to place the choker under a large, partially rotted log than under a small log that may be on top of the ground. Choker setting is an especially difficult job when timber has been down several years. Distance affects choker-

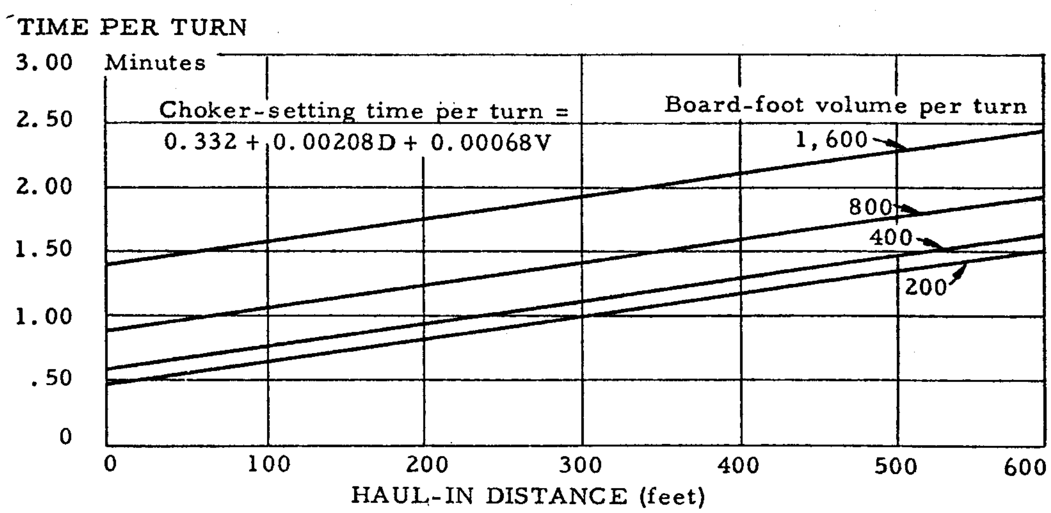

Figure 5.--Relation of choker-setting time to haul-in distance and log volume.

setting time because logs are generally farther from the main line at greater distances from the yarder, and it's often necessary to slack off on the line to reach them. Occasionally, extra chokers had to be used near the ends of long yarding roads. On the average, choker setting required 1.22 minutes per log--about one-quarter of the total turn time.

Haul-In Time

Net haul-in time, which averaged 1.61 minutes or almost one-third of the turn time, was the most important part of the yarding cycle. Net haul-in time is directly related to distance yarded because it includes only the times when the lines are actually moving, and because the yarder generally has sufficient power to maintain fairly constant line speeds. The linear relation between haul-in time and haul-in distance for the mobile yarder is shown in figure 6.

Haul-in time was also found to be related to log volume (fig. 6), although once initial inertia was overcome, slower line speed was associated with only the largest logs. In the multiple

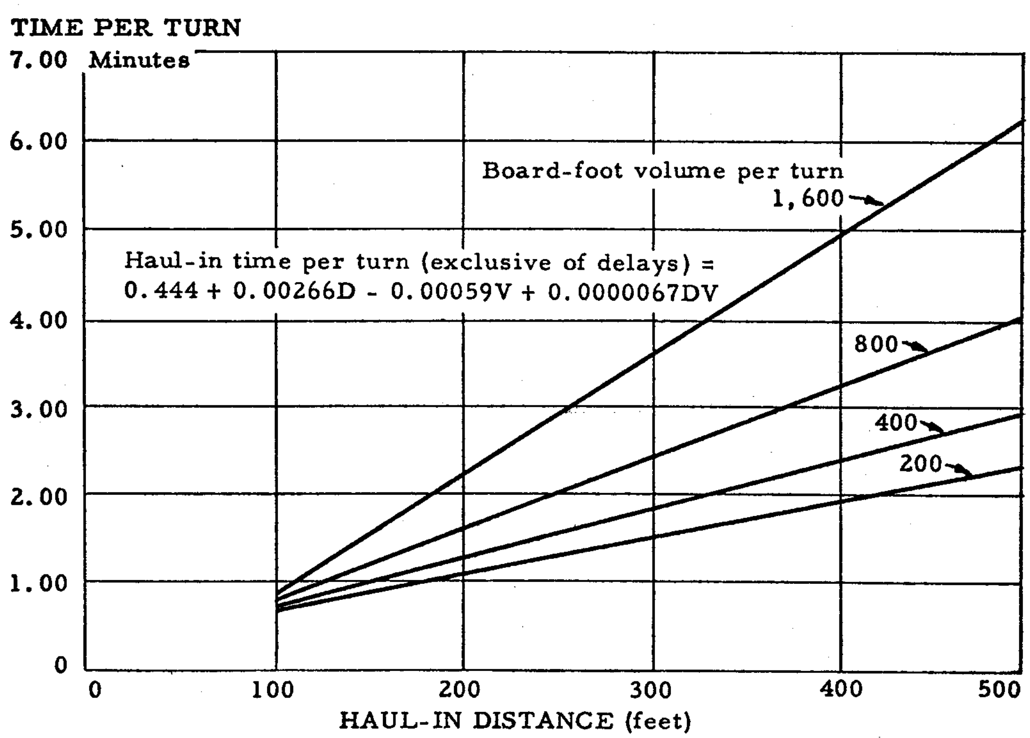

Figure 6.--Relation of haul-in time to haul-in distance and log volume.

regression, the combined variable "yarding distance x log volume" was also significantly involved in haul-in time.

Unhooking Time

The task of disengaging the choker at the landing averaged 0.34 minute per turn. It was not related to log size.

Delays Associated with Completed Turns

Delay times occurring during completed turns were recorded separately in order to free haul-in time of their influence. With conventional high-lead yarding, a curvilinear relation would be expected between such delay time and haul-in distance because delays usually occur more frequently at long yarding distances, where the lift effect of the lead is lessened.[3/] [4/] With the SJ-4 mobile logger, however, the lead provided by the short boom appears to have little effect beyond 100 feet. Thus, yarding beyond that distance is essentially ground-lead and the delay time as well as hauling time was found to have a linear relation to distance (fig. 7). Delays occurring during completed turns were found to be significantly related to the combined variable "yarding distance x log volume," but they were not significantly related to either of these variables taken individually.

Hangups were responsible for most of the delay time on completed turns. During the study, the observers noted that hangups were more frequent when large logs were yarded long distances, and that much time was often required to free logs by rolling them with the choker. Altogether, delays associated with completed turns averaged 1.45 minutes per turn, or 29 percent of total turn time. Hangups occurred on 211 out of the 386 turns studied.

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

4/ Tennas, Magnus E., Ruth, Robert H., and Berntsen, Carl M. An analysis of production and costs in high-lead yarding. U.S. Forest Serv. Pac. NW. Forest and Range Expt. Sta. Res. Paper 11, 37 pp., illus. 1955.

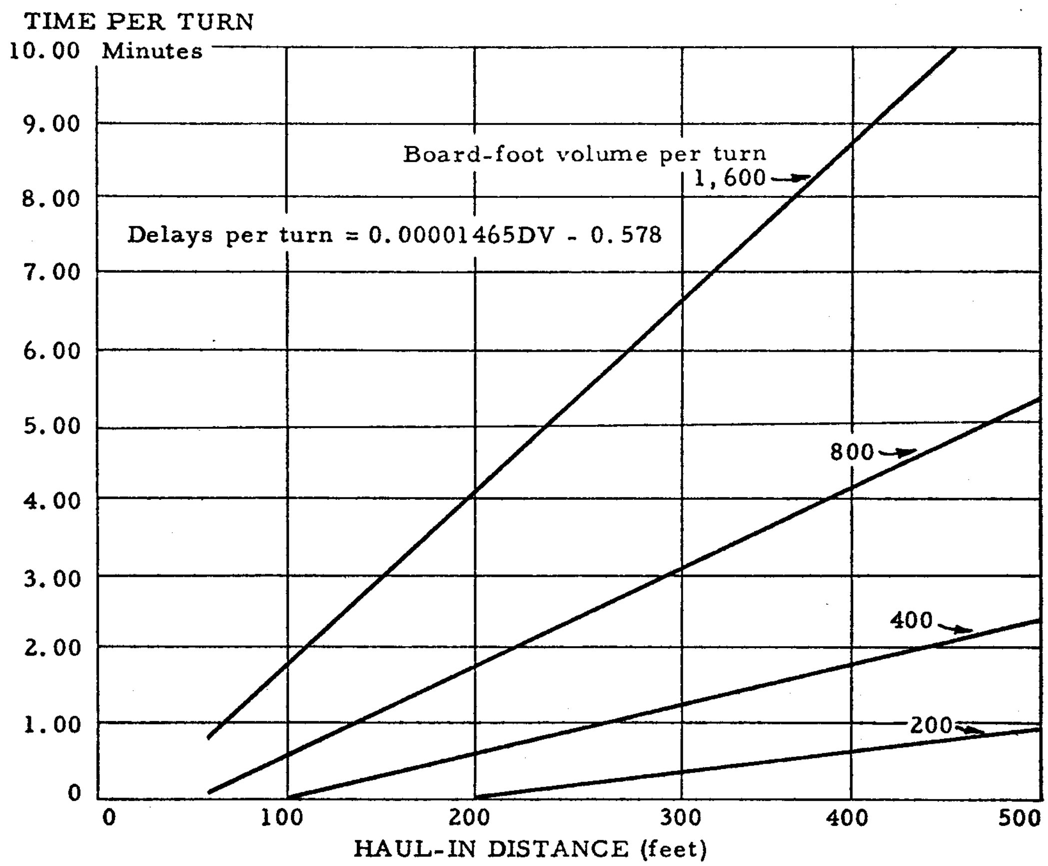

Figure 7.--Relation of delay time on completed turns to haul-in distance and log volume.

Delays Not Associated with Completed Turns

Forty percent of delay time occurred between turns and was not related to any of the independent variables studied. These non-associated delays averaged 0.96 minute per completed turn.

Yarding Time

The vertical columns in table 1 present data that can be used in equations for estimating the time involved in each basic step of the yarding process and for the delays occurring on completed turns. When the constants and regression coefficients are added horizontally, the resulting data in the right-hand column can be used in an equation for estimating total turn time. When 0.96 minute per turn is added to the constant to allow for delays not associated with

Table 1.--Summary of data used in equations for estimating yarding time per turn, with standard errors in percent

Item	Haulback	Choker-setting	Haul-in	Turn delays	Unhooking	Total turn time
Constant (minutes)	0.143	0.332	0.444	-0.578	0.340	[1/] 0.681
Regression coefficient, and percent error:						
D[2/]	0.00136 (±5.6)	0.00208 (±24.6)	0.00266 (±18.8)	--	--	0.00610
V[3/]	--	0.00068 (±21.8)	-0.00059 (±28.4)	--	--	0.00009
DV[4/]	--	--	0.00000672 (±10.4)	0.00001465 (±8.7)	--	0.00002137
Correlation coefficient	0.68	0.29	0.85	0.51	--	--
Standard error of estimate (percent of mean)	32.1	79.7	29.2	8.7	2.7	--
Mean (minutes)	0.45	1.22	1.61	1.45	0.34	[1/] 5.07

[1/] When yarding delays not occurring on completed turns are prorated, the constant term and the mean are increased by 0.96 minute, becoming 1.641 and 6.03, respectively.

[2/] D represents haul-in distance in feet.

[3/] V represents gross volume per log in board feet, Scribner rule.

[4/] DV is the product of D and V.

completed turns, the equation becomes:

$$\text{Total time in minutes per turn} = 1.641 + 0.00610D + 0.00009V + 0.00002137DV$$

Where: D = haul-in distance in feet

V = gross log volume in board feet, Scribner rule

DV = product of D and V

Solutions of this equation for various combinations of log size and haul-in distance are given in table 2.

Table 2.--Yarding time per turn for various haul-in distances and log volumes

(In minutes per 1-log turn)

Haul-in distance (feet)	Gross log scale, board feet, Scribner rule							
	200	400	600	800	1,000	1,200	1,400	1,600
100	2.7	3.1	3.6	4.0	4.5	4.9	5.4	5.8
200	3.7	4.6	5.5	6.3	7.2	8.1	9.0	9.8
300	4.8	6.1	7.4	8.6	10.0	11.2	12.5	13.8
400	5.8	7.5	9.3	11.0	12.7	14.4	16.1	17.9
500	6.8	9.0	11.1	13.3	15.4	17.6	19.7	21.9
600	7.9	10.4	13.0	15.6	18.2	20.7	23.3	25.9

Standard errors of estimate and correlation coefficients for each of the regression equations are also given in table 2. That choker setting is by far the most variable of the yarding steps is indicated by a high standard error and a low correlation coefficient. The correlation coefficient was significantly different from 0, however.

Line-Changing Time

When all logs within reach of the main line have been yarded, it is necessary to start a new yarding road by changing the direction of the main line, relocating the tail block, and sometimes relocating the corner blocks along the haulback line. Time consumed in line changing is fairly constant per change. It can also be logically considered as a constant per acre yarded. On the experimental salvage operation, line changing required an average of 17 minutes per change, or 31 minutes per acre yarded.

Loading Time

Loading with the SJ-4 on the salvage sale was an efficient operation. Though the log trucks often had to wait while the mobile yarder completed decking a full load of logs at the landing, the delay was reflected in higher hauling costs rather than higher loading costs.

A regression analysis relating loading time to number of logs per load, based on 187 loads, provided the following:

$$\text{Loading time per load in minutes} = 14.3 + 1.13(\text{number of logs per load})$$

Average time per load was 21.1 minutes, with a standard error of estimate of 28.3 percent. The average load had six logs and 2,800 board feet, net volume.

YARDING COSTS

Salvage yarding costs in dollars per thousand board feet were determined by estimating the operating-cost rate for the SJ-4 mobile logger and then applying yarding time from the regression equations. Hourly cost of machine operation was estimated, using information from the Tuff Luck Logging Co.'s records as much as possible. A breakdown of estimated cost is shown in the following tabulation:

	Charge per hour (Dollars)
Ownership costs:	
Depreciation $\left(\frac{\$30,000}{5 \text{ yrs.} \times 1,300 \text{ hrs.}}\right)$	4.62
Interest on investment $\left(\frac{30,000 \times 6}{10} \times 0.06 \div 1,300\right)$	.83
Taxes and insurance	.54
Total ownership costs	5.99
Operating costs:	
Labor:	
1 hook tender--first loader	2.75
1 engineer	2.50
1 choker setter--second loader	2.25
1 chaser (unhooker)	2.10
1 signalman--timekeeper	2.10
Holiday and vacation pay	.44
Industrial insurance (6.8% of payroll)	.82
Social security, unemployment insurance (5% of payroll)	.61
Total	13.57
Supplies and repairs:	
Fuel 1.5 gal. per hr. at $0.20	.30
Grease, oil, waste, etc.	.12
Wire, rope, and rigging	1.90
Repairs (estimate)	3.50
Miscellaneous	.50
Total	6.32
Total operating costs	19.89
Total cost of operation	1/ 25.88

1/ $0.431 per minute.

Depreciation was computed by the straight-line method over a 5-year life to approximate an average charge. The rate is computed on a 1,300-hour working year, which is about equivalent to seventy-five 8-hour and seventy 10-hour days. A five-man yarding crew was assumed, although the job could be done with as few as three men.

Table 2 presented the yarding time in minutes per turn for various haul-in distances and log volumes according to the regression equation developed from the time study. Table 3 gives the yarding time per thousand board feet for the same independent variables. When the figures of table 3 are multiplied by the machine rate of $0.431 per minute, the yarding cost in dollars per M b.m. results (table 4).

PLANNING AN EFFICIENT SALVAGE OPERATION

Many other factors in addition to yarding costs must be considered in planning an efficient operation. For instance, table 4 shows yarding costs to be least for the shortest yarding distances. Though this is true as far as direct costs are concerned, overhead costs (represented by moving and setting up, cable road changing, and truck road construction) require that settings cover a considerable area and timber volume, even though yarding costs will then be increased. In formula form, the cost per M b.m. for yarding, moving, and building spur roads is:

Yarding, moving, and
road cost per M b.m. = direct yarding cost per M
+ cable road changing cost per M
+ moving and rig-up cost per M
+ truck road cost per M

It is this total yarding, moving, and road cost that will be minimized by an efficiently planned operation.

Before examining the cost formula further, it is well to consider the layout of settings along contour roads. Assuming an even distribution of logs and a lack of special terrain problems, the shape of the area to be yarded to a given landing will depend on the slope of the ground. On flat ground, the yarder can work around a complete circle, although some shifting of guy lines and rigging is required. To avoid leaving corners, the setting shape may more

Table 3.--Yarding time per thousand board feet, Scribner rule, for various haul-in distances and log volumes

(In minutes per M b.m.)

Haul-in distance (feet)	Gross log volume, board feet, Scribner rule							
	200	400	600	800	1,000	1,200	1,400	1,600
100	13.4	7.8	6.0	5.0	4.5	4.1	3.8	3.6
200	18.6	11.5	9.1	7.9	7.2	6.7	6.4	6.1
300	23.8	15.2	12.3	10.8	10.0	9.4	9.0	8.6
400	29.0	18.8	15.4	13.7	12.7	12.0	11.5	11.2
500	34.2	22.5	18.6	16.6	15.4	14.6	14.1	13.7
600	39.4	26.1	21.7	19.5	18.2	17.3	16.7	16.2

Table 4.--Yarding cost per thousand board feet, Scribner rule, for various haul-in distances and log volumes

(In dollars per M b.m.)

Haul-in distance (feet)	Gross log volume, board feet, Scribner rule							
	200	400	600	800	1,000	1,200	1,400	1,600
100	5.80	3.40	2.60	2.20	1.90	1.80	1.60	1.60
200	8.00	5.00	3.90	3.40	3.10	2.90	2.80	2.60
300	10.30	6.60	5.30	4.60	4.30	4.00	3.90	3.70
400	12.50	8.10	6.60	5.90	5.50	5.20	5.00	4.80
500	14.70	9.70	8.00	7.20	6.60	6.30	6.10	5.90
600	17.00	11.20	9.40	8.40	7.80	7.50	7.20	7.00

nearly resemble a square. As slope increases, the difficulty of yarding along the sidehill and downhill without excessive hangups and damage to residual trees will necessitate reducing the width of the settings and shortening the reach on the uphill side.

Figure 8 illustrates placement of the yarder on level ground and on slopes along a contour road. The long dimension of the setting in figure 8B is labeled S--and the short side ZS, where Z is a decimal. Z will become smaller as the slope increases and sidehill yarding becomes more difficult. Matthews[5] and Suddarth,[6] in analyzing problems of yarding to landings, developed tables expressing average haul-in distance as a percent (p) of side S, when the width ZS is known. (On the experimental salvage sale, where slopes averaged about 30 percent, Z was found to be about 0.5 and p was 0.53. The average yarding distance was, therefore, 0.53S.) The area of the setting expressed in terms of these symbols is $\frac{ZSxS}{43,560}$ acres which becomes $\frac{ZS^2}{4.356}$ if S is measured in units of 100 feet. Also if V denotes volume per acre, then volume per setting would be $\frac{ZS^2V}{4.356}$.

The formula cost per M for yarding, moving, cable road changing, and truck road construction can now be expressed in symbols that will show how setting dimensions relate to efficient operation under varying conditions. If R is the cost of roads per mile, then the cost of a contour road across the setting will be $\frac{RZS}{52.8}$, and this divided by the volume available from the setting $\left(\frac{ZS^2V}{4.356}\right)$ will give a road cost per M of $\frac{R}{12.1VS}$. Moving and rig-up cost per M is the total cost per setting (L) divided by the total volume, or $\frac{4.356L}{ZS^2V}$. Cable road changing cost per M becomes $\frac{F}{V}$ when F is cost

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5/ Matthews, Donald Maxwell. Cost control in the logging industry. 374 pp., illus. New York and London. 1942.

6/ Suddarth, Stanley K. Cost minimization in the primary transport of forest products. 1952. (Unpublished thesis. Copy on file Purdue University, Lafayette, Ind.)

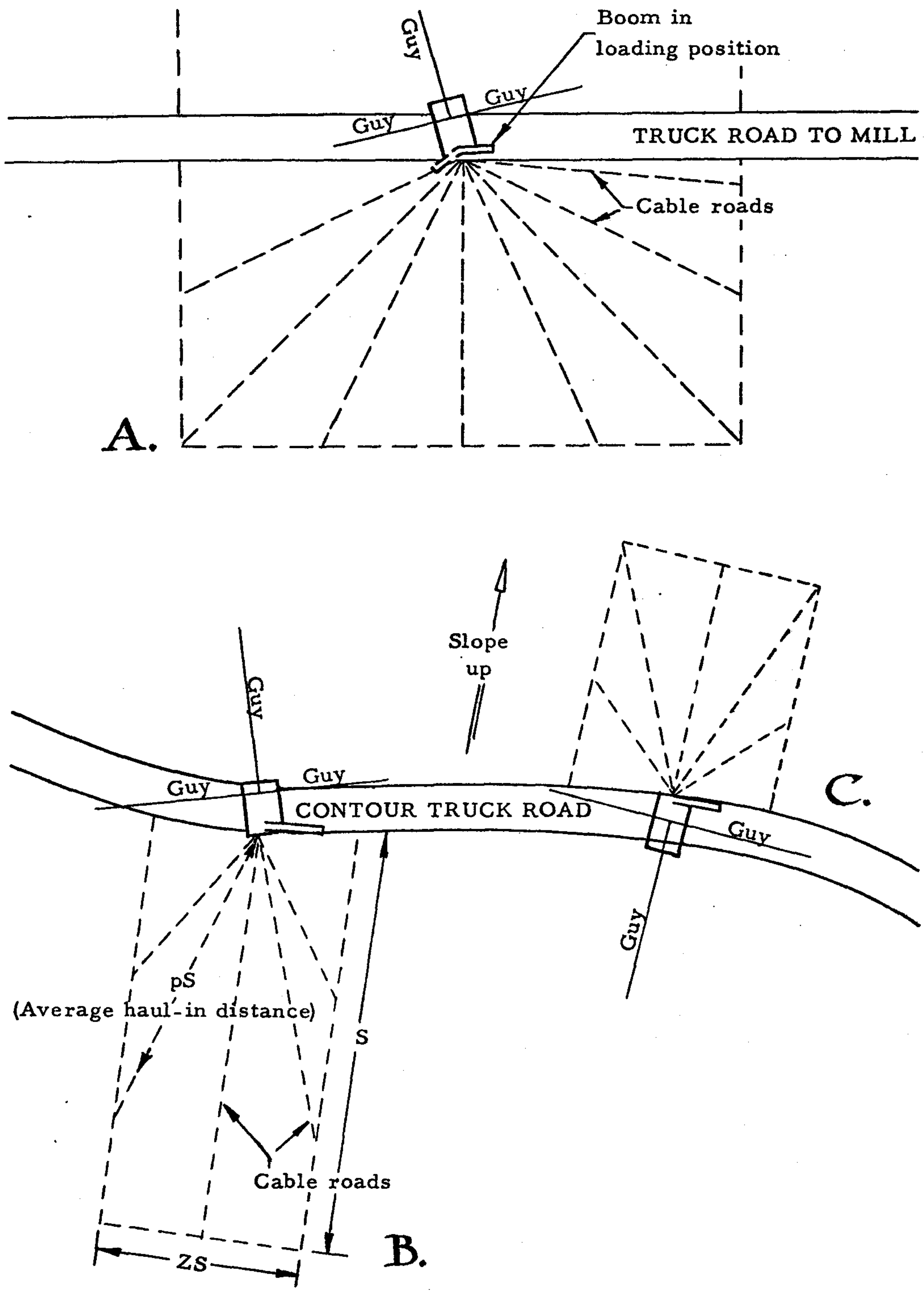

Figure 8.--Placement of mobile yarder-loader on typical settings. A. On level ground. B, On slope, yarding uphill. C, On slope, yarding downhill.

per acre. Direct yarding cost per M including delays, as presented in table 4, can be used directly in computing total cost under conditions similar to those encountered in the experimental sale. To make the results more general, a different form of presentation can be used--one that recognizes that direct yarding costs are partly related to yarding distance and partly independent. The related part is here expressed as C in terms of dollars per M per 100 feet of yarding distance. The unrelated part can be called I and expressed as dollars per M. Log size affected these values as follows:

Gross log scale (Board feet)	C (yarding costs related to distance) (Dollars per M per 100 ft.)	I (yarding costs unrelated to distance) (Dollars per M)
200	2.23	3.57
400	1.59	1.81
600	1.38	1.22
800	1.25	.95
1,600	1.08	.52

In a typical downhill-oriented rectangular setting, then:

$$\text{Yarding, moving, and road cost per M b.m.} = pCS + I + \frac{F}{V} + \frac{4.356L}{ZS^2V} + \frac{R}{12.1VS}$$

It will be noted that cost per M is directly related to yarding costs, road changing costs, moving and rig-up costs, and road costs per mile. On the other hand, cost per M is inversely related to volume available per acre and setting width. The effect of S, the long dimension of the setting, is mixed; a large value for S will increase some of the yarding costs. The formula can be solved to determine the value of S that will yield minimum cost, but the solution is complex. The determination of optimum external distance is more easily done graphically, as shown in figures 9 and 10.

Figure 9 shows cost per M for both average and external yarding distances when there is no truck road cost; i.e., when

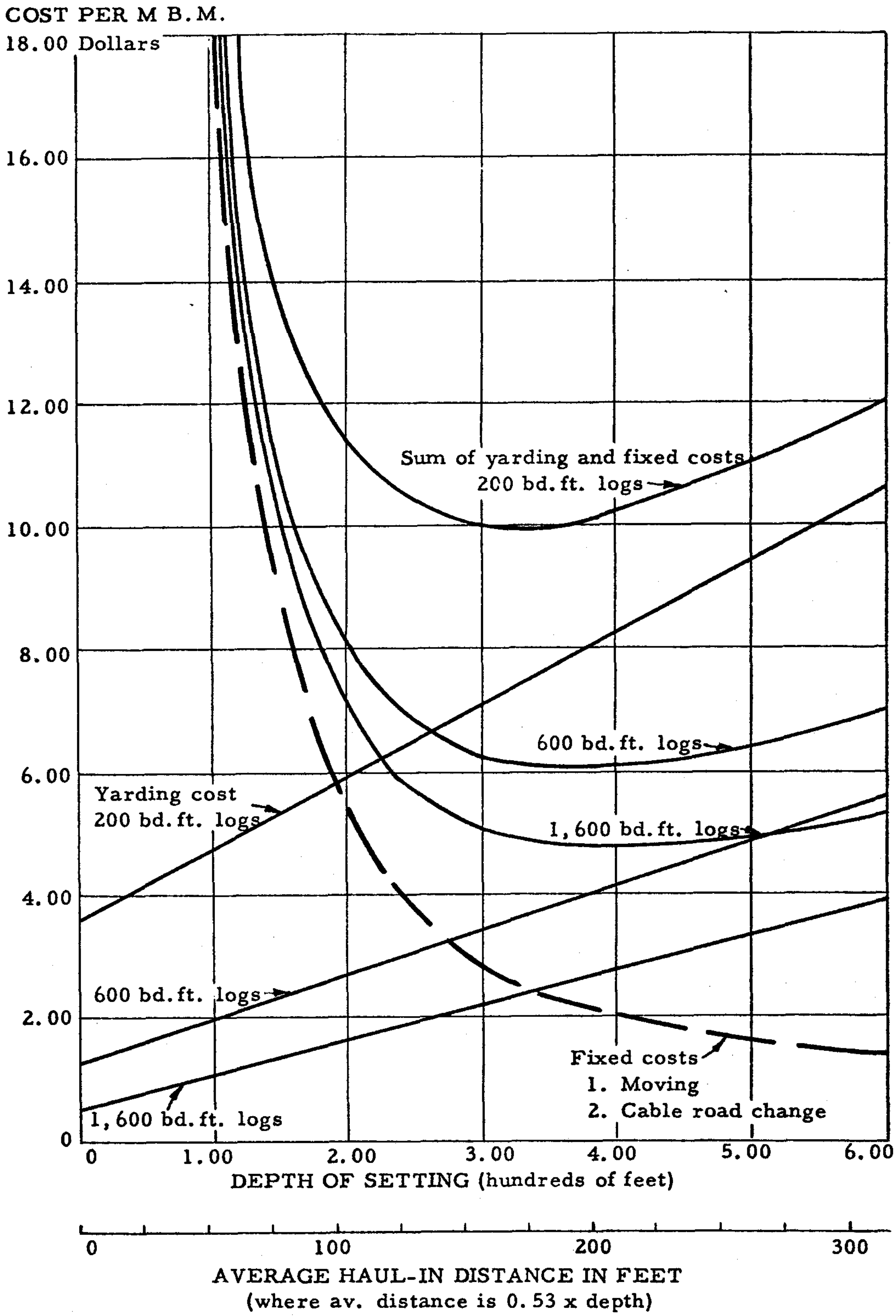

Figure 9.--Cost per thousand board feet for yarding, moving, and cable road changing as related to haul-in distance or depth of setting and to log size, when yarding from existing roads. (At 15 M b.m. per acre.)

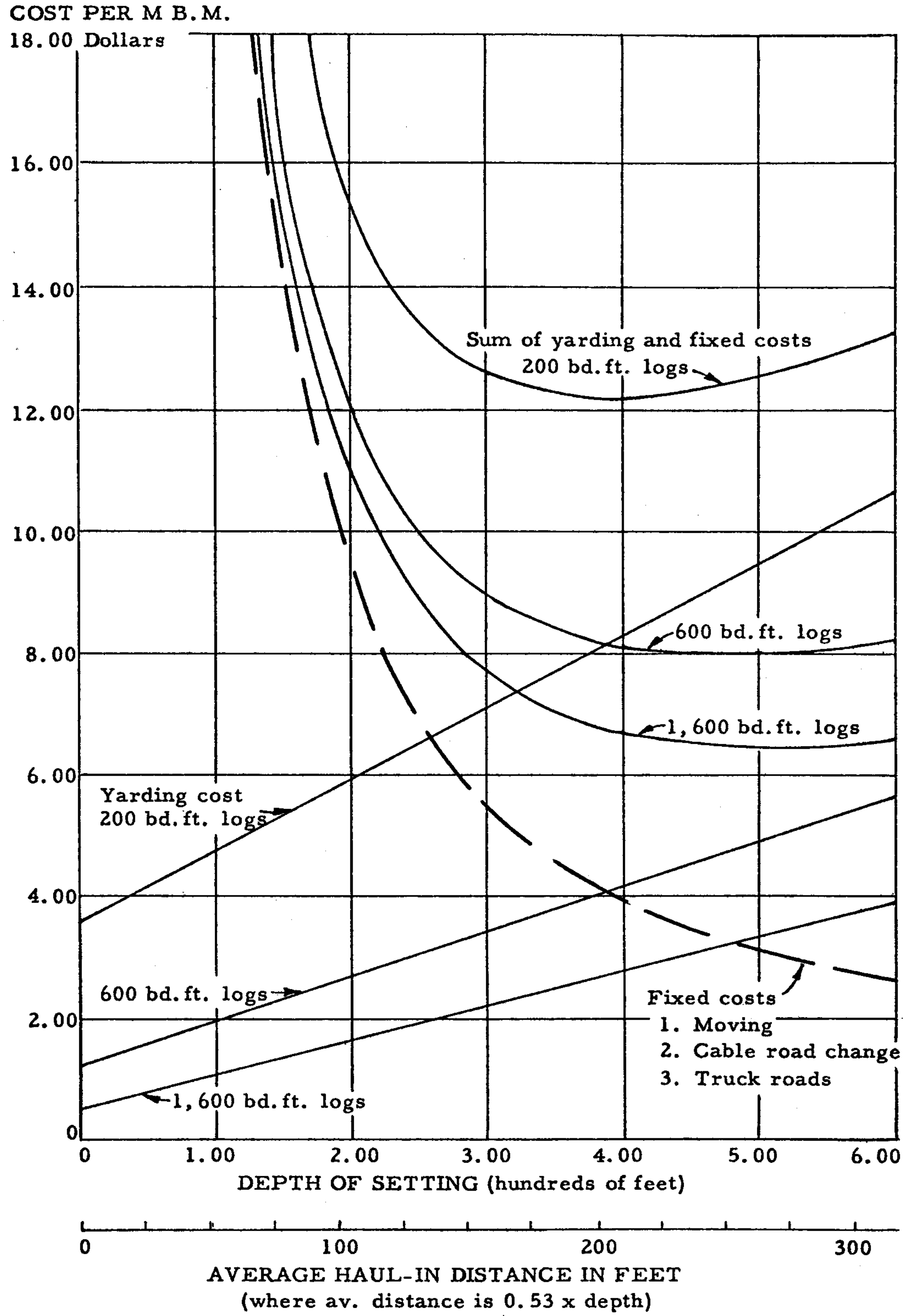

Figure 10.--Cost per thousand board feet for yarding, moving, cable road changing, and truck road construction as related to haul-in distance or depth of setting and to log size, when low-standard roads must be built. (At 15 M b.m. per acre.)

yarding is done from existing roads. Figure 10 shows the same picture when road costs must be included. Here, road construction costs are figured at $1,400 per mile, and moving and rig-up at $31 per setting; cable road changing costs of $13.35 per acre are represented in the fixed cost curve that falls as distance increases. The rising straight lines are from the regression analysis presented earlier in this paper. The curved lines that are the sum of the yarding and other costs are the costs per M given by the formula for three log sizes.

Several observations may be made from figures 9 and 10 regarding efficient planning on this and similar salvage operations.

1. There are definite optimum external distances for each log size, and the optimum for large log sizes is greater than for small sizes.

2. The range of economic external distance is broader for large logs than for small logs.

3. On the experimental sale, where average logs scaled 620 board feet, the average haul-in distance of 220 feet was economical but might have been increased with no increase in unit costs on areas where low-standard roads were required.

4. If markets set narrow limits on the amount that can be spent for moving, yarding, and roads; then graphs of this type can show which log sizes, if any, are operable.

Since available volume per acre is so important in spreading development and moving costs, the data have been recalculated to better reveal the significance of this variable. The 15-M b.m.-per-acre volume that was average for the test sale was used for figures 9 and 10. In contrast, figure 11 shows for two external yarding distances and three log sizes how costs per M change with volume density. Volume per acre appears to be less critical with the 500-foot than with the 300-foot setting depth; but with more than 10 M per acre, the curves show that density may not be decisive. Under the assumptions used, however, stands of less than 5 M per acre are relatively uneconomical.

In figures 10 and 11, setting depths of 500 feet appear to have been satisfactory for the Andrews Experimental Forest under assumptions of one-way skidding. Therefore, a 500-foot road spacing would

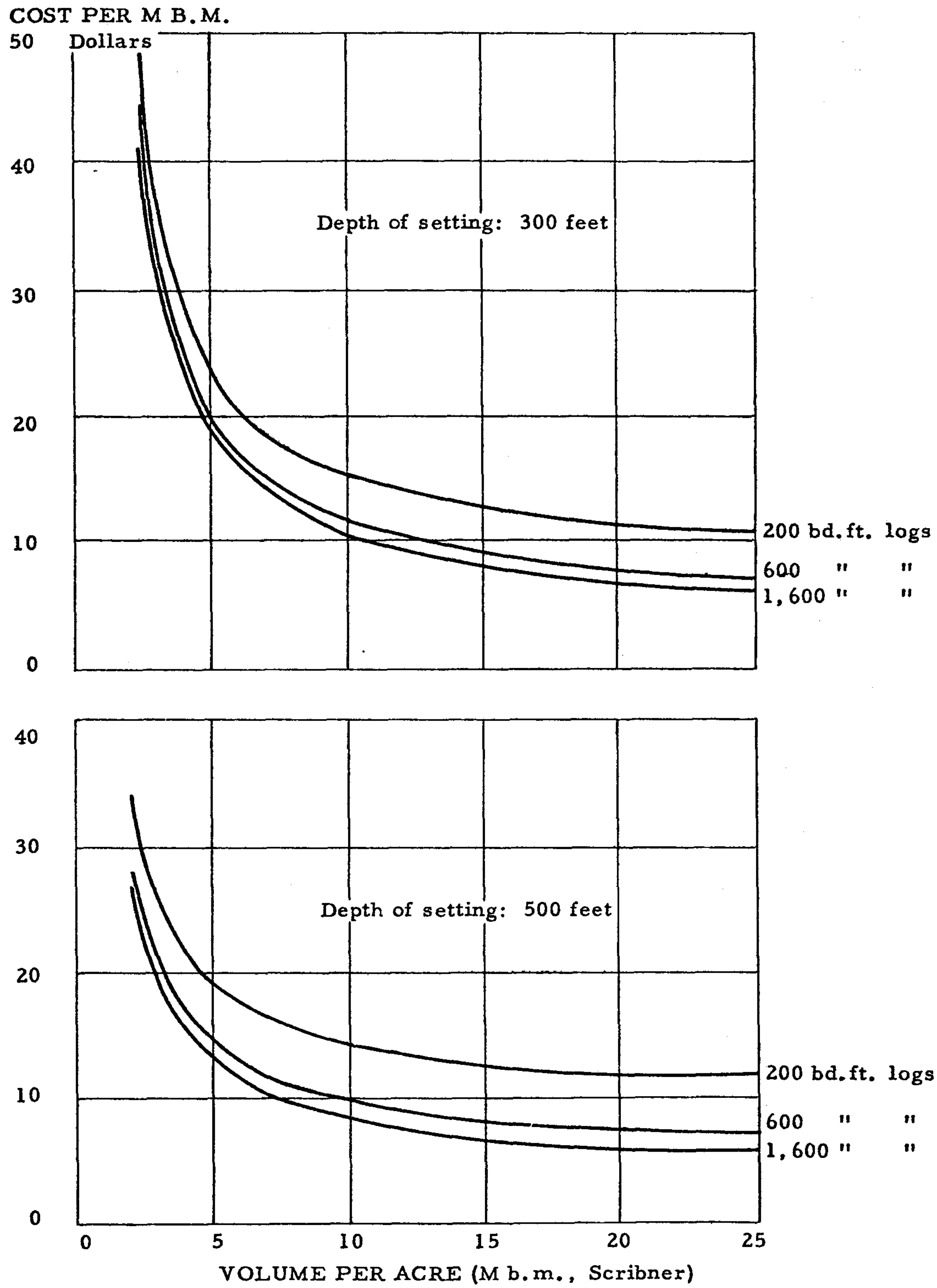

Figure 11.--Cost per thousand board feet for yarding, moving, cable road changing, and truck road construction as related to available volume per acre, log size, and depth of setting.

seem justified if yarding were all uphill and roads cost no more than $1,400 per mile. If some downhill yarding could be done, the spacing of roads might be increased to 600 or 700 feet with the same--or possibly reduced--unit costs. The presence of existing roads will of course reduce costs, but it will not change the optimum yarding distance greatly. Since existing roads on the Andrews Forest sale were at 1,000 to 1,500 feet horizontal spacing, or 1,100 to 1,700 feet on the slope, their design appears to have been well adapted to salvage yarding with one low-standard road between each of the existing roads.

Figures 9 through 11 can be used to help appraise the feasibility of salvage operations where timber and operating conditions are similar to those of the experimental sale. The even distribution of log size and volume per acre that was assumed in the figures will not be found over any considerable area, however--it wasn't on the Andrews Experimental Forest. Uneven distribution poses the problem of whether to salvage at all, whether to cover the area completely, or whether to confine the operation to certain favorable locations.

When other logging costs, market values, minimum stumpage prices, and profit margins are known, the amount available for moving, yarding, and road construction across settings can be compared with the costs presented in figure 11 to decide the minimum volume density that can be economically salvaged. If distribution is uniform, or if exceptionally dense areas can be expected to offset sparse areas, a plan for complete coverage may be made. In other situations, salvage will be justified only on those parts of the tract that have volumes exceeding the economic minimum.

When the data from this study is used, it should be noted that costs include labor and equipment for moving, yarding, and road construction across settings. For full cost estimates, an allowance must also be made for some ineffective use of time at the beginning and ending of the work day, when changing from yarding to loading, and when work interruptions occur from fire-danger shutdowns, rain, and machine breakdowns. These inefficiencies could not be measured in the course of a short time study, but they are part of the whole job and are often calculated at from 10 to 20 percent of total work time. Full cost estimates would also include felling and bucking, loading, hauling, cost of access roads and roads between widely spaced settings, road maintenance, fire protection and slash disposal, and allowance for supervision and administration.

For example, if we assume that a tract with short logs averaging 600 board feet net scale has varying amounts of salvable material available, then estimates to appraise the feasibility of the operation can be made as follows:

	Dollars per M b.m.
Selling value at mill	50.00
Logging costs:	
Felling and bucking	5.00
Loading (including depreciation and other machine costs)	3.20
Trucking	6.50
Access roads and roads between settings	1.00
Road maintenance	.30
Fire protection and slash disposal	2.50
General and administrative costs	5.00
Supervision	.50
	24.00
Minimum stumpage ($2.00 per M) and profit	8.00
	32.00
Balance for yarding, moving, and building roads across settings	18.00

Figure 10 shows that for 600-board-foot logs and 15-M b.m.-per-acre volume, settings should be nearly 500 feet deep. Figure 10 also shows yarding cost to be nearly $4.90 per M b.m. A 10-percent allowance for expected inefficiency would mean roughly 50 cents per M extra cost. This could be allowed for in figure 11 by raising the cost curves; or the $18.00 balance calculated above (which is to be compared with figure 11) could be reduced by this amount. The comparison in this hypothetical case indicates that stands running as low as 4,000 board feet per acre could be operated profitably and yield minimum stumpage values. Higher stumpage returns would require greater volume density. The cost figures presented could also be used in making stumpage appraisals for areas where the practicality of salvage is obvious.