Production Rates and Costs for Yarding by Cable, Balloon, and Helicopter Compared for Clearcuttings and Partial Cuttings

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Forest Research Laboratory
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FOREWORD

This study was a cooperative undertaking by Oregon State University and the Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Dept. of Agric., under the Master Memorandum of Understanding of September 1, 1961, as amended, Supplement 118, April 1, 1974.

This bulletin supplements FRL Bulletin 18. It contains data from the second field season of the Pansy Basin Study using different harvesting systems and different silvicultural treatments.

ACKNOWLEDGMENTS

The primary financial assistance that made this research possible was provided by the Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture. The timber sales were administered by the Estacada Ranger District of the Mt. Hood National Forest. Logistic support for the time-study crew was provided by the Clackamas Ranger District.

Data were collected by Denis Van Winkle and Steven Bratz, graduate and undergraduate students, respectively, for the School of Forestry, Oregon State University.

Analysis of the field data was made possible by a grant from the Computer Center, Oregon State University.

A special note of appreciation is extended to the loggers whose daily cooperation and interest made the study possible: Erickson Aircrane, Inc., Flying Scotsman, Inc., and VanDerBeck Logging Company.

CONTENTS

ABSTRACT

This report supplements Research Bulletin 18 (1975) of the Forest Research Laboratory, School of Forestry, Oregon State University. Bulletin 18 summarized analyses of data for the first field season of the Pansy Basin Study. This Bulletin extends those analyses to the second, and final, field season.

Time-study observations during the second field season were made of three yarding systems: running skyline, balloon haulback, and heavy-lift helicopter. The running skyline was observed in a partial cutting, the balloon in a clearcutting, and the helicopter in both clearcuttings and partial cuttings. All of the cutting units were designed to reduce damage to the appearance of the landscape.

Results of the analyses suggest that productive yarding time is a function of yarding distance, volume per turn and per log, chordslope, and numbers of logs or chokers per turn. For the running skyline and the balloon, lateral yarding distance was also an important determinant of productive yarding time. In addition, the number of men in the rigging crew was found to be a statistically significant predictor for the running skyline, as was tagline length for the balloon.

For the running skyline system, the data in this study support the hypothesis that yarding production rates are significantly influenced by silvicultural treatment. For the helicopter, however, no significant difference appeared in yarding rates between the clearcutting and partial cutting treatments.

The effect of cutting unit design on yarding efficiency for cable systems cannot be generalized, although it did not appear to be significant for the cutting units in the Pansy Basin Study. Certainly, cutting units can be designed for which unit shape is an important determinant of cable yarding productivity. Shape of cutting unit would not be expected to influence helicopter yarding productivity, however.

PRODUCTION RATES AND COSTS FOR YARDING BY CABLE, BALLOON, AND HELICOPTER COMPARED FOR CLEARCUTTINGS AND PARTIAL CUTTINGS

INTRODUCTION

During the summer of 1973, a study was made by the School of Forestry, Oregon State University, in cooperation with the Pacific Northwest Forest and Range Experiment Station in which yarding production rates and costs were obtained for one conventional and five aerial yarding systems operating in large, old-growth timber (8). The purpose of that study was to provide data and experience useful for analysis of aerial yarding system efficiencies under a variety of operating conditions.

The study in 1973 was restricted to a single harvesting prescription (clearcutting) on conventionally designed cutting units and to a limited range of independent variables. Recent emphasis on landscape quality as a forest resource (16, 17), coupled with experience in reforestation problems associated with harsh sites (5, 6) and successful tests of shelterwood harvesting in the Douglas-fir region (15), have led to an increase in partial cutting of old-growth Douglas-fir. On clearcut areas, the trend in cutting unit design is away from the familiar geometric shapes, toward irregular boundaries that harmonize with the existing landscape of forested areas (17). Partial cutting has long been known to increase logging costs, particularly for cable yarding systems (2), but accurate measures of the loss in efficiency that results from partial-cut yarding in large, old-growth timber have not been documented previously. Similarly, cutting units designed specifically to preserve landscape quality may reduce efficiency by increasing average yarding distance, increasing the number and altering the character of cableway changes required for a given unit size, and increasing the unit's perimeter relative to its area. None of these effects has been investigated previously in actual case studies. We therefore conducted a second study during the summer of 1974, designed specifically to assess the effects on production rates and costs for partial cutting and clearcutting with irregular boundaries. This report describes the systems observed during the field study, the analytical methods to which the data were subjected, and the results of that analysis. Where appropriate, the results are compared with those of the study of 1973, and recommendations are made for further research.

YARDING SYSTEMS AND EQUIPMENT

Three aerial yarding methods were studied. A medium-size, mobile yarder-tower combination mounted on a trailer was used to skyline yard portions of a partial cutting to uphill landings; a 530,000 cubic foot natural-shape logging balloon was used in haulback configuration to yard a single clearcutting to a downhill landing; and a heavy-lift helicopter in standard logging configuration was used for yarding seven clearcut and two partial-cut units to a downhill landing.

The study was located within the Pansy Creek drainage of the Estacada Ranger District of the Mount Hood National Forest in Oregon. Terrain on the study areas was primarily steep and broken. The timber was largely (about 80 percent by volume) old-growth Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco]; secondary species on the study areas included western hemlock [*Tsuga heterophylla* (Raf.) Sarg.], noble fir [*Abies procera* Rehd.], and western redcedar [*Thuja plicata* Donn]. Estimated stand volumes (thousand board feet per acre, Scribner long-log scale) averaged about 65 on the skyline unit, 40 on the balloon unit, and 80 on the helicopter units, net of defect. Approximate net-to-gross ratios for this study were, respectively, 80 percent, 80 percent, and 85 percent for the skyline, balloon, and helicopter units. Net volumes listed above convert to about 12,500, 7,000, and 130,000 cubic feet per acre and to 880, 440, and 910 cubic meters per hectare for the three systems. Average age of the timber on the study areas was more than 200 years.

Skyline

A Skagit GT-3 "Grapple Yarder"[1] in running skyline configuration with a slackpulling carriage and chokers (Figure 1) was observed during the skyline portion of the study. Machine attributes for the GT-3 are as follows:

Engine	Cummins NH 220 diesel
Rated engine power	220 bhp
Undercarriage	Trailer
Tower type	Inclined, steel box-section truss
Tower height	44 feet, 6 inches
Weight	88,880 pounds without lines
Drum capacities:	
Mainline	1,200 feet of 5/8-inch diameter
Slackpulling	1,200 feet of 5/8-inch diameter
Haulback	2,200 feet of 3/4-inch diameter
Strawline	3,200 feet of 3/8-inch diameter
Guylines	2(7/8-inch diameter, 140 feet)

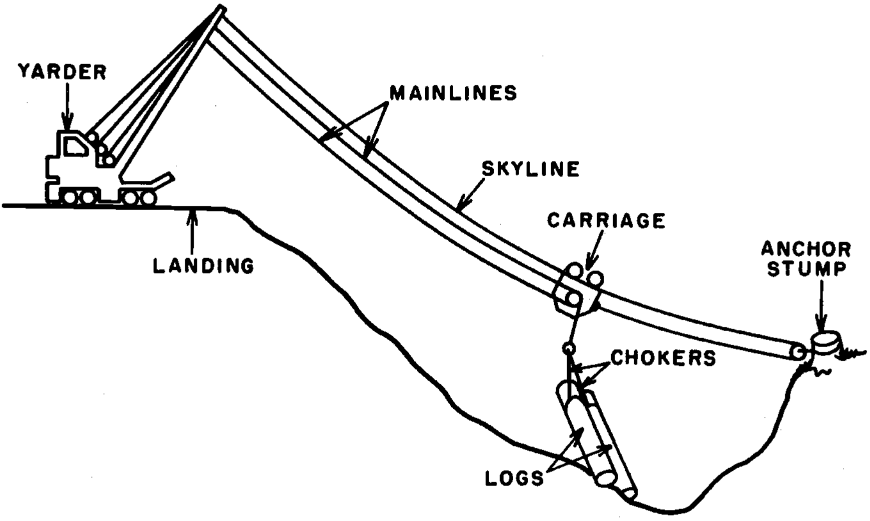

Figure 1. Running skyline system in slackpulling configuration with a three-drum carriage.

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[1] The use of trade names or equipment designations in this report is for information only and does not imply endorsement by either Oregon State University or the Forest Service, U.S. Department of Agriculture.

Line speeds:	
Mainline and slackpulling	1,460 feet per minute (full drums)
Haulback	2,275 feet per minute (full drum)
Line pulls:	
Mainline and slackpulling	67,600 pounds (empty drums)
Haulback	41,300 pounds (empty drum)
Interlock	Mechanical (links mainline, slackpulling, and haulback drums)

Unlike the yarders observed during the portion of the Pansy Basin Study made in 1973, the GT-3 is mounted on a turntable that permits the yarder engineer to swing the turn for positioning at the landing. This capability is especially useful where landing space is restricted. It was used to good advantage on the operation observed, where landings were usually placed on the shoulder of a mainline road.

Balloon

A standard natural-shape logging balloon in conventional haulback configuration (Figure 2) was observed for this study. The layout of a haulback balloon system is essentially that of a ground-lead system; the balloon itself provides lift to the butt rigging, so height on the lead is unnecessary. This operation utilized the large Washington Iron Works Aero Yarder, Model 608A, which was designed specifically for balloon yarding. Equipment specifications for the system were as follows:

Balloon volume	530,000 cubic feet
Lifting gas	Commercial helium
Net design lift	25,000 pounds (sea level, 90 percent inflation)

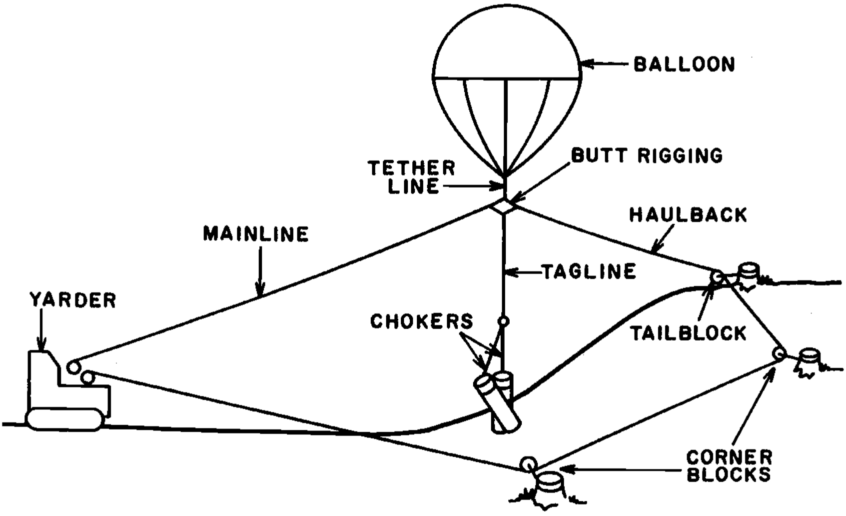

Figure 2. Balloon yarding system in haulback configuration.

Envelope diameter	105 feet
Balloon height	113 feet
Yarder engine	Detroit Diesel 12V-71N65
Rated engine power	700 bhp
Undercarriage	Caterpiller D9
Weight	149,600 pounds (without lines)
Drum capacities:	
Mainline	5,100 feet of 1-inch diameter
Haulback	7,680 feet of 1-inch diameter
Strawline	9,700 feet of 7/16-inch diameter
Line speeds:	
Mainline	1,591 feet per minute (full drum)
Haulback	2,156 feet per minute (full drum)
Line pulls:	
Mainline	90,000 pounds (empty drum)
Haulback	46,000 pounds (empty drum)
Interlock	Hydraulic

Helicopter

The helicopter observed during 1974 was a heavy-lift Sikorsky S64E Skycrane with the following characteristics:

Engines	Pratt and Whitney JFTD 12A-4A (2)
Takeoff power (TOP)	4,500 shaft hp (each engine)
Maximum continuous power (MCP)	4,000 shaft hp (each engine)
Average cruise speed at 90 percent of gross capacity	95 knots (109 mph) at sea level
Fuel consumption	525 gallons per hour
Vertical rate of climb at MCP	1,330 feet per minute at sea level

The configuration of the helicopter system is illustrated in Figure 3. The lifting capacity of the S64E as a logging vehicle may be calculated:

Maximum gross lifting capacity[2]	42,000 pounds
Less:	
Weight of the helicopter (empty)	19,194
30 minutes' (average) fuel supply (270 gallons at 6.2 pounds per gallon)	1,674
Pilot and copilot at 200 pounds each	400
Radio equipment	100
Tagline, hook assembly, and chokers	500
Oil and trapped fluids	36
Net external load, hover out of ground effect	20,096 pounds

The effect of air density on lifting capacity is discussed in an earlier publication (8), and here we repeat only that, for mountainous operations in hot weather, the reduction in load capacity as a result of decreased air density can be significant. For the S64E, as an example, the mean elevation encountered in this study (4,000 feet) would reduce lift capacity to about 17,660 pounds if the field air temperature was 80 F (12); this represents a reduction of about 12 percent. Any additional increase in temperature or decrease in barometric pressure would further degrade the lift capacity of the aircraft and thus reduce operating efficiency.

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[2] At mean sea level with an atmospheric temperature of 59 F, barometric pressure of 29.92 inches of mercury, and no wind.

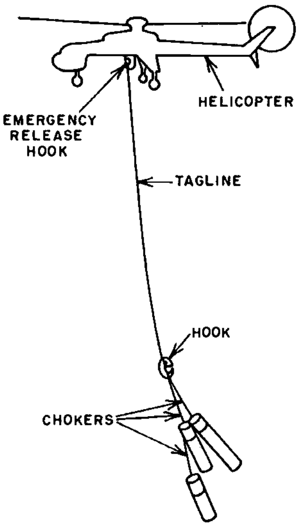

Figure 3. Helicopter logging configuration.

STUDY PROCEDURES AND MEASUREMENTS

A complete description of the study methods is given in Research Bulletin 18 (8). Several procedural differences that were made during the present study are worth noting, however.

Cycle-time Observations

In addition to the four basic subcycles recorded in 1973 (outhaul, hook, inhaul, and unhook), during 1974 we measured the subcycles listed below.

Lateral-out. This is the time required for the rigging crew to pull the skidding line laterally from the skyline or mainline to the turn of logs. It was measured for both the balloon and skyline systems.

Vertical-in. Yarding of partial-cut units with helicopters necessitates this subcycle, which is the time required for the helicopter to lower vertically until the tagline reaches the turn of logs. Vertical-in also occurs in clearcut units, but generally is not defined as clearly. To permit comparisons between clearcutting and partial cutting, however, we recorded vertical-in times for both types of operations.

Lateral-in. This is the time required to skid the turn of logs to the skyline. It is not defined for the balloon because the sphere moves over the load when tension is placed on the tagline by the release of the balloon.

Vertical-out This is the time required for the helicopter to lift the turn to an altitude where inhaul may commence.

Field Measurements

Procedures followed were essentially identical to those previously described (8), except that only a single two-man crew was used to record time study data. In addition to the response variable, time, factors upon which cycle times were expected to be dependent also were recorded in detail. Each of these "independent variables" is identified by a single word with which it is associated throughout the remainder of this report.

CHORDSLOPE is the slope, in percentage, of a line segment that connects the skyline fairlead on the yarder tower to the tailhold. For the helicopter, it is the slope of a line segment that connects the landing and the hook point. Chordslope inclination was taken from the landing, so chordslopes for uphill yarding were assigned negative values, and those for downhill yarding were given positive values.

GROUNDSLOPE is an average side slope, in percentage, measured perpendicular to the contours at the hook point. Measurement was by means of a percent clinometer, to the nearest 10 percent. Groundslope was recorded as an absolute value.

SOIL is a subjective code that describes the observer's estimate of ground surface conditions at the hook point, as follows: 0 = firm, even footing–solid and dry soil; 1 = muddy, slippery, or loose soil; and 2 = rocky, gravel-strewn, or otherwise hazardous footing.

BRUSH is a subjective index used to describe the brush and slash conditions at the hook point, as follows: 0 = light or nonexistent–does not restrict movement; 1 = medium–causes some difficulty in movement; and 2 = heavy–hampers movement considerably.

RIGGERS is the number of men in the rigging crew. Where chokers were preset, only the number of crewmen actually participating in the hooking operation (usually one) was recorded.

CHASERS is the number of men who remove chokers from logs at the landing.

TAGLINE is the length, in feet, of the helicopter or balloon tagline.

SYDIST is the yarding distance, in feet, measured along the average slope from the landing to the hook point.

LOGS is the number of logs yarded for each turn.

BFVOL is the gross board-foot volume in the turn, which includes unmerchantable pieces. Small-end diameter, large-end diameter, and length of each piece yarded were measured by the crewman at the landing. Diameters were recorded to the nearest inch; length to the nearest foot.

CHOKERS is the number of chokers to which logs were attached during yarding.

LDIST is the lateral yarding distance, in feet, measured along the average slope from the hook point to the carriage.

HTRESID is the height to which the turn had to be lifted by the helicopter to clear timber adjacent to the hook point.

DATA ANALYSIS

In this section we attempt to quantify relations that may exist between independent variables and the dependent variable, productive time. For the purpose of analysis, we consider the data first in a qualitative framework; we then turn to statistical regression techniques for the quantitative testing of hypothetical dependencies.

Qualitative Analysis

Table 1 summarizes yarding-element time as a percentage of productive time. Comparing these results with those summarized for the study in 1973 (8), we note that hook time as a percentage of total time is always significantly less than for the data of 1973. We might be tempted to conclude that the three logging crews observed during 1974 were considerably more efficient at hooking turns than those observed during 1973. This may be partially true; all three operators tended to emphasize efficiency in hooking. The skyline and balloon rigging

Table 1. Yarding Element Time as a Percentage of Total Productive Time.

Element	Skyline	Balloon	Helicopter
	%	%	%
Outhaul	14	31	29
Lateral-out	14	12	--
Vertical-in	--	--	14
Hook	23	23	8
Vertical-out	--	--	17
Lateral-in	6	--	--
Inhaul	32	26	35
Unhook	11	8	0
Total time[1]	2.6	7.2	2.4

[1]Average total productive time, in minutes, for a turn.

crews were encouraged to preset turns whenever possible, and the helicopter operation regularly had two hookers so that the aircraft could alternate between hookers without having to wait for a turn to be prepared. The major reason for this apparent improvement in efficiency, however, was a change in the degree to which delays were isolated by the time-study crew. During 1974, delay events such as the time required for the rigging crew to move away from the hook point were isolated; during 1973, this time would have been accumulated as part of hook time. Although this detailed partitioning of delays will prove useful in our analysis of nonproductive time, it somewhat complicates a comparison of the "productive" events for 1973 and 1974.

Frequency distributions for the eight productive-time events plus total turn time are presented in Figures 4-10. Several comparisons among these distributions will be useful for assessing qualitative differences between yarding systems and production cycles. Close inspection reveals that, as expected, outhaul time (unloaded) is less than inhaul time (loaded) for the skyline and the helicopter, although the difference for the helicopter is slight. Surprisingly, however, the opposite is true for the balloon. This is particularly remarkable in view of the fact that the reverse relation was found in 1973. Because the balloon system studied in 1974 used a powered outhaul we would expect the same relation to hold, with possibly even greater difference between inhaul and outhaul times. Field observations suggested, however, that the methods of operation of the two balloon systems were substantially different. In the inverted skyline configuration, where outhaul is powered by the lift of the balloon, outhaul time is dictated by factors beyond the control of the yarder operator. The powered outhaul of the haulback system, however, permits direct control over outhaul time, and the operator in this study appeared to run the yarder at considerably less than full speed during outhaul, whereas inhaul was treated as a high-speed operation. Because outhaul is in the direction of the lifting force of the balloon, good reasons exist for caution during that subcycle. During inhaul, on the other hand, the balloon tends to act as a brake so that the operator is not so concerned with the accumulation of excess momentum in the system.

As in 1973, the unhook times were always less than the corresponding hook times. Furthermore, both hook and unhook times were less for the systems of 1974 than for those studied during 1973. As mentioned earlier, this is largely because delays were segregated more closely during 1974. Increased emphasis on the presetting of chokers appeared also to play a part in reducing hook times for the skyline and balloon systems.

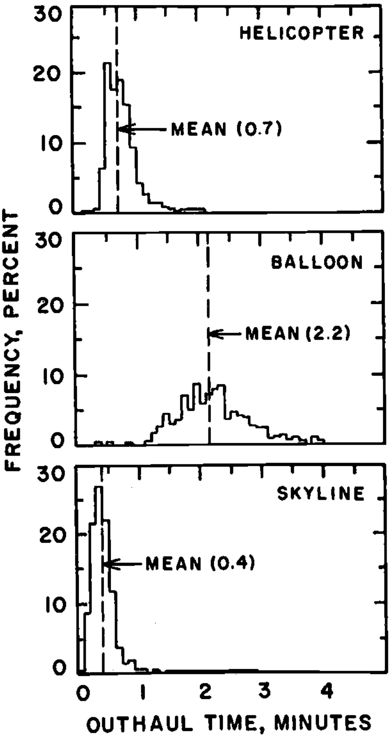

Figure 4. Frequency distributions of outhaul time.

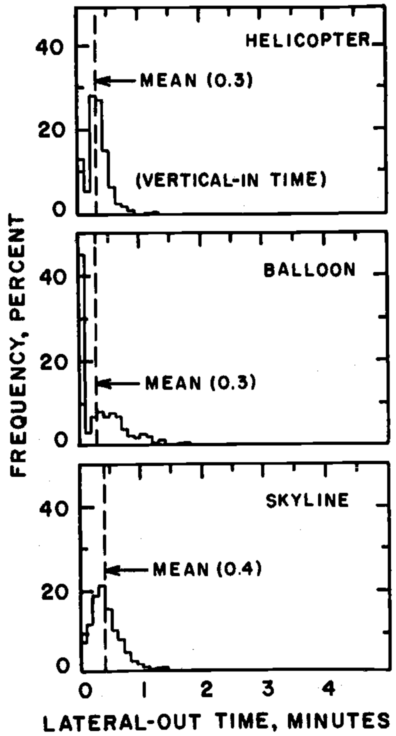

Figure 5. Frequency distributions of lateral-out time (vertical-in time for the helicopter).

For the subcycles that were not segregated in the study in 1974, the following relations are demonstrated by the frequency distributions: vertical-in time for the helicopter (unloaded) was slightly less in general than vertical-out time (loaded); and lateral-out time for the skyline (unloaded) was significantly greater than lateral-in time (loaded), which suggests that the machine-intensive portion of lateral yarding is more efficient than the labor-intensive portion, even when a carriage with a mechanical slackpulling device is used.

Table 2 summarizes the values recorded during the time study for each of the independent variables. Frequency distributions for the variables that were ultimately included in the production equations are presented in Figures 11-20. The range of variables recorded for the three yarding systems in 1974 tends to be broader than that for the corresponding variables in 1973, indicating that we can apply production equations derived from these observations over a wider range of conditions with greater confidence. No claim is made, however, that the range of variables recorded during the study is as broad as we would like. As an example, the GT-3 was designed to operate at yarding distances in excess of 1,000 feet, yet the maximum yarding distance observed for the machine in this study was 610 feet. Furthermore, the GT-3 is fully

Table 2. Representative Values of the Independent Variables Recorded for Each Yarding System.

Independent variables		Skyline	Balloon	Helicopter
Chordslope, *percent*	min	-38	22	13
	max	- 7	40	37
	avg	-16.0	33.6	25.8
Groundslope, *percent*	min	0	0	0
	max	90	95	65
	avg	18.9	57.4	42.5
Soil index	min	0	0	0
	max	1	1	1
	avg	0.0	0.3	0.0
Brush index	min	0	0	0
	max	2	2	2
	avg	1.0	1.2	1.4
Riggers (men)	min	1	1	1
	max	3	4	2
	avg	2.0	1.4	1.0
Chasers (men)	min	1	1	1
	max	2	2	4
	avg	1.0	1.0	2.3
Tagline, *feet*	min	-	170	200
	max	-	420	200
	avg	-	264.5	200.0
Yarding distance, *feet*	min	35	300	950
	max	610	2,325	3,785
	avg	273.0	1,436.1	2,232.5
Lateral distance, *feet*	min	0	0	-
	max	85	140	-
	avg	20.3	18.2	-
Logs per turn, *pieces*	min	1	1	1
	max	6	7	12
	avg	2.3	2.5	3.2
Chokers per turn	min	1	1	1
	max	2	6	9
	avg	2.0	2.1	3.1
Bfvol, *fbm*	min	0	116	108
	max	2,820	3,399	4,275
	avg	329.5	1,060.7	1,644.5
Cubic foot volume, ft^3	min	0	19	17
	max	362	514	715
	avg	63.7	180.8	267.5
Bfvol per log, *fbm*	min	0	59	87
	max	2,820	3,399	4,275
	avg	168.8	630.5	698.9
Height of residual timber, *feet*	min	-	-	130
	max	-	-	180
	avg	-	-	152.1
Yarding roads		22	10	-
Turns		833	453	938

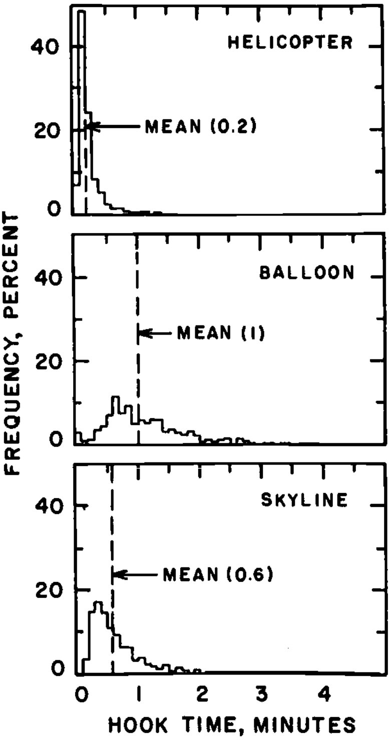

Figure 6. Frequency distributions of hook time.

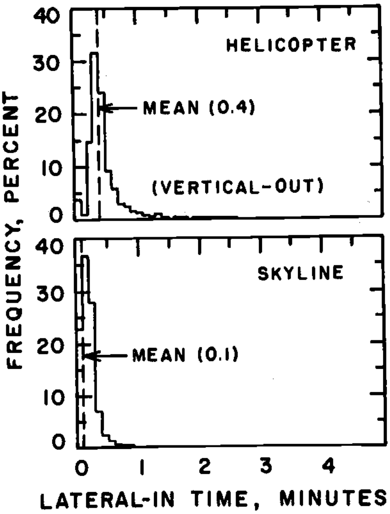

Figure 7. Frequency distributions of lateral-in time for the skyline and vertical-out time for the helicopter.

capable of downhill yarding, although the operation here included only yarding to an uphill landing. The range of chordslopes observed for all three systems, although greater than that for the study in 1973, is limited. Tagline length for the helicopter was restricted to 200 feet throughout the study; this meant that it could not be used as a regression variable, even though it had been found useful for the prediction of hook time in 1973. These problems and others like them are characteristic of logging production studies. Their resolution will require sophisticated experimental design to insure a broad range of independent variables and logging treatments. Strong control over the logging contractor during the study is an absolute necessity if controlled logging experiments are to be conducted. On operational timber sales such as those used for our study, the kind of control necessary for complete experimentation is impossible.

The tendency of the skyline crew to hook two logs per turn is illustrated clearly in Figure 16, and confirms a similar finding for the cable systems in 1973. The skyline distribution in Figure 16 is, in fact, remarkably similar to the earlier cable distributions, which is surprising, particularly in that the GT-3 operated in a partial cutting and the observations in 1973 were all made in clearcuttings. We note that the number of chokers per turn (Figure 17), which was not recorded in 1973, appears to explain this tendency. Obviously, the helicopter and balloon crews, always more conscious of weight limitations (and capabilities), are more effective at gauging the number of logs that should be hooked to utilize fully the lifting capacity of the

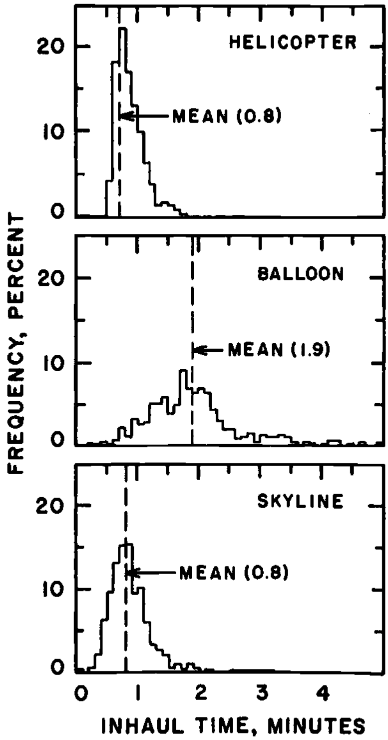

Figure 8. Frequency distributions of inhaul time.

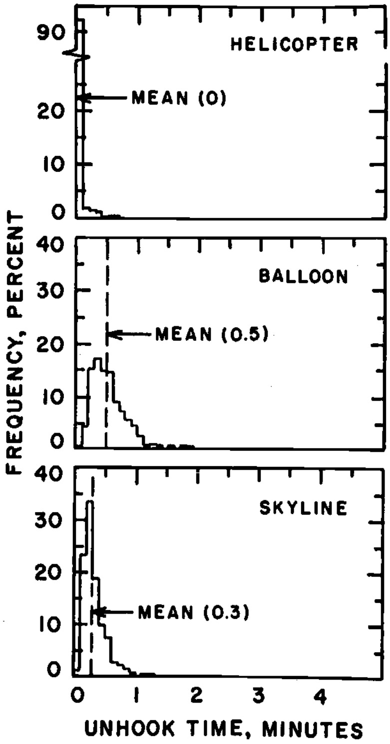

Figure 9. Frequency distributions of unhook time.

yarding system. Skyline crews in this study simply tended to be less flexible, even when using a bullhook to which additional chokers could be added with very little effort. As we have suggested previously (8), this may be a key to improving the efficiency of skyline logging systems.

Regression Analysis

In contrast to the qualitative analysis, which describes the variables themselves, the purpose of regression analysis is to quantify the functional relations between variables. In the regression equations listed in this section,

**** indicates that the regression coefficient associated with an independent variable is significantly different from zero at the 0.01 probability level;

*** indicates that the regression coefficient is significant at the 0.05 probability level but not at the 0.01 level;

** indicates the regression coefficient is significant at the 0.10 probability level but not at the 0.05 level;

* indicates that the regression coefficient is significant at the 0.20 probability level but not at the 0.10 level;

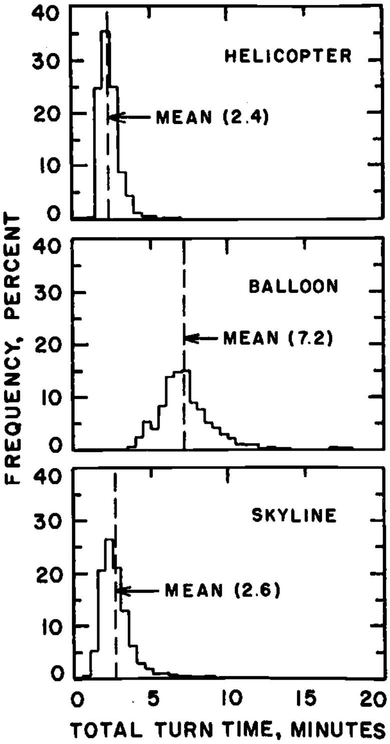

Figure 10. Frequency distributions of total turn time.

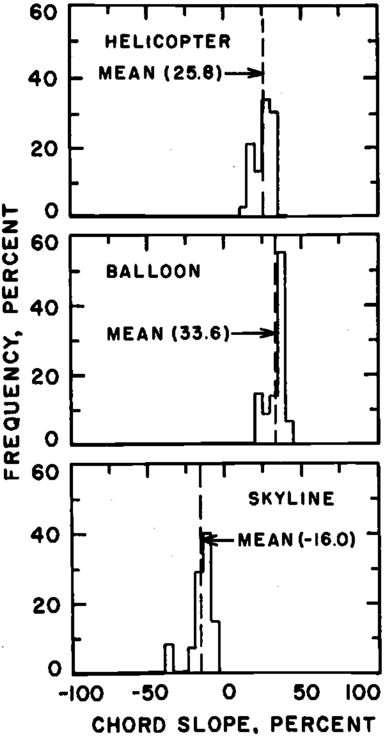

Figure 11. Frequency distributions of chordslope.

R is the multiple correlation coefficient, an index of fit between the observed response values and those estimated by the regression equation (an R of 1.0 indicates a perfect fit and an R of 0.0 indicates no fit);

n is the number of observations in the sample.

All times estimated by the regression equations are in minutes.

Regression Hypothesis for Outhaul Time

H_0 : outhaul time = f(CHORDSLOPE, SYDIST)

Regression Equations for Outhaul Time

Skyline

Outhaul time = 0.18600 (R = 0.374, n = 833)
+ 0.00062433 (SYDIST) ****

Balloon

Outhaul time = 1.5815 (R = 0.464; n = 453)
- 0.042351 (CHORDSLOPE) ****
+ 0.0014566 (SYDIST) ****

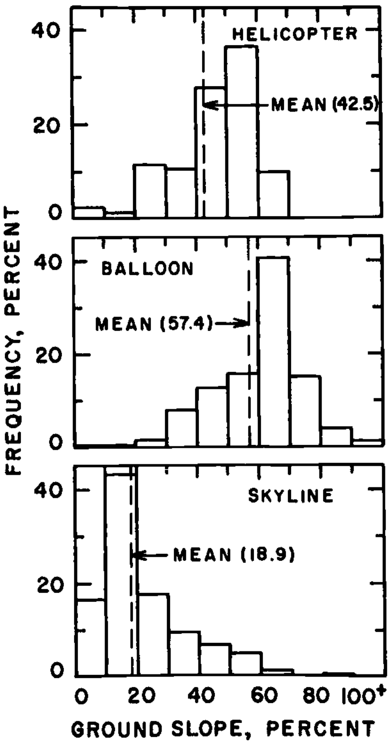

Figure 12. Frequency distributions of groundslope.

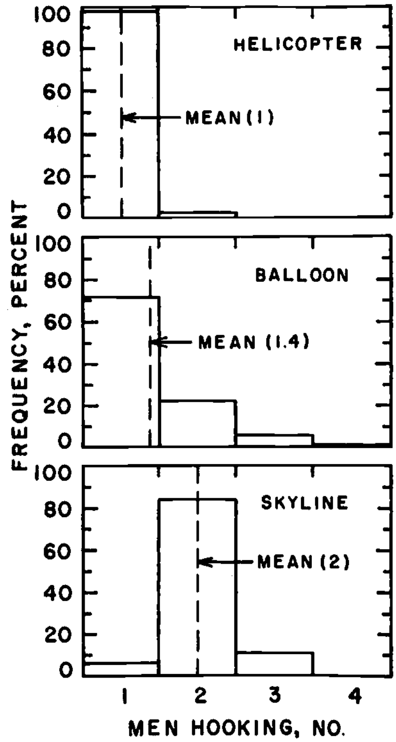

Figure 13. Frequency distributions of the number of men in the hooking operation.

Helicopter

Outhaul time = 0.36329 (R = 0.353; n = 938)
+ 0.0065919 (CHORDSLOPE) ****
+ 0.000079211 (SYDIST) ****

The regression coefficient and intercept obtained for the skyline are close to those that were derived for the Berger system in 1973. Because both the GT-3 and the Berger were operated as running skyline systems and because both machines have positive interlocks between the mainline and haulback drums, system mechanics may be more important in the determination of production rates than the characteristics of individual yarders.

As we found in 1973, CHORDSLOPE is an important predictor of outhaul time for the balloon. The regression coefficients for both studies are, in fact, similar, although the coefficient in the present study is much more strongly significant. The effect of SYDIST on outhaul time, on the other hand, is considerably more pronounced for the balloon haulback system than was true of the inverted skyline configuration. As discussed earlier, this apparent discrepancy seems largely to be the influence of the yarder operator. It also may be because, in part, most data in 1974 were obtained at longer yarding distances. Several writers, for example Adams (1) and Sinner (13), have hypothesized that outhaul time varies with the square of

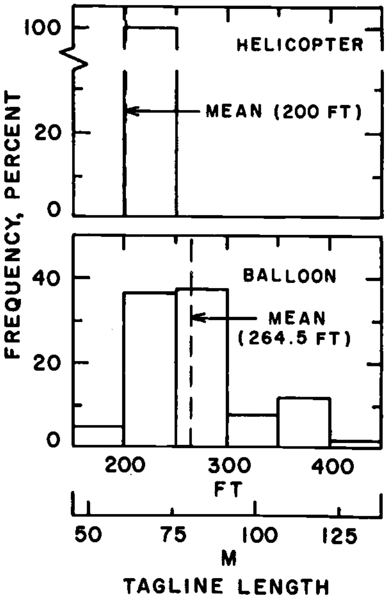

Figure 14. Frequency distributions of tagline length.

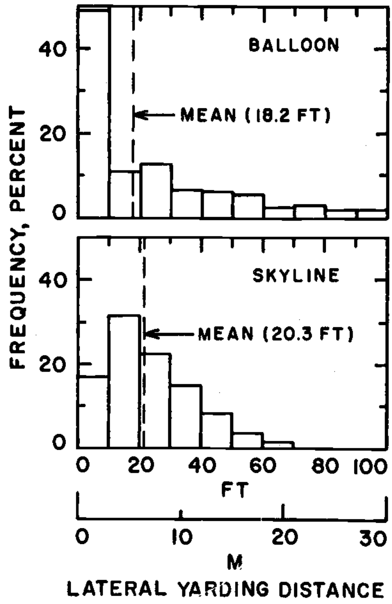

Figure 15. Frequency distributions of lateral yarding distance.

yarding distance. Because of the limited range over which yarding distance was observed for most of the systems in the two studies, however, we have restricted the present analysis to the linear hypothesis.

For the helicopter data in 1974, CHORDSLOPE proved to be a significant predictor variable, although it had been excluded in 1973 because of poor correlation with outhaul time. The coefficient for yarding distance in the equation for 1974 is much smaller than in the equation for 1973. This suggests that the S64E was flown at higher speeds during outhaul than the Boeing-Vertol 107. The multiple correlation coefficient (R) for the outhaul equation in 1974 is considerably lower than that for 1973, which generally was true for all of the helicopter equations. This is somewhat surprising because more care was taken during the study in 1974 to segregate productive time into specific subcycles and to delineate delay times. Part of the increase in variance about the S64E regressions as compared with that about the Vertol equations may be because slope yarding distance was about 800 feet longer, on the average, for the Vertol than for the S64E. For shorter yarding distances, acceleration and deceleration occupy a larger percentage of total outhaul time; we would thus expect somewhat greater variance in outhaul time at shorter distances. The primary reason for the higher R-values in the helicopter equations for 1973 appears, however, to be a statistical quirk related to the data. In 1973, most turns were recorded at three or four yarding distances (8, Figure 15, p. 25). We therefore have only three or four effective pieces of information (even though we recorded over 900 turns), and the multiple correlation coefficient will be artificially inflated as a result. During 1974, the yarding-distance observations represent more of a continuum (Figure 18), and the regressions based upon these observations may thus be considerably better than those derived in 1973, even though our measure of fit between the equations and the observed data is smaller.

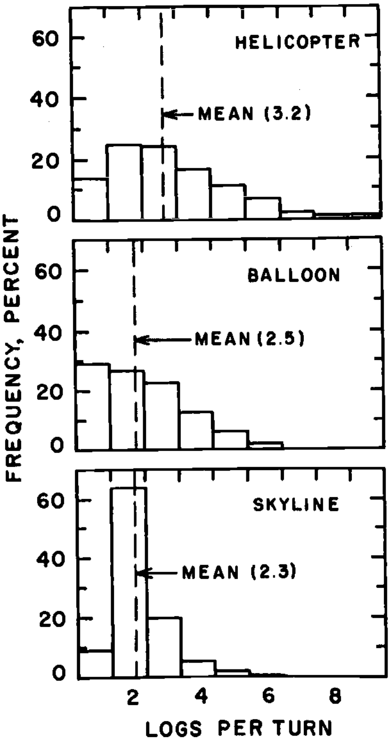

Figure 16. Frequency distributions of logs per turn.

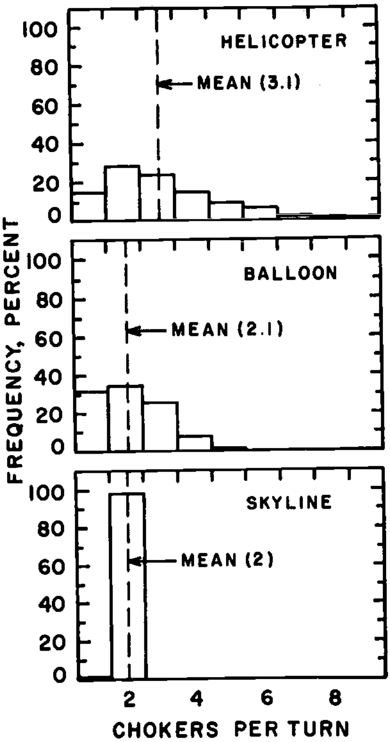

Figure 17. Frequency distributions of chokers per turn.

Figure 21 is a composite plot of the three regression equations for outhaul time against yarding distance. Each curve has been plotted over the range of yarding distances observed during the study for that yarding system (see Table 2). This does not imply that yarding beyond those limits is not practical; rather the implication is that extrapolation beyond those limits may be precarious, and we have chosen to discourage such extrapolation by constructing the regression curves in this manner. Following a precedent established in the earlier study (8), we have again used the median of observations for calculating the effect of independent variables that do not explicitly appear in the two-dimensional plot. Table 3 summarizes the median values in the regression plots in this paper.

Regression Hypotheses for Lateral-out and Vertical-in Time

Skyline

H_0: lateral-out time = f(CHORDSLOPE, GROUNDSLOPE, SOIL, BRUSH, LDIST, SYDIST)

Balloon

H_0: lateral-out time = f(CHORDSLOPE, GROUNDSLOPE, SOIL, BRUSH, TAGLINE, LDIST, SYDIST)

Helicopter

H_0: vertical-in time = f(GROUNDSLOPE, TAGLINE, HTRESID)

Table 3. Median Values Observed for Independent Variables Used in the Regression Equations.

System	Independent variable	Median value
Skyline	BFVOL	240 fbm
	BFVOL/LOG	120 fbm
	CHORDSLOPE	-13 %
	LDIST	20 ft
	LOGS	2 pieces
	RIGGERS	2 men
	SYDIST	245 ft
Balloon	BFVOL	1,010 fbm
	BFVOL/LOG	505 fbm
	CHOKERS	2
	CHORDSLOPE	+35 %
	LDIST	10 ft
	SYDIST	1,570 ft
	TAGLINE	270 ft
Helicopter	BFVOL	1,620 fbm
	BFVOL/LOG	540 fbm
	CHORDSLOPE	+30 %
	LOGS	3 pieces
	SYDIST	1,945 ft

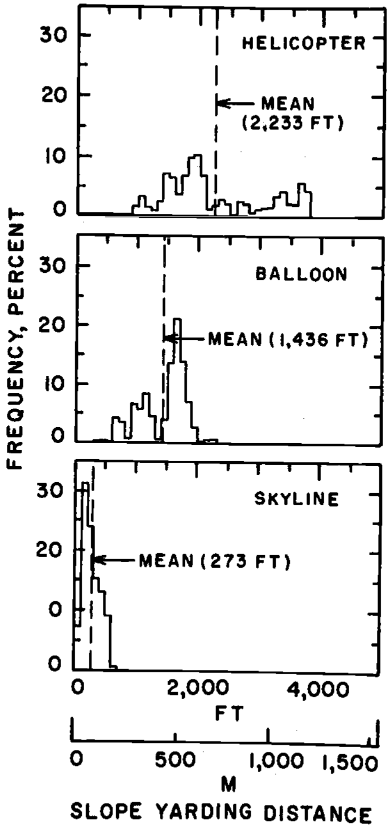

Figure 18. Frequency distributions of yarding distance.

Regression Equations for Lateral-out and Vertical-in Time

Skyline

Lateral-out time = - 0.012513 (R = 0.625; n = 833)
+ 0.0019426 (GROUNDSLOPE) ****
+ 0.063938 (BRUSH) ****
+ 0.00032666 (SYDIST) ****
+ 0.0089169 (LDIST) ****

Alternate equation without GROUNDSLOPE and BRUSH:

Lateral-out time = 0.069213 (R = 0.588; n = 833)
+ 0.00038444 (SYDIST) ****
+ 0.0091850 (LDIST) ****

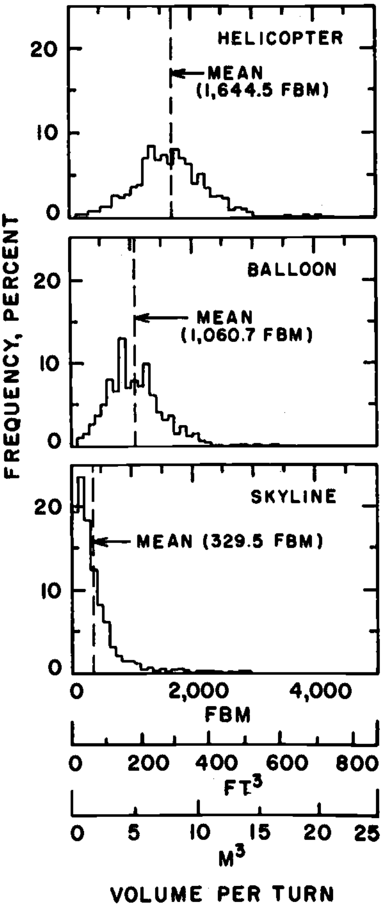

Figure 19. Frequency distributions of volume per turn.

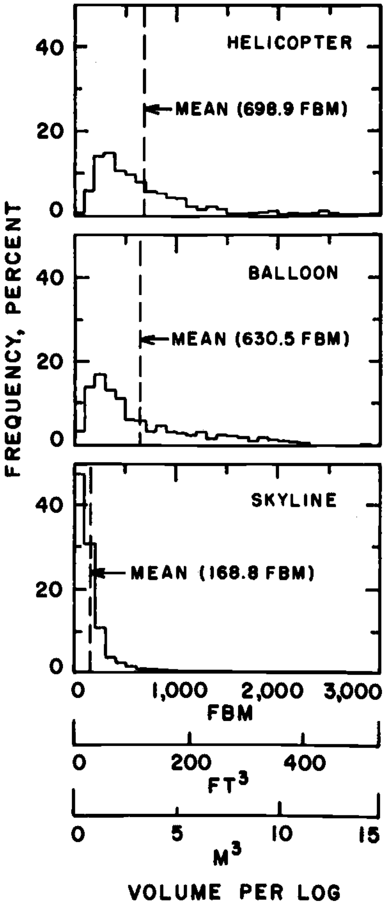

Figure 20. Frequency distributions of volume per log.

Balloon

Lateral-out time = - 0.05672 (R = 0.581; n = 453)
+ 0.088633 (SOIL) ***
+ 0.00012558 (SYDIST) ****
+ 0.0091955 (LDIST) ****

Alternate equation without SOIL:

Lateral-out time = - 0.37784 (R = 0.573; n = 453)
+ 0.00012913 (SYDIST) ****
+ 0.0091442 (LDIST) ****

Helicopter

No regression; mean vertical-in time = 0.27196

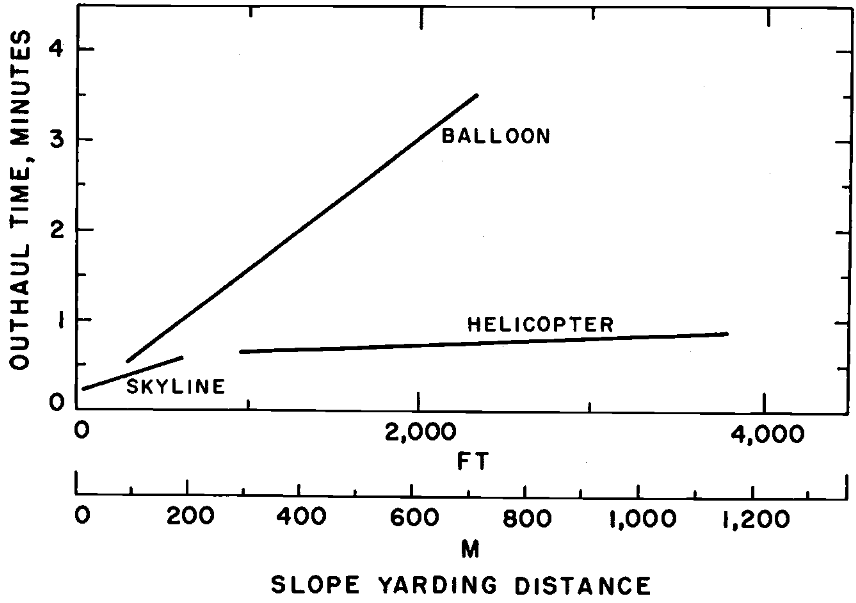

Figure 21. Outhaul time as a function of slope yarding distance.

Alternate equations are presented for both the skyline and the balloon, for the following reasons. First, GROUNDSLOPE, SOIL, and BRUSH (which are excluded in the second equation for each system) are difficult to quantify even during a time study. Before logging, the estimation of values for these equations would presumably be all but impossible. Second, their exclusion does not seriously bias the equation parameters, which suggests that their effect on lateral-out time for this study was not great. Finally, the use of SOIL and BRUSH, which are subjective, arbitrarily defined indices, necessitates the mapping from an ordinal scale onto the ratio scale of real numbers. We have presented the full equations with SOIL and BRUSH included to demonstrate that ground surface and vegetation do appear to influence lateral-out time. Furthermore, this may encourage research to develop consistent, easily measured indices for these variables, perhaps along the lines of silvicultural indices reported recently by MacLean and Bolsinger (10).

In the equations for lateral-out time, the influence of lateral yarding distance, which is the most significant variable for both the skyline and the balloon, is almost equal for both systems. The effect of yarding distance, though, is about three times as great on the skyline as on the balloon. This may be because the mechanical slackpulling on the skyline is more time consuming at extended yarding distances because of increased sag in the main and slackpulling lines. It could also be because of collinearity between SYDIST and LDIST, which we might expect for a radial pattern of cableways extending from a single landing. Covariance matrices for both the skyline and the balloon indicate negligible correlation between SYDIST and LDIST for either system, however. For the skyline operation, ground surface conditions were almost constant over the entire unit, but brush and slash concentrations varied considerably in the partial cuttings. Thus, we are not surprised to find that SOIL is not a significant predictor of lateral-out time for that system. On the balloon operation, however, both SOIL and BRUSH

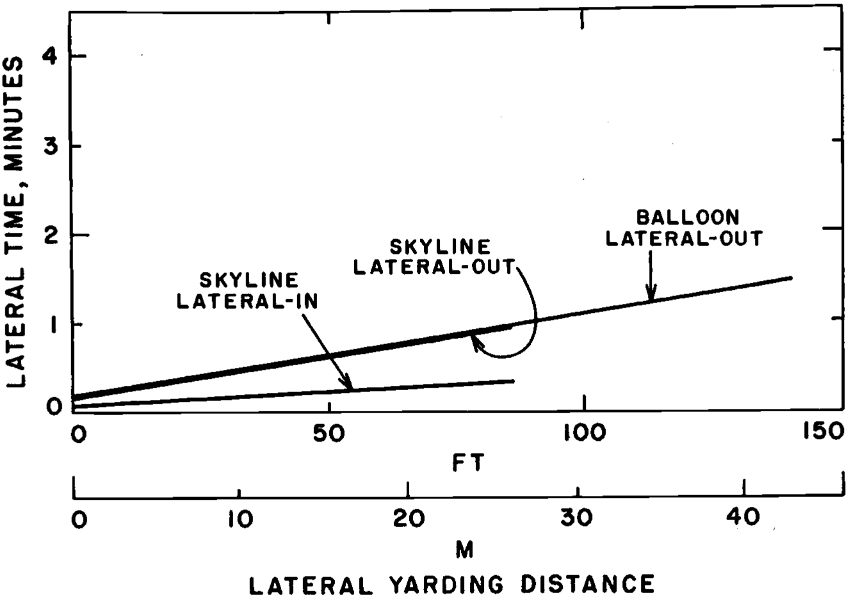

Figure 22. Lateral time as a function of lateral yarding distance.

varied considerably; here, collinearity between the two indices forced the exclusion of BRUSH from the final equation. The effect of lateral yarding distance on lateral-out times for the skyline and the balloon is illustrated in Figure 22. Also shown is skyline lateral-in time, which is discussed in a later section.

A valid equation could not be obtained for helicopter vertical-in time. TAGLINE had to be excluded from consideration because it was singular for this study. This is unfortunate, as the study in 1973 suggested that a change of 50 feet in tagline length could affect total turn time by 0.055 minute. Although this difference appears small, it could amount to more than 8 minutes in a 150-turn day. This could mean the equivalent of three extra turns and, at an average of more than 1,600 fbm per turn, that works out to 4,800 fbm—or about an extra truckload! Tagline length was maintained at a constant 200 feet, and thus we can neither confirm nor refute the results for 1973.

Height of the residual timber adjacent to the hook point entered the test regressions at a high level of significance, but was excluded from consideration because its sign was negative, which indicated that the higher the residual timber at the hook point, the shorter would be the expected vertical-in time. This result is almost certainly spurious; it appears to arise because the variance in the observed height of residual timber during the study was small, so that we have essentially a single observation on that independent variable.

Figure 23 illustrates the theory upon which GROUNDSLOPE was introduced into the regression hypothesis for helicopter vertical-in time. This concept was originated by Ledoux (9), who suggested that for shorter tagline lengths and steep slopes, groundslope might have an impact on vertical-in times in clearcuttings (Figure 23a). In partial cuttings, to the extent that treetop slope mimics groundslope, we would expect the same effect (Figure 23b). GROUNDSLOPE did enter the test regressions with the expected sign, but at a significance

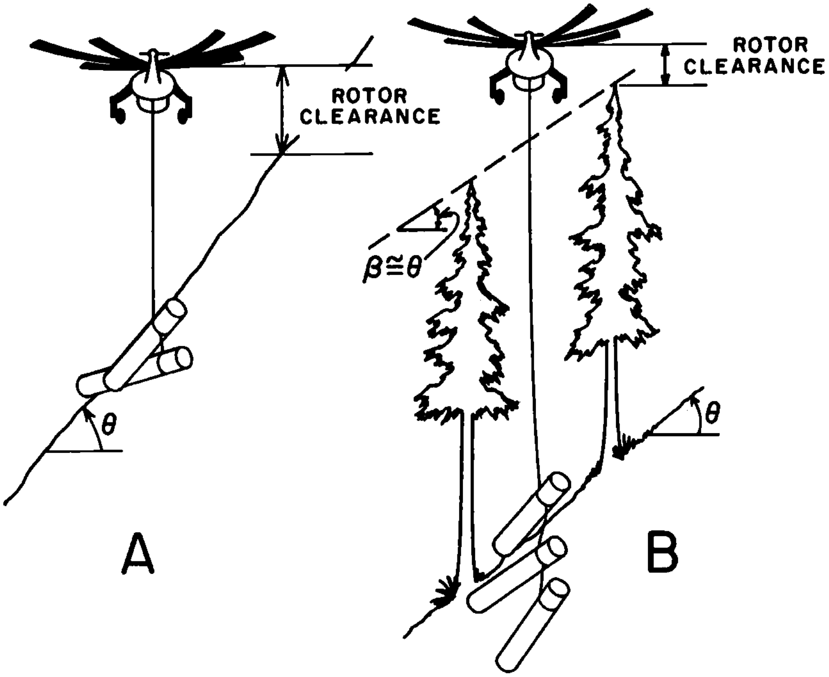

Figure 23. Hypothetical effect of groundslope on vertical-in and vertical-out times in (a) clearcuttings and (b) partial cuttings.

level slightly below the established limit for this study, and the equation was therefore discarded. As we will see later, however, a similar hypothesis for vertical-out time did prove successful.

Regression Hypotheses for Hook Time

Skyline

H_0: hook time = f(GROUNDSLOPE, SOIL, BRUSH, RIGGERS, CHOKERS, LOGS, BFVOL, BFVOL/LOG)

Balloon

H_0: hook time = f(GROUNDSLOPE, SOIL, BRUSH, TAGLINE, RIGGERS, CHOKERS, LOGS, BFVOL, BFVOL/LOG)

Helicopter

H_0: hook time = f(GROUNDSLOPE, SOIL, BRUSH, TAGLINE, CHOKERS, LOGS)

Regression Equations for Hook Time

Skyline

Hook time = 0.60146 (R = 0.343; n = 833)
+ 0.0023699 (GROUNDSLOPE) ***
+ 0.11840 (BRUSH) ****
- 0.13895 (RIGGERS) ****
+ 0.00051346 (BFVOL) ****
- 0.00033732 (BFVOL/LOG) ***

Alternate equation without GROUNDSLOPE and BRUSH:

Hook time = 0.72361 (R = 0.307; n = 833)
- 0.11478 (RIGGERS) ****
+ 0.00051381 (BFVOL) ****
- 0.00036255 (BFVOL/LOG) ****

Balloon

Hook time = 0.83889 (R = 0.322; n = 453)
+ 0.16508 (SOIL) ***
+ 0.10380 (BRUSH) **
+ 0.083793 (CHOKERS) **
- 0.00074252 (TAGLINE) *
+ 0.00024813 (BFVOL) ***
- 0.00033611 (BFVOL/LOG) ****

Alternate equation without SOIL and BRUSH:

Hook time = 1.0077 (R = 0.288; n = 453)
+ 0.086693 (CHOKERS) ***
- 0.00079978 (TAGLINE) *
+ 0.00025360 (BFVOL) ***
- 0.00032523 (BFVOL/LOG) ****

Helicopter

Hook time = 0.14937 (R = 0.119; n = 938)
+ 0.012032 (LOGS) ****

The correspondence between the skyline hook-time equation and the actual response as estimated by the multiple correlation coefficient is significantly higher than for any of the cable system equations in the study for 1973, which suggests a somewhat more consistent relation of treatment to response. The finding that RIGGERS and BRUSH are significant predictor variables confirms hypotheses that could not be tested in 1973 because of singularity in the data for those variables. A similar finding for GROUNDSLOPE agrees with results reported by Binkley (3), for which a published replication had not previously been available. The effect of volume per turn on hook time for the skyline was nearly the same as for the cable systems in 1973; the effect of volume per log, however, was much less. This may be partly because of bias in the coefficients of 1973 caused by the exclusion of some independent variables that actually influence hook time (such as RIGGERS) or because of greater observed variance in the data of 1974 for volume per log.

For the balloon system, the coefficients for the three independent variables that were present also in the equation of 1973 (TAGLINE, BFVOL, and BFVOL/LOG) are much smaller than in 1973. This is unlikely to result from any change in the system, as the hooking activity is labor intensive for both systems. It may be, in part, because of the influence of other variables (SOIL, BRUSH, and CHOKERS), but the major effect is probably a generally faster rate of hooking from more frequent presetting of chokers and from better segregation of delays by the time-study personnel. Average balloon hook time in 1973 was 3.2 minutes; in 1974, 1.0 minute.

Hook time for the helicopter is less affected by ground and brush conditions than it is for the cable and balloon systems because chokers are fully preset and the hooker usually does not have to move the rigging laterally. The variables BRUSH and GROUNDSLOPE, however, did enter the test regressions at a high level of significance, but with negative coefficients. Both were presumed, therefore, to have entered spuriously and were excluded from the final equation. As mentioned earlier, TAGLINE was singular and could not be entered, although it had been significant in 1973. Both CHOKERS and LOGS were statistically significant for the S64E. They were highly correlated, however, and thus could not be entered into the equation

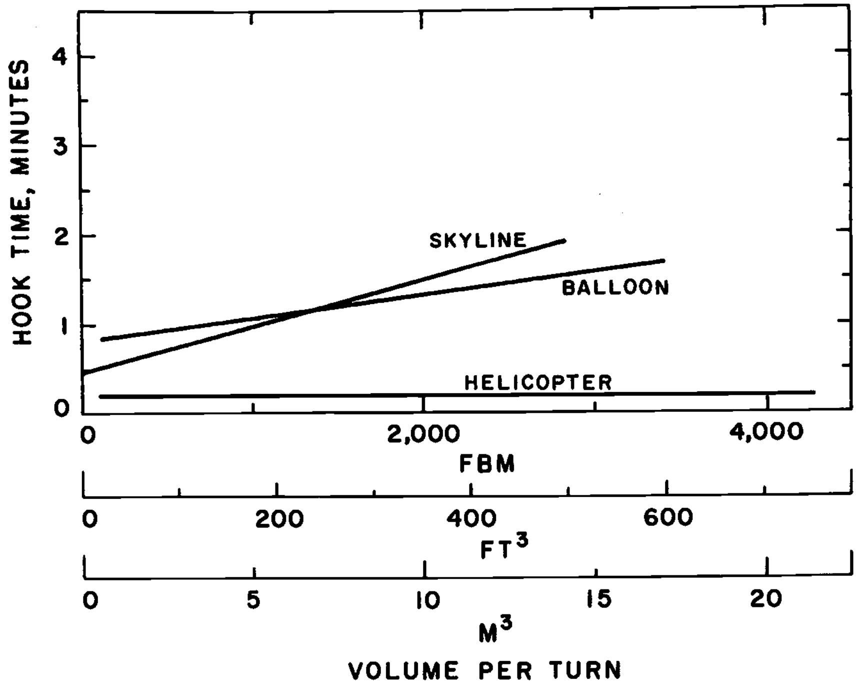

Figure 24. Hook time as a function of volume per turn.

together. For the data of 1974, LOGS was the more significant of the two and thus appears in the final equation.

For the skyline and balloon equations, the most important variable (quantitatively) is volume per turn, and the hook-time equations for the three systems are plotted against BFVOL in Figure 24.

Regression Hypotheses for Lateral-in and Vertical-out Time

Skyline

H_0 : lateral-out time = f(SYDIST, LDIST, BFVOL, BFVOL/LOG)

Helicopter

H_0 : vertical-out time = f(GROUNDSLOPE, TAGLINE, HTRESID, CHOKERS, LOGS, BFVOL, BFVOL/LOG)

Regression Equations for Lateral-in and Vertical-out Time

Skyline

Lateral-in time = 0.031967 (R = 0.336; n = 833)
+ 0.00011009 (SYDIST) ****
+ 0.0026715 (LDIST) ****
+ 0.000088795 (BFVOL) ****

Helicopter
Vertical-out time = 0.25338 (R = 0.166; n = 938)
+ 0.0020802 (GROUNDSLOPE) ****
+ 0.018767 (LOGS) ****
Alternate equation without GROUNDSLOPE:
Vertical-out time = 0.34042 (R = 0.128; n = 938)
+ 0.019168 (LOGS) ****

Lateral-in time for the skyline was most strongly influenced, as we would expect, by lateral yarding distance. Total weight of the turn (approximated by BFVOL) and main yarding distance also exert strong influences on the time required for this subcycle. The effect of lateral yarding distance on lateral-in time for the skyline is plotted in Figure 22.

For helicopter vertical-out time, TAGLINE and HTRESID again had to be excluded because of insufficient variance in the observations of those variables. Neither of the volume measures (BFVOL and BFVOL/LOG) was significant at any level, which suggests that weight is not an important determinant of vertical-out time, at least insofar as it is within the payload capabilities of the aircraft. The number of logs per turn, however, is important, probably because it serves as an index of the height the helicopter must ascend to clear any residual timber. The lower logs in multiple-log turns were usually attached to adjacent logs rather than to the hook itself and as a result, the turn would often be strung out for several log lengths below the hook (Figure 3). For reasons illustrated in Figure 23 and discussed in a previous section, GROUNDSLOPE was also presumed to influence vertical-out time, and the regression analysis appears to confirm this hypothesis.

Regression Hypothesis for Inhaul Time

H_0 : inhaul time = f(CHORDSLOPE, SYDIST, BFVOL, BFVOL/LOG)

Regression Equations for Inhaul Time

Skyline
Inhaul time = 0.49484 (R = 0.478; n = 833)
+ 0.0010009 (SYDIST) ****
+ 0.00026053 (BFVOL) ****
Balloon
Inhaul time = - 0.54139 (R = 0.583; n = 453)
+ 0.028445 (CHORDSLOPE) ****
+ 0.00069742 (SYDIST) ****
+ 0.00053374 (BFVOL) ****
- 0.00017332 (BFVOL/LOG) **
Helicopter
Inhaul time = 0.23812 (R = 0.594; n = 938)
+ 0.0061005 (CHORDSLOPE) ****
+ 0.00016753 (SYDIST) ****
+ 0.000060987 (BFVOL) ****
- 0.000050837 (BFVOL/LOG) ****

The inhaul equations for this study, which have been plotted against yarding distance in Figure 25, agree in general with those obtained for the study in 1973. For the skyline, we find, as we did for all of the cable systems in 1973, that only slope yarding distance and volume per turn are significant predictor variables of inhaul time. Furthermore, the parameter values of the skyline equation are only slightly different from those obtained for the Berger in 1973. As

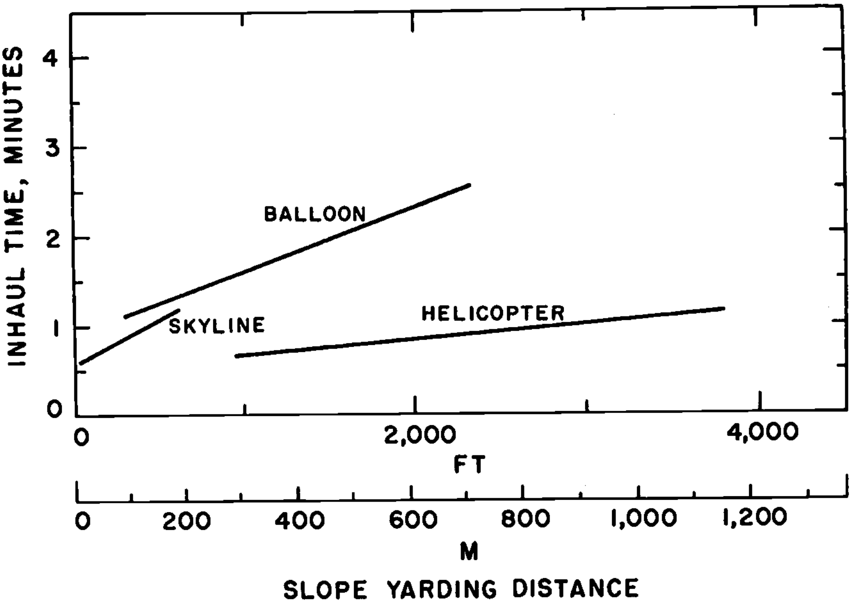

Figure 25. Inhaul time as a function of slope yarding distance.

we mentioned for outhaul time, this strongly suggests that the operating characteristics of running skyline systems (for medium-size yarders) may, in general, be consistent. A complete empirical validation of this hypothesis will have to await further research; if confirmed, it would have important implications for the appraisal of yarding operations on which the yarding system to be used is specified but the actual yarding equipment is not.

For the balloon, our final equation contains the same independent variables as that of the study in 1973. The effect of chordslope on inhaul time is much less for the haulback system than for the inverted skyline, however. The coefficient of volume per turn is virtually the same for the data of 1974 as for the data in 1973; the parameter corresponding to volume per log, however, is somewhat smaller, perhaps because the average log on the balloon operation in 1974 was some 30 percent larger than that encountered during 1973. The coefficient of SYDIST for the regression for 1974 is somewhat larger than that for 1973. As mentioned earlier, this may suggest a nonlinear relation between yarding time and yarding distance, as the data for 1974 were obtained at much greater yarding distances than were those for the study in 1973. Field observations also suggested that the yarder engineer tended to operate the yarder somewhat more conservatively in 1974.

The regression equation for helicopter inhaul time shows three sign changes from the equation of 1973: CHORDSLOPE and BFVOL now have positive coefficients, and BFVOL/LOG has become negative. The switching of signs between BFVOL and BFVOL/LOG is not surprising, because both variables entered the equation of 1973 at only the 20-percent probability level, and we therefore had little confidence that the equation expressed their correct functional relations to inhaul time. Furthermore, the change is satisfying because the signs that result agree with those in all of the other inhaul equations (except the helicopter equation of 1973, of course).

The fact that the signs on CHORDSLOPE for the two equations disagree is more surprising, however, as that variable entered both equations at the 1-percent level. If we check the data, however, we are confronted by two facts: first, chordslope during the study in 1973 was, like yarding distance, observed at only a few values; second, it was strongly correlated with yarding distance. These facts raise questions about the validity of our estimate of the chordslope coefficient in the equation for 1973. In our discussion of the regressions for 1973, in fact, we warned that

> This result should be viewed with some caution, however, because observations during the study suggested that for steep chordslopes (over about 50 percent), the aircraft's inhaul speed drops off rapidly because of its steep angle of descent toward the landing. Thus, the influence of chordslope on helicopter inhaul time may be more complex than the regression equation indicates (8, p. 31).

For the data of 1974, chordslope and yarding distance are positively correlated, although the collinearity is not as strong as in the data of 1973. Because of a better spread of observations, we can feel somewhat more confident about our estimate of the chordslope coefficient. In addition, the fact that the coefficient is positive confirms the stated preference of helicopter pilots for a minimum gradient to the landing (14). The fact remains, however, that the problem of multicollinearity exists in both sets of data. Perhaps, as suggested by Sinner (13), chordslope and yarding distance are interactive rather than independent. Certainly we cannot claim at present to have analyzed fully the functional relations between these two variables and inhaul time. Additional research is needed before any such claim is made.

Regression Hypotheses for Unhook Time

Skyline

H_0 : unhook time = f(CHOKERS, CHASERS, LOGS, BFVOL, BFVOL/LOG)

Balloon and Helicopter

H_0 : unhook time = f(CHOKERS, CHASERS, TAGLINE, LOGS, BFVOL, BFVOL/LOG)

Regression Equations for Unhook Time

Skyline

Unhook time = 0.21181 (R = 0.151; n = 833)
+ 0.030463 (LOGS) ****
- 0.000035174 (BFVOL/LOG) *

Balloon

Unhook time = - 0.27087 (R = 0.348; n = 453)
+ 0.19841 (CHOKERS) ****
+ 0.0014022 (TAGLINE) ****

Helicopter

No regression; mean unhook time = 0.0089552

Of the nine yarding systems for which data were recorded during the Pansy Basin studies, unhook-time regressions were successfully computed for only four: the Berger, the GT-3, and the two balloon systems. Furthermore, all four of the equations are substantially different. Although admittedly the unhooking operation is labor intensive and subject to many factors that are either difficult to measure (such as the skill of the chaser) or are not predictable before logging (such as the height of the log deck), the same is true of the hooking operation for which much more consistent results were obtained. We admit to having had difficulty in attempting to compute unhook-time equations that could be used effectively to compare production rates for alternative yarding systems. Individually, the variables in each of the four equations appear justifiable. The main problem with our result is that comparable variables do not appear in all four equations, although LOGS or CHOKERS, which are virtually collinear, do appear in three of the four. Furthermore, the sign associated with TAGLINE in the balloon equations has changed from 1973 to 1974. This is not too surprising, as tagline length was significant in the equation for 1973 only at the 20-percent level, and we could not, therefore, be highly confident about the magnitude or sign of its slope. In addition, the distribution of tagline lengths observed during 1974 was significantly better than that for 1973; this would be expected to give us a more satisfactory estimate of the regression coefficient for that variable.

A final problem is that neither of the equations for 1974 includes BFVOL, which is the variable against which unhook times were plotted for the equations of 1973. For this reason, we have elected not to provide a plot for the unhook-time equations of 1974.

Regression Equations for Total Time

The total-time equations listed below were obtained by summing the elemental equations for each system. The constants for these equations include the average of several "events" that were isolated by the study crew but are not considered normally as separate yarding events. For all three systems, this includes the time required for the rigging crew to approach and move away from the hook point. For the balloon, it includes the time required to raise and lower the balloon at the hook point and, for the skyline, the time required to raise and lower the skyline.

Skyline

Total time = 2.39219
+ 0.0019426 (CHORDSLOPE)
- 0.11478 (RIGGERS)
+ 0.00211976 (SYDIST)
+ 0.0118565 (LDIST)
+ 0.030463 (LOGS)
+ 0.000863135 (BFVOL)
- 0.000397724 (BFVOL/LOG)

Balloon

Total time = 4.1458
- 0.01391 (CHORDSLOPE)
+ 0.0006024 (TAGLINE)
+ 0.00228315 (SYDIST)
+ 0.0091442 (LDIST)
+ 0.285103 (CHOKERS)
+ 0.00133352 (BFVOL)
- 0.00049855 (BFVOL/LOG)

Helicopter

Total time = 1.3721152
+ 0.0126924 (CHORDSLOPE)
+ 0.000246741 (SYDIST)
+ 0.031200 (LOGS)
+ 0.000060987 (BFVOL)
- 0.000050837 (BFVOL/LOG)

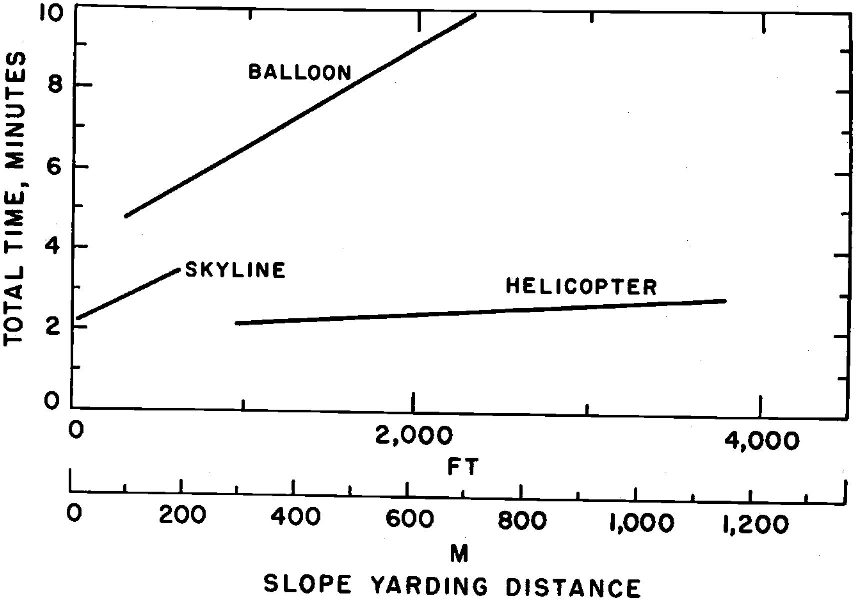

Figure 26. Total turn time as a function of slope yarding distance.

Figure 26 is a plot of total time as a function of slope yarding distance, which was the most influential single variable for the three systems (also for the six yarding systems in the study in 1973). As with the other plots, the median values of the independent variables other than SYDIST (see Table 3) were used to calculate the end points of the plotted lines. This procedure yields curves that are representative of the median conditions encountered during the study and are useful, therefore, for making comparisons among the systems as they were operated while field observations were being made. The curves in Figure 26 are not useful for deriving estimates of total turn time for other conditions, however. For that purpose, the regression equations themselves should be used with estimates of the relevant independent variables.

Volume Conversions

Because of the growing emphasis on the use of cubic volumes rather than conventional board foot measures, we have derived ratios for converting Scribner volumes measured during this study to their cubic foot and cubic meter equivalents as estimated by Smalian's formula (7). These ratios are listed in Table 4. Also listed for reference are the equivalent ratios for the systems in 1973 not previously published. To convert the coefficients for BFVOL and BFVOL/LOG in the regression equations to the corresponding coefficients for cubic foot or cubic meter volume, the listed coefficient should be multiplied by the appropriate conversion ratio. As an example, the coefficient of BFVOL in the GT-3 total-time equation is + 0.000863135. To convert to its cubic volume equivalents, we have

for cubic feet: (+ 0.000863135)(5.173) = + 0.00446500; and
for cubic meters: (+ 0.000863135)(182.6) = + 0.157608.

These conversions will be used in a later section to express yarding costs in terms of both board measure and cubic measure.

Delays

The regression equations discussed above estimate delay-free yarding times. To estimate yarding costs, however, we must also consider nonproductive time during the yarding operation. Many costs, such as those of ownership, overhead, and sometimes labor, are incurred whether or not the yarding system is operative. Other costs, such as those related to fuel consumption and line wear, accumulate only during productive time. As yarding systems differ in the percentage of time they are nonproductive, their overall "cost efficiency" would also be expected to differ. Table 5 summarizes the procedure followed in the present analysis to compute the portion of total time that was nonproductive during the time study. We have excluded road-changing time from this total, as it will be considered separately in the next section. The percentages of nonproductive time (Table 5, column C) are much higher for the skyline and balloon systems than for the corresponding systems in the study of 1973. Some of this increase may be an actual increase in delay time: the systems in 1974 were, of course, different than in 1973, and the skyline was operated in a partial cutting. Some of the apparent increase in delay time, however, is because of more complete segregation of delays by the study crew. Some events that had previously been considered part of productive time were isolated as delays; as a result, the number of delays recorded in 1974 averaged 982 per system

Table 4. Average Volume per Turn and Volume Conversion Ratios.

Yarder	Volume per turn			Conversion ratios	
	Fbm	*Ft*^{3}	*M*^{3}	*Fbm/ft*^{3}	*Fbm/m*^{3}
CABLE SYSTEMS					
Berger Marc I	493.3	93.5	2.65	5.276	186.3
West Coast North Bend	586.2	103.8	2.94	5.647	199.4
West Coast highlead	246.1	57.5	1.63	4.280	151.1
Skagit BU90/T90	758.8	132.4	3.75	5.731	202.4
Skagit GT-3	329.5	63.7	1.80	5.173	182.6
BALLOON SYSTEMS					
Inverted skyline	919.2	158.8	4.50	5.788	204.4
Haulback	1,060.7	180.8	5.12	5.867	207.1
HELICOPTERS					
Vertol	683.6	114.3	3.24	5.981	211.2
S64E	1,644.5	267.5	7.57	6.148	217.0

compared to only 205 per system in 1973. The purpose of this segmentation was to allow a separate analysis of nonproductive times[3]. As we mentioned earlier, however, the fact that we changed procedures between the two studies essentially precludes any direct comparison of delay time between the two. This is no great disadvantage; now we are interested primarily in developing cost data for the yarding systems and therefore concerned mainly with total time rather than productive compared to nonproductive time.

The total of productive and nonproductive time exclusive of road-changing time is computed as follows:

$$\text{Time} = \text{DFT}/[(100\text{-C})/100]$$

where DFT = the estimated delay-free yarding time calculated from regression equations, and C = the percentage of time that is nonproductive (Table 5). This procedure is useful (8) for deriving total yarding time for computation of yarding costs after an operation has been concluded. In general, however, delays do not tend to exhibit consistency even for a specific yarding system: we have no reason to believe that the value obtained in column four of Table 5 can be used with confidence to predict delays on future yarding operations. A preferable method would be to use local experience to obtain a range of values for "C" so that the expected cost of a larger or smaller percentage of nonproductive time could be assessed.

Yarding Road Changes

The task of moving the lines to permit access to the unyarded portion of a cutting unit can require a significant investment in time and effort for any cable system. The length of time required to change an individual cableway may be dependent upon many factors, such as external yarding distance, size of rigging, type of yarding system, skill of the rigging crew, and whether the operation is in a partial cutting or a clearcutting. Variance among observed times is usually great, even for a single yarding system and in constant operating conditions. Thus, we were unable to derive any meaningful expressions for estimating road-changing time. Table 6 illustrates the wide range of road-changing times in this study. Although estimating the time required to change an individual yarding road is difficult, we can make a reasonably accurate estimate of the number of yarding roads that will be required to yard a specific cutting unit, for example, with procedures outlined by Binkley and Lysons (4). After such an estimate has been made, we can compute the expected total yarding time, including changes of yarding roads as follows:

$$\text{Time} = [(\text{ARCT})(\text{NRDS})] + \text{DFT}/[(100\text{-C})/100]$$

Table 5. Total Productive and Nonproductive Yarding Time, Exclusive of Road Changes.

System	[A] Total productive time	[B] Total nonproductive time	[C]=[B]/[A + B] Portion of time that is nonproductive	Delays timed
	Minutes	*Minutes*	*Percent*	
Skyline	2,319.2	883.9	27.6	1,138
Balloon	3,280.1	1,327.4	28.8	1,152
Helicopter	2,267.3	826.7	26.7	655

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[3] Dykstra, D. P. 1975. Delays and downtime related to cable, balloon, and helicopter yarding in old-growth Douglas-fir: a catalog for the Pansy Basin Study. Unpublished report presented to the U.S. Dept. of Agric., Forest Service, Pac. N.W. Forest and Range Expt. Sta., Portland, Oregon.

where ARCT = average road-changing time (from Table 6); NRDS = number of changes of yarding-roads to be made; DFT = estimated delay-free time computed from regression equations; and C = percentage of time occupied by delays (Table 5).

As suggested by the range of values recorded for road-changing time in Table 6, we cannot, in general, expect to use the average road-changing times from the Pansy Basin Study to predict the time required to change roads on future yarding operations; the variance in observed road-changing times is simply too great to be of value in making such predictions. Again, a wise course of action would be to rely on local experience to obtain a range of values for "ARCT" to weigh the effects of possible extremes.

Note that we have intentionally omitted an array of times that might be called "indirect" yarding times. These include move-in and set-up times and any other time when the yarding crew is occupied by tasks other than direct yarding. Such considerations are beyond the scope of the present analysis.

YARDING COSTS

To make costs from the present study comparable with those reported for the study in 1973, we have followed the same procedures in calculating direct yarding costs. We used wages and equipment prices from 1973 to avoid effects of inflation and the time value of money. The basis for yarding costs per unit volume is gross scale without deductions for defect. Only costs directly associated with the yarding activity are presented. Similarly, the cost of equipment necessary for yarding but not actually used in the yarding process (such as spool trucks, crew vehicles, and landing tractors) is excluded. Certain other costs that would be appropriately considered in any industrial cost analysis are not included here because they have been specifically excluded from Forest Service appraisals. These include such items as taxes, interest, and expenses of forest management (18). Costs have been subdivided into labor and equipment. Both were calculated on an assumed 200-day (1,600-hour) year, except that costs of aircraft equipment for the helicopter were based on a 1,200-flight-hour year. Wire rope costs were calculated directly on the assumption that line wear is proportional to the gross volume of timber yarded with the line.

Labor Costs

The estimated hourly costs for yarding crew labor are summarized in Table 7. To allow comparisons, wages have been based upon Forest Service appraisal guidelines for 1973, and we have assumed that a specific job on one operation pays the same as the corresponding job on either of the other operations.

Equipment Costs

Hourly costs of equipment and costs of wire rope per volume are derived in detail in the Appendix, and summaries for each system are presented in columns A and E of Table 8.

Table 6. Summary of Times Required to Change Yarding Roads.

System	Maximum time	Minimum time	Average time	Road changes timed
	Minutes	*Minutes*	*Minutes*	
Skyline	91.9	15.6	44.0	18
Balloon	119.2	41.4	68.1	6

Table 7. Estimated Hourly Yarding Crew Costs, in Dollars per Hour.

Position	Unit hourly cost			Men in each job			Resultant hourly cost		
	Wage[1]	Payroll[2]	Total	Sky-line	Bal-loon	Heli-copter	Sky-line	Bal-loon	Heli-copter
Hooktender	6.65	1.60	8.25	0	1	1	0	8.25	8.25
Yarder operator	5.71	1.37	7.08	1	1	0	7.08	7.08	0
Rigging slinger	5.46	1.31	6.77	1	1	0	6.77	6.77	0
Hooker[3]	4.85	1.16	6.01	0	0	2	0	0	6.01
Choker setter[3]	4.85	1.16	6.01	1	2	4	6.01	12.02	24.04
Chaser[3]	4.85	1.16	6.01	2	2	4	12.02	12.02	24.04
Pilot[4]	-	-	14.06	0	0	4	0	0	56.24
Aircraft mechanic[5]	-	-	7.81	0	0	4	0	0	31.24
Total							31.88	46.14	149.82

[1] Includes $0.35/hour travel pay.

[2] Estimated payroll expense is 24 percent of wages including travel pay.

[3] The wages used for these positions differ slightly from those published in Forest Service appraisal guidelines. For the systems in this study, chasers and choker setters tended to receive the same pay and often switched jobs from day to day. On the helicopter operation, the hookers and choker setters frequently alternated.

[4] Based on salary and other compensation estimated at $22,500 per year (assuming 1,600 work-hours per year).

[5] Based on salary and other compensation estimated at $12,500 per year (assuming 1,600 work-hours per year).

Table 8. Yarding Cost Summary.

Yarding system	[A] Equipment costs[1]	[B] Labor costs[2]	[C] Production rate	[D]=(A+B)/C Equipment and labor costs	[E] Wire rope costs[3]	D+E= total cost		
	$/hr	*$/hr*	*M fbm/hr*	*$/M fbm*	*$/M fbm*	*$/M fbm*	*$/ccf*	*$/m³*
Skyline	18.83	31.88	3.6	14.09	0.57	14.66	7.58	2.68
Balloon	56.43	46.14	5.5	18.65	1.20	23.65[4]	13.88	4.90
Helicopter	1,363.62	149.82	37.8[5]	42.76[6]	0.10	42.86	26.35	9.30

[1] 1,600 hours per year, except 1,200 hours per year for the helicopter. From Table 11 (Appendix).

[2] 1,600 hours per year, all systems. From Table 7.

[3] From wire rope costs in Table 12 (Appendix).

[4] Includes the cost of the initial fill of helium ($20,500) amortized over 5,400 M fbm (gross volume) scheduled for harvest on the sale ($3.80/M fbm).

[5] Labor costs accrue during nonflight delays, so the production rate for labor costs is reduced by the amount of those delays. For this study, the appropriate rate =

$$\frac{1{,}542.5 \text{ M fbm}}{(3{,}094.0 \text{ min})/(60 \text{ min/hr})} = 29.9 \text{ M fbm/hr},$$

where 1,542.5 M fbm is from Table 9 and 3,094.0 minutes is the total of columns A and B, Table 5.

[6] The hourly production rate for the helicopter is based upon 1,200 flight-hours per year, so labor costs for that system (column B) must be converted to a 1,200-hour basis, as follows:

$$B_{1200} = \frac{B_{1600}}{1{,}200 \text{ hrs}} \times 1{,}600 \text{ hrs} = \frac{149.82}{1{,}200} \times 1{,}600 = 199.76.$$

Then column D $= \frac{1{,}363.62}{37.8} + \frac{199.76}{29.9} = 42.76.$

Total Direct Yarding Costs

Tables 8 and 9 illustrate the procedure for combining costs of labor and equipment on a per volume (gross) basis. To adjust these estimates for scaling deduction, the following formula should be used:

$$C_n = C_g/(\text{net/gross})$$

where C_n = cost per volume, net basis; C_g = cost per volume, gross basis (from Table 9); and net/gross = the ratio of net volume to gross volume.

Table 9. Summary of Total Times and Production Rates.

Yarding system	[A] Total productive time	[B] Total delay time	[C] Apportioned road-changing time[1]	[D]=A+B+C Total work time	Total gross volume yarded	Yarding rate	
						Per hour	Per day[2]
	Minutes	*Minutes*	*Minutes*	*Minutes*	*M fbm*	*M fbm/hr*	*M fbm/day*
Skyline	2,319.2	1,685.2	561.1	4,565.5	274.5	3.6	28.8
Balloon	3,280.1	1,586.3	346.8	5,213.2	480.5	5.5	44.0
Helicopter	2,267.3	183.8[3]	--	2,451.1	1,542.5	37.8	302.1

[1] Calculated as follows:

$$\frac{\text{Area yarded while timing was in progress}}{\text{Total area yarded on n yarding roads}} \times \text{[estimated time to make n-1 yarding road changes]}$$

where n = the number of yarding roads on which time study observations were made (see Figures 27-28).

[2] Assumes 8 hours/day (for the helicopter, 8 flight-hours/day).

[3] Helicopter equipment costs are based upon 1,200 flight-hours per year. Thus the delay time included here is only for in-flight delays and refueling stops; the remaining 642.9 minutes recorded during the time study (see Table 5) were for delays that required that the aircraft be shut down.

For comparison, we discuss briefly the costs in Table 9 compared to costs for the corresponding systems in the study of 1973. For the cable systems, the comparison of most interest is between the GT-3 (1974) and the Berger (1973). Both were operated in running skyline configurations; both yarders were of about the same size and mobility and have similar mechanical characteristics; hourly equipment and labor costs for the two systems are virtually the same; the regression equations for outhaul and inhaul time for the two systems were nearly identical; the terrain and timber in which the systems operated were comparable; and the ranges over which the independent variables were observed for both systems were similar.

Given these similarities, we note from Tables 6, 8, and 9 and the corresponding tables in Res. Bull. 18 (8) the following: average road-changing time is about 56 percent higher for the GT-3 than for the Berger; productivity is about 45 percent lower; and the resulting total direct yarding cost is about 67 percent higher. The Berger system was operated in a nearly square clearcutting; the GT-3, in an irregularly shaped partial cutting (Figure 27). From our analysis, apparently almost all of the difference in yarding cost between the two operations can be attributed to the difference between clearcutting and partial cutting.

The Berger unit appeared to offer little, if any, advantage over the GT-3 unit in the effect of cutting unit design on yarding cost. We cannot conclude that this result would hold in general, however; certainly a cutting unit shaped so that additional yarding roads are required to give access to a given volume of timber would be at a significant cost disadvantage. The effect in a partial cutting would be even greater, because our analysis suggests that the road-changing operation itself tends to be more time-consuming when the lines must be pulled through standing timber. For the Berger, apportioned road-changing time was about 4 percent of total work time; on the GT-3 operation, it amounted to over 12 percent. Finally, we emphasize that the 67 percent cost differential between the clearcut and partial-cut operations is not by itself useful for appraisal purposes. The correct procedure for appraising logging-system applications is as we have illustrated in Tables 7, 8, and 9; application of cost-differential rules of thumb should be avoided.

The balloon operations (Figure 28) observed during the studies in 1973 and 1974 are less comparable than the running skyline systems discussed above. Although both operations were in landscape-designed clearcuttings, the cable systems for tethering the balloons were different and the yarders themselves had fundamentally different capabilities. Labor and equipment costs were higher on the operation in 1974, and average yarding distance during that study was 1.9 times greater than during 1973. Surprisingly, at that yarding-distance ratio, production rates for the two systems were nearly identical. As a result of higher hourly costs, however, the balloon in haulback configuration cost about 24 percent more than in the inverted skyline configuration. We do not suggest that the latter configuration be used extensively in balloon operations, however. Because of reduced control over the balloon and apparently less safe operating conditions, the inverted skyline should be reserved for use in the special situations to which it is suited (11).

The two helicopter operations studied during 1973 and 1974 appear to be reasonably comparable. The ranges over which the independent variables were observed for both systems were similar, although average yarding distance in 1974 was about 27 percent less than in 1973. Because of the small effect of yarding distance on total turn time for the helicopter, however (see Figure 26), this should not significantly reduce comparability of the two operations. Gross lifting capabilities of the two aircraft are different, of course, but one purpose of comparisons is to ascertain the effect of such differences on system performance. Two major differences between the systems did exist that would influence, at least theoretically, direct cost comparisons. The first of these is that in 1973 the main yarding aircraft was frequently utilized to return empty chokers to the chokersetting crew. In 1974, a small utility helicopter was used for this purpose, and we would expect this to account for some of the difference in productivity between the two systems. The second major difference was that only clearcut units were yarded the first year, but in 1974, two of the nine cutting units yarded were partial cuttings (Figure 29). Although we made

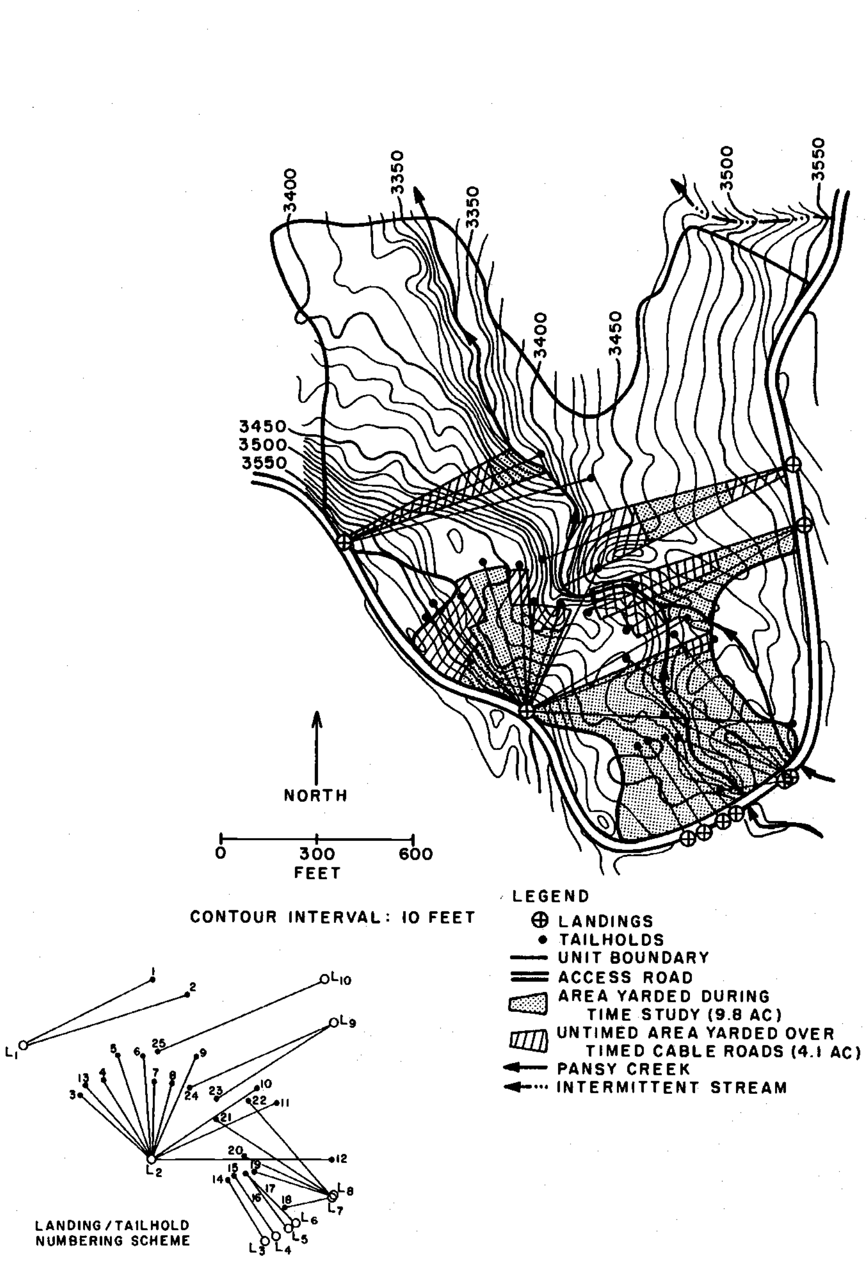

Figure 27. Running skyline unit (partial cutting).

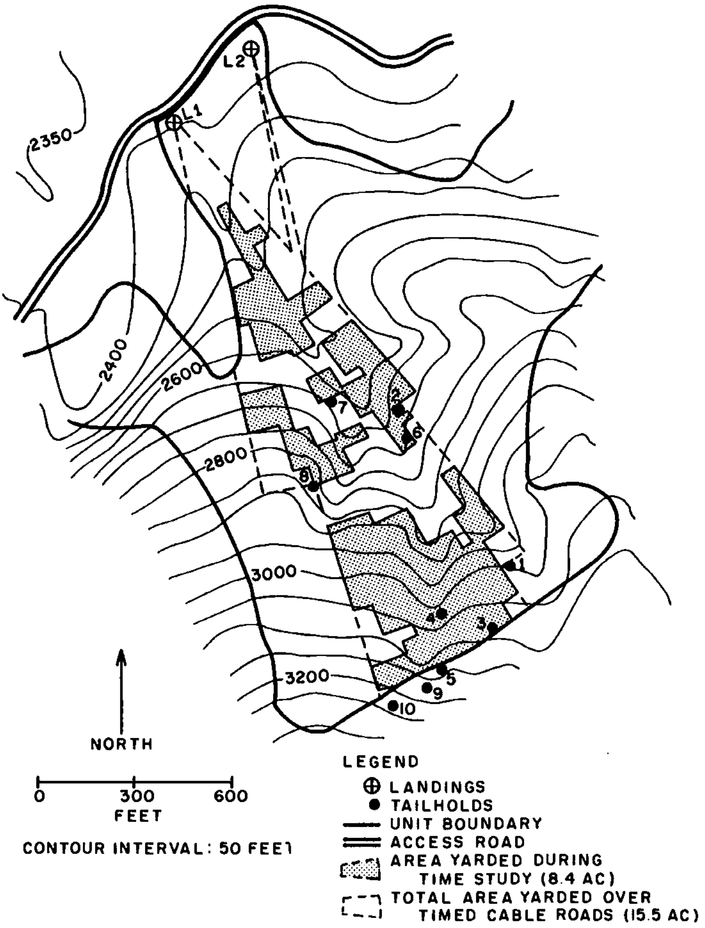

Figure 28. Balloon haulback unit (clearcutting).

extensive statistical tests in an effort to isolate differences in production rates between the clearcut and partial-cut units yarded by the S64E, we were unable to do so at any level of significance. Thus, helicopter production rates did not appear to be influenced by silvicultural method, at least in the heavy partial cuttings observed for this study.

The productivity of the S64E in the conditions encountered at Pansy Basin was nearly three times that of the Boeing-Vertol 107. Substantial differences in hourly labor and equipment costs, however, offset much of this advantage, and the resulting total costs of direct yarding for the two systems differ by less than 30 percent. Remember that we have not included support and maintenance equipment in this analysis, nor have we considered prolonged delays. Separate data

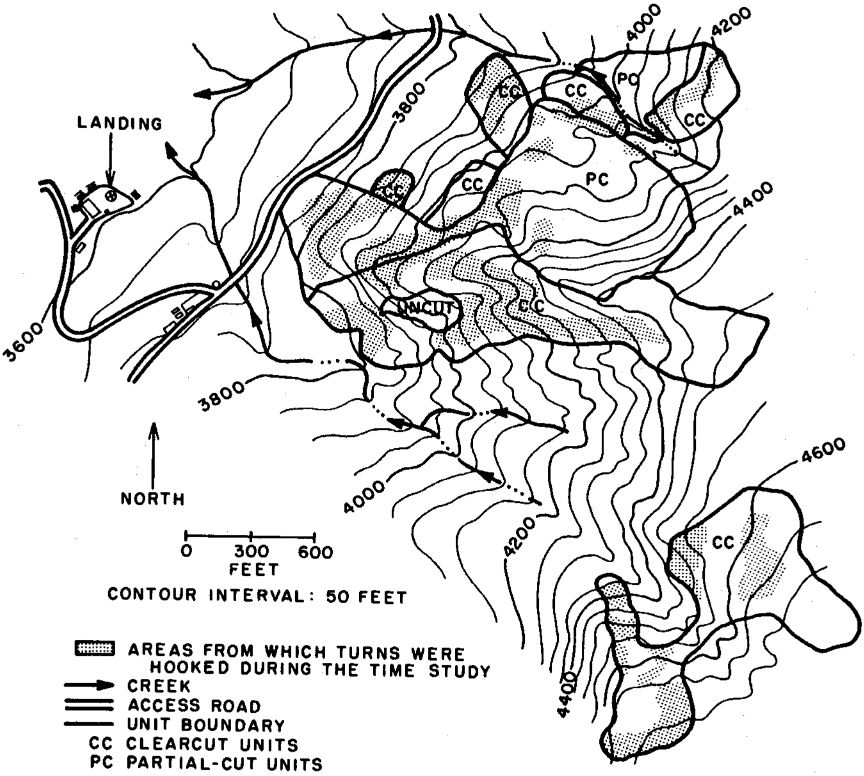

Figure 29. Helicopter units.

collected by the Forest Service from the Pansy Basin logging operators[4] will be more appropriate for making cost estimates of total yarding costs, as distinguished from direct yarding costs, and will include these considerations.

Energy Efficiency

Our estimates of fuel efficiency for the three yarding systems in this study are summarized in Table 10. Although these consumption rates are only for the yarders themselves, to a large extent the fuel consumed during loading and hauling is independent of the yarding system. Thus, these comparisons are essentially complete. Some additional differences might be considered, however; systems that require larger crews and additional support vehicles would, of course, be expected to consume more total fuel than smaller systems. Whether this difference is significant when judged according to volume yarded would depend upon the relative productivity of the yarding systems considered.

[4] Clarke, E. H. 1973. Summary plan for gross production and time studies on aerial logging systems. Unpublished study plan on file at the Pac. N.W. Forest and Range Expt. Sta., U.S. Dept. of Agric., Forest Service, Portland, Oregon, 12 p.

Table 10. Estimated Fuel Consumption Rates.

Yarding system	[A] Fuel consumption rate[1]	[B] Average production rate			A/B= Fuel consumption		
	Gal/hr	*M fbm/hr*	*Ccf/hr*	M^3*/hr*	*Gal/M fbm*	*Gal/ccf*	*Gal/*m^3
Skyline	8.2	3.6	7.0	19.7	2.3	1.2	0.4
Balloon	27.5	5.5	9.4	26.6	5.0	2.9	1.0
Helicopter	525.0	37.8	61.5	174.2	13.9	8.5	3.0

[1] From Table 11, Appendix.

The relations illustrated in Table 10 are generally similar to those found for the study in 1973. Fuel consumption rates by volume for all three systems are close to the rates for the comparable systems in the earlier study, in spite of significant differences in some of the production rates.

CONCLUDING REMARKS

The second phase of the Pansy Basin Study has provided detailed time-study data for a heavy-lift helicopter, a balloon, and a running skyline yarding system operating in large, old-growth timber. Our analysis suggests that productive yarding time is a function of yarding distance, volume per turn and per log, chordslope, and number of logs or chokers per turn. For the running skyline system operating in a partial cutting and the balloon haulback system in a clearcutting, lateral yarding distance is also an important determinant of productive yarding time. The number of men in the rigging crew was also statistically significant for the running skyline, as was tagline length for the balloon.

In contrast to the 1973 phase of the study, in 1974 we were able to derive subjective indices of brush and ground surface conditions at the hook point. These conditions proved to be statistically significant independent variables in several of the subcycle regression equations for the skyline and the balloon. The slope of the ground at the hook point was also found to influence productive yarding time for the skyline system and the helicopter. This influence in the helicopter operation appeared to result primarily from the difficulty the helicopter crew had in maneuvering the aircraft above the hook point. On steeper sideslopes, timber adjacent to the hook point forces the aircraft to hover higher than would otherwise be required, which makes control of aircraft and hook more difficult. Brush and ground surface indices and groundslope present problems as variables in predictive equations for productive yarding time because they are difficult to estimate before yarding. Furthermore, the two indices used to evaluate conditions at the hook point are subjective and therefore cannot be applied without bias. Research is needed to derive measures for these conditions that can be easily estimated on the ground and are mathematically consistent.

The present study confirms earlier observations that the hooking operation is done more efficiently in helicopter than in balloon or cable logging systems. Hooking occupied a smaller percentage of total turn time for both the skyline and balloon systems than for the cable and balloon systems in the first phase of the Pansy Basin Study. For the balloon, this was apparently because of greater emphasis on the presetting of chokers; for the skyline it appeared to result from the tendency of the partial cutting to slow the machine yarding subcycles, while hook time remained about the same as on previous clearcuttings. Major improvements in yarding efficiency apparently could be made by adapting the helicopter system of presetting chokers for use in cable systems.

Comparisons of partial cutting for the helicopter and the running skyline in the present study with clearcutting for the corresponding systems in the previous study suggest different conclusions for the two systems. Helicopter production rates apparently are not substantially influenced by cutting intensity, at least for the relatively heavy partial cuttings for which helicopter yarding data were obtained. Productivity on the running skyline operation in the partial cutting, however, was significantly lower than on the previously reported clearcutting operation; direct yarding costs in the partial cutting were about 67 percent higher than in the clearcutting. This cost differential seems to be attributable almost entirely to the difference in silvicultural methods. Yarding efficiency did not appear to be influenced by shape of cutting unit for the two running skyline systems. This result is specific to the present study, however, and should not be construed as a general conclusion. Certainly, cutting units can be designed for which unit shape is an important determinant of cable-yarding productivity. Cutting unit shape appears to have no significant influence on helicopter yarding productivity, however.

The research described in this report was an effort to obtain comparative data on aerial yarding systems designed to reduce disturbance to the environment in heavy timber and rugged terrain. The procedures developed here are useful for analyzing the production rates and costs of such systems. The extent to which yarding systems are employed to best advantage depends largely upon the ability of forest managers to predict the economic result of alternative applications. Toward this end, the Pansy Basin Study was conducted. Continued research into the relative efficiencies of aerial yarding systems is essential if the capabilities of these systems and the utility of their application are to be advanced.

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APPENDIX
YARDING EQUIPMENT COSTS

Hourly Equipment Costs (Table 11)

Except where noted otherwise, initial costs of equipment used here were derived from Chapter 415.82 of the Timber Appraisal Handbook (18); estimates of salvage value and useful equipment life are from Chapter 410 of the same source. Maintenance and repair costs were based on depreciation, after Adams (1) and Binkley (3). Fuel and lubricant costs were estimated by converting rated engine horsepower into an equivalent rating for intermittent operation at median engine speeds, and then deriving consumption rates for fuel and for lubricants, filters, and grease. This procedure is outlined in Section S, Chapter 415.82 of the Timber Appraisal Handbook (18).

Wire Rope Costs (Table 12)

Wire rope cost estimates are based upon procedures outlined in the Timber Appraisal Handbook (18), Chapters 415.82 (cost per foot of line) and 410 (estimated line life).

Table 11. Estimated Hourly Costs for Yarders, Less Wire Rope.

Equipment item	Hourly cost
	Dollars
SKYLINE	
Depreciation	
Yarder-tower ($155,750 initial cost, depreciated to 20% salvage value, estimated useful life of 8 years)	9.73
Radios ($3,564, 10%, 4-year life)	0.50
Ross S-30B carriage ($4,750, 10%, 4-year life)	0.67
Rigging equipment--tail tree	
Hardware ($2,820, 10%, 4-year life)	0.40
Installation equipment ($770, 10%, 4-year life)	0.11
Guylines (2 x 7/8 in., $0.633/ft x 280 ft = $177, no salvage value, 4-year life)	0.03
Subtotal	11.44
Maintenance and repair costs	
Yarder-tower (50% of depreciation)	4.87
Radios (60% of depreciation)	0.30
Carriage (20% of depreciation)	0.13
Subtotal	5.30
Fuel and lubricants	
Fuel (220 hp rating converts to 150 hp intermittent rating @ median rpm: 8.2 gph x 23¢)	1.89
Lubricants, filters, and grease	0.20
Subtotal	2.09
Total	$18.83
BALLOON	
Depreciation	
Yarder ($205,000, 20%, 8-year life)	12.81
Caterpillar D9 undercarriage (5 years old, partially depreciated: $55,000, 10%, 8-year life)	3.87
Balloon ($121,000, 10%, 4-year life)	17.02
Radios ($3,564, 10%, 4-year life)	0.50
Rigging equipment ($6,700, 10%, 4-year life)	0.94
Rigging installation equipment ($600, 10%, 4-year life)	0.08
Subtotal	35.22

Table 11. (continued)

Equipment item	Hourly cost
	Dollars
Maintenance and repair costs	
Yarder and undercarriage (50% of depreciation)	8.34
Balloon (10% of depreciation)	1.70
Radios (60% of depreciation)	0.30
Subtotal	10.34
Fuel, helium, and lubricants	
Fuel (700 hp rating converts to 500 hp intermittent rating @ median rpm: 27.5 gph x 23¢)	6.33
Helium (anticipated loss of 400 cu ft per day: 400 cu ft per day x 30 days per mo ÷ 176 work-hours per mo = 68 cu ft per work-hour x 6¢ per cu ft)	4.08
Lubricants, filters, and grease	0.46
Subtotal	10.87
Total	56.43
HELICOPTER[1]	
Fixed ownership	
Aircraft depreciation ($2,800,000, 15%, 7-year life)	283.33
Spares ($1,181,000, 15%, 7-year life)	119.51
Hull insurance (13% of acquisition cost annually)	303.33
Property damage and liability insurance ($5,000 annually)	4.17
Subtotal	710.34
Operating	
Fuel (525 gph x 40¢ per gal)	210.00
Lubricants, filters, and grease (3% of fuel costs)	6.30
Maintenance and overhaul	
Engines	156.00
Gear boxes and rotor heads	113.80
Consumables and repairables	71.12
Rotor blades	46.06
Radios and other equipment	50.00
Subtotal	653.28
Total	$1,363.62

[1] Helicopter cost estimates are based upon a data sheet from Sikorsky Aircraft entitled "Sikorsky S64E Skycrane--Estimated Costs of Operation." Stratford, Connecticut. June 1973.

Table 12. Wire Rope Costs.

Wire rope item	Estimated life	Cost
	MM fbm	*$/M fbm*
SKYLINE		
Chokers (5/8 in. x 18 ft) $25.34 per choker	0.2	0.13
Mainline (5/8 in.) $0.347 per ft x 1,200 ft	10	0.04
Haulback (3/4 in.) $0.511 per ft x 2,200 ft	5	0.22
Slackpulling line (5/8 in.) $0.347 per ft x 1,200 ft	10	0.04
Carriage skidding line (5/8 in.) $0.347 per ft x 250 ft	2	0.04
Strawline (3/8 in. fiber core) $0.164 per ft x 3,200 ft	5	0.10
Total		$0.57
BALLOON		
Chokers (3/4 in. x 18 ft) $29.97 per choker	0.2	0.15
Mainline (1 in.) $0.777 per ft x 5,100 ft	15	0.26
Haulback (1 in.) $0.777 per ft x 7,680 ft	10	0.60
Strawline (7/16 in. fiber core) $0.193 per ft x 9,600 ft	10	0.19
Total		$1.20
HELICOPTER		
Chokers (3/4 in. x 18 ft) $29.97 per choker	0.3	0.10
Tagline and hook (included in aircraft costs)	--	0
Total		$0.10