Production Rates of Skyline,
Balloon, and Helicopter Yarding
Systems From Gross Time Study Analysis

by

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Abstract approved: Dennis P. Dykstra
(Dennis P. Dykstra)

This paper describes the analysis of data from a three-year gross time study of skyline, balloon, and helicopter yarding systems operating in Western Oregon. Data collection activities were designed and supervised by the Pacific Northwest Forest and Range Experiment Station, U.S.D.A. Forest Service. The specific logging systems studied were running skyline, North Bend standing skyline, long-span standing skyline, balloon (inverted skyline, highlead, inverted skyline yo-yo, and highlead yo-yo), medium helicopter, and heavy helicopter. These systems were observed under a wide range of silvicultural and landscape design prescriptions, timber type, terrain, and weather conditions.

The objective of this study was to develop yarding production equations, to summarize delays, road change times, and landing change times, and to compare yarding production estimates made from both gross and detailed time study data. This kind of information is useful for the comparison of alternative logging methods in environmentally sensitive, landscape-designed harvest units.

The data were segregated according to the individual logging systems and analyzed via multiple regression. Then individual system data were combined into the categories of short-span skyline, long-span skyline, balloon, and helicopter. These combined data were also analyzed via multiple regression. Chi-square tests were performed to determine whether the equations developed from the combined data were significantly different from the set of equations developed from the segregated data. The results of these tests support a conclusion, at the 95 percent level of fiducial probability, that the equations developed from the combined data are as adequate for predicting yarding production rates for these logging systems as the equations developed from the individual-system data.

The variables shown statistically to influence yarding production rates for all logging systems studied were yarding distance and number of logs per turn. In addition, helicopter yarding productivity was also found to be influenced by the type of cutting prescription, and short-span skyline yarding, by chordslope. A variable combining aspect and the season of work was found to be significant for both the running skyline and the heavy helicopter.

Yarding delays were found to be affected by yarder, landing size, season, and crews' experience. In order to compare similar systems' delays, it was found important to segregate out weather-related delays.

In a separate study, detailed time studies were made on four of the yarding systems analyzed in this paper. This allowed a comparison between the measurements of yarding production rates made during the detailed time study and those made during the gross time study. The gross time study rates were consistently lower than the detail time study rates. This suggests that the detailed method does not reflect the total downtime as accurately as the gross method. Thus the gross method appears better suited for developing information that is useful for appraisal purposes and the detailed method is better suited for evaluation of system efficiency.

ACKNOWLEDGEMENTS

The primary financial assistance and data that made this study possible were provided by the Pacific Northwest Forest and Range Experiment Station, U.S.D.A. Forest Service. My sincere thanks to all who collected data and provided assistance in interpreting it, including loggers and Forest Service employees. I wish to express my gratitude to Dennis P. Dykstra, my major professor, whose guidance and inspiration were invaluable. A special thank you to all my friends and family whose unselfish support kept me going and made this possible.

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INTRODUCTION

The need to harvest timber from more difficult terrain has called for the use of more advanced logging systems. Skylines, balloons, and helicopters have been used in an effort to fill this need. As with any innovation, these applications have been accompanied by problems associated with the design of cutting units, the determination of system feasibility, the estimation of production rates, and the appraisal of costs. In an effort to obtain data which would be useful for solving these problems, the Pacific Northwest Forest and Range Experiment Station of the U.S.D.A. Forest Service recently conducted administrative studies of timber sales designed for advanced logging systems. These sales were located at Pansy Basin on the Mt. Hood National Forest and at Dinner Creek on the Umpqua National Forest. They were logged between 1973 and 1976.

The purpose of these studies was to investigate difficulties associated with logging environmentally sensitive and landscape-designed cutting units, the effect of slash removal requirements on logging productivity and cost, the feasibility of using helicopter and balloon systems to yard partial-cut areas, and the problems associated with the use of skylines to log over plantations and around leave strips (Clarke, 1973).

The purchasers of the Pansy Basin and Dinner Creek Sales were required to keep gross (shift-level) time study records of their operations from 1973 to 1976, and these records are the source of the data analyzed in this paper. A summary report describing the analysis of these data and including the felling and bucking operations as well as yarding has been forwarded to the Forest Service (Dykstra, 1977).

In addition to the gross data, detailed (turn-level) time study data were obtained for the 1973 and 1974 summer sessions at Pansy Basin. The analysis of those data has been reported by Dykstra (1974, 1975, 1976a, b, c) and Van Winkle (1976).

OBJECTIVES

The purpose of this study was to present information which will assist forest managers in evaluating alternative logging systems. The specific objectives were as follows:

1. Summarize the gross time study data collected for the Pansy Basin and Dinner Creek administrative study timber sales.
2. Develop equations to predict yarding production rates using the critical parameters of the logging units and yarding systems upon which production is determined to be dependent.
3. Determine whether statistically significant differences exist among the production rates of similar yarding systems.
4. Compare measured yarding production rates for yarding systems that were studied by both detailed and gross time study methods.

SCOPE

Data analyzed for this study were limited to those obtained for yarding operations in connection with the Forest Service administrative study timber sales at Pansy Basin on the Mt. Hood National Forest and at Dinner Creek on the Umpqua National Forest (Figure 1). The study was designed to represent a wide range of silvicultural and landscape design prescriptions, terrain, timber type and weather conditions (Clarke, 1973).

This report covers the production results for the logging systems listed below:

1. Short-span skyline (Pansy Basin)--two medium-sized, mobile skyline yarders were used. A Skagit GT-3, operating as a running skyline system, yarded both clearcuts and partial-cut areas. An Interstate West Coast Tower, operating as a North Bend standing skyline system, yarded several clearcut areas.

2. Long-span skyline (Pansy Basin)--a heavy skyline yarder with a wooden spar yarded clearcuts and partial-cut units which were designed specifically for long-span skyline yarding. Spans up to 3000 feet were yarded, and the study included both uphill and downhill yarding.

3. Single-yarder balloon (Pansy Basin)--two single-yarder balloon systems were used: a highlead system and an inverted skyline system. Both systems used large balloons (530,000 cubic-foot capacity) to yard clearcuts to downhill landings.

4. YO-YO balloon (Dinner Creek)--a double-yarder balloon system was used to yard clearcuts, overstory removal, and shelterwood units.

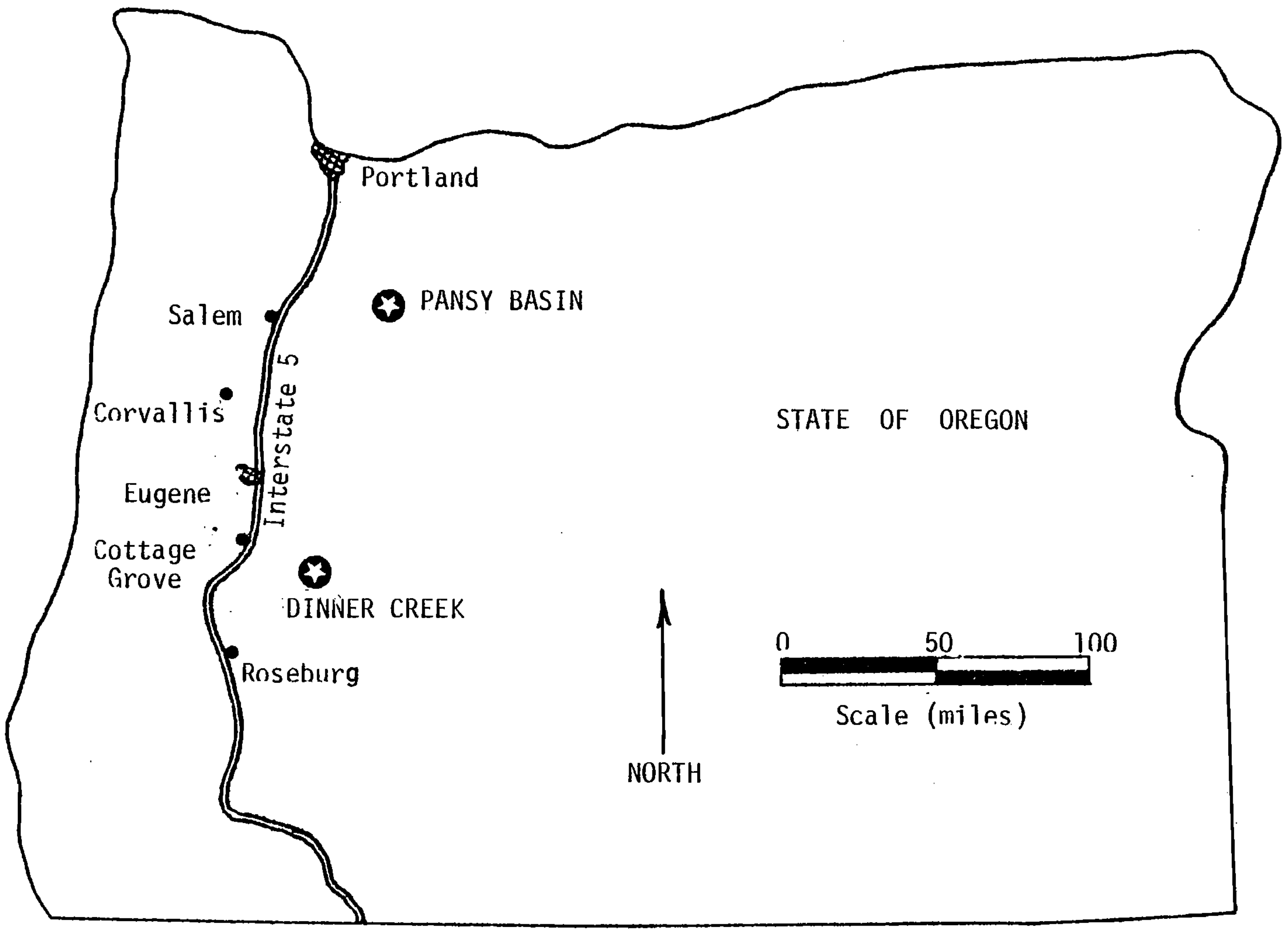


Figure 1. Location map. (Source: Dykstra, 1977)

Two configurations were used: "highlead" yarding to downhill or uphill landings, and "inverted skyline" yarding to downhill landing. Both incorporated a 530,000 cubic-foot balloon.

5. Heavy helicopter (Pansy Basin)--a Sikorsky S64E helicopter, with a rated lifting capacity of about 20,000 pounds, was used to yard both clearcuts and partial-cut units. Also, about 2 percent of logs on this sale were yarded in the fall of 1973 by a medium-sized helicopter, a Sikorsky S61L.

6. Medium helicopter (Dinner Creek)--a Boeing-Vertol 107 Model II, with a rated lifting capacity of about 11,000 pounds, was used to yard clearcuts, shelterwood, and overstory removal units.

A detailed summary of the area yarded by the various systems according to silvicultural prescription is contained in Tables 1 and 2. The units referred to in these tables are shown on maps in Figures 2-6. The general timber type on all of the sales was old-growth Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), with mixed hemlock (Tsuga heterophylla (Raf.) Sarg), western red cedar (Thuja plicata Donn), and associated subalpine fir species. The average volumes per log by yarding system are presented in Table 3 and seasons of work are listed in Table 4.

Table 1. Silvicultural prescription and logging system summary for Pansy Basin operations and Dinner Helicopter operation

Sale	Cutting Units	Area, ac.	Type of cut	Logging System
Skyline Short-span	1,2,14,15,16	22	Clearcut	North Bend (uphill)
	5,6,7,8,9,17	18	Clearcut	Running skyline (uphill)
	11,13	46	Shelterwood	Running skyline (uphill)
		86		
Skyline Long-span	3,4,21	67	Clearcut	Standing skyline (uphill)
	12,22	144	Shelterwood	Standing skyline (uphill)
	22	30	Shelterwood	Standing skyline (downhill)
		241		
Pansy	1	37	Clearcut	Inverted skyline (downhill)
Basin	2,3	68	Clearcut	Haulback(downhill)
Balloon		105		
Pansy	1-38	118	Clearcut	Heavy helicopter
Basin	41-51	93	Shelterwood	Heavy helicopter
Helicopter		211		
Dinner	1	43	Shelterwood	Medium helicopter
Helicopter	5-8,36,37	81*	Clearcut	Medium helicopter
	21,22,43,44,45	357	Overstory Removal	Medium helicopter
		481		

*9 acres near the service landing were yarded by tractor.

Table 2. Classification of areas logged by type of cut, logging system, and yarding direction combinations for the Dinner Balloon operation.

	Clearcut			Overstory Removal			Shelterwood		
	Yo-Yo Highlead		Yo-Yo Inverted Skyline	Yo-Yo Highlead		Yo-Yo Inverted Skyline	Yo-Yo Highlead	Yo-Yo Inverted Skyline	
Unit No.	Uphill	Downhill	Downhill	Uphill	Downhill	Downhill	Downhill	Downhill	Total area, ac.
1	15	–	–	–	–	–	–	–	15
2	–	15	4	–	–	–	–	–	19
4	–	–	–	–	7	2	–	–	9
5	–	19	–	–	–	–	–	–	19
6	–	9	–	–	–	–	–	–	9
7	7	8	–	–	–	–	–	–	15
8	–	–	–	13	11	1	–	–	25
9	–	–	–	–	–	–	36	5	41
10	53	–	–	–	–	–	–	–	53
11	–	–	–	8	–	–	–	–	8
51	–	–	–	–	14	–	–	–	14
81	–	16	2	–	–	–	–	–	18
Direction Totals	75	67	6	21	32	3	36	5	245
System Totals	142		6	53		3	36	5	
Type of Cut Totals	148			56			41		

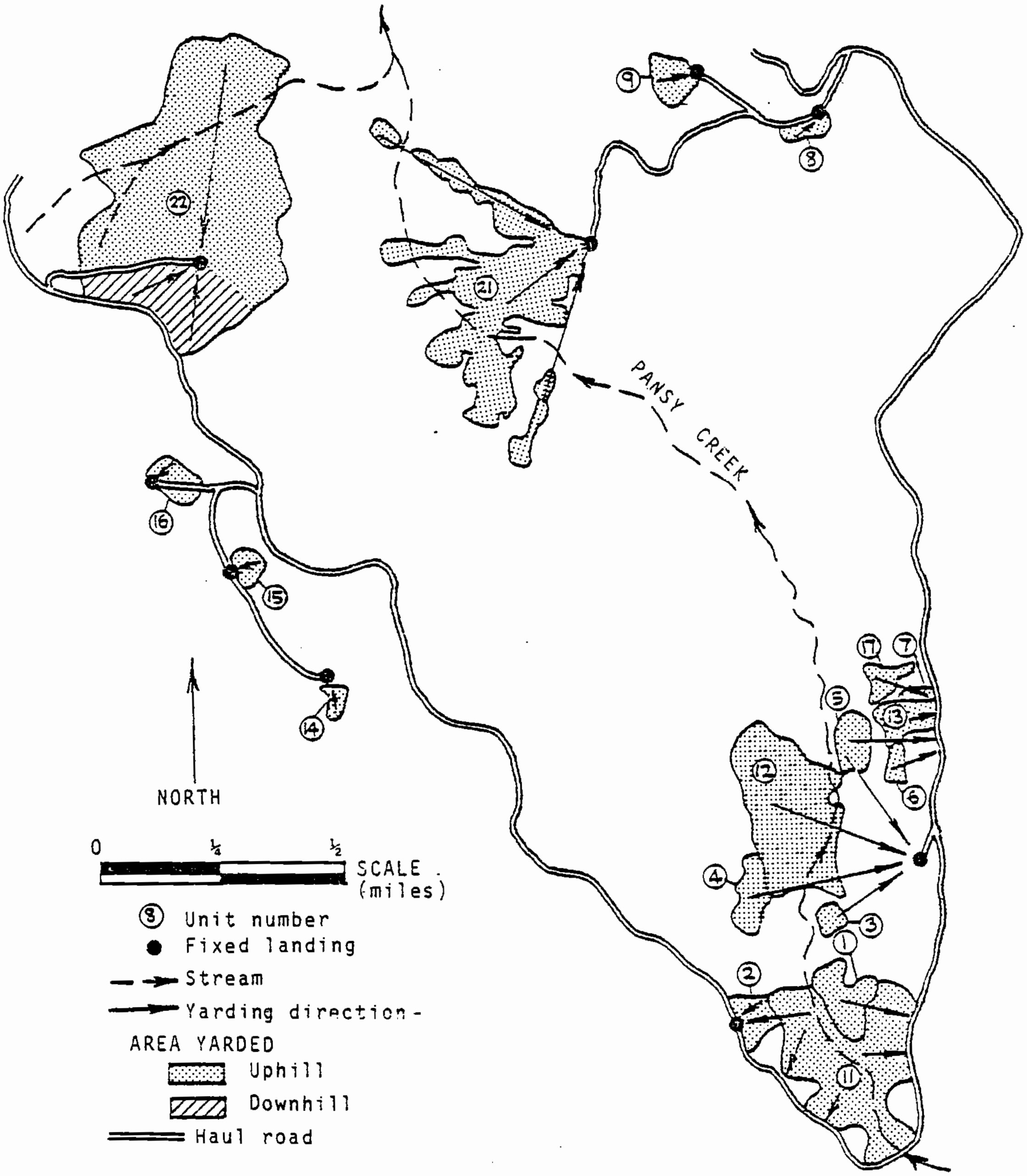


Figure 2. Pansy Basin skyline units
(Source: Dykstra, 1977)

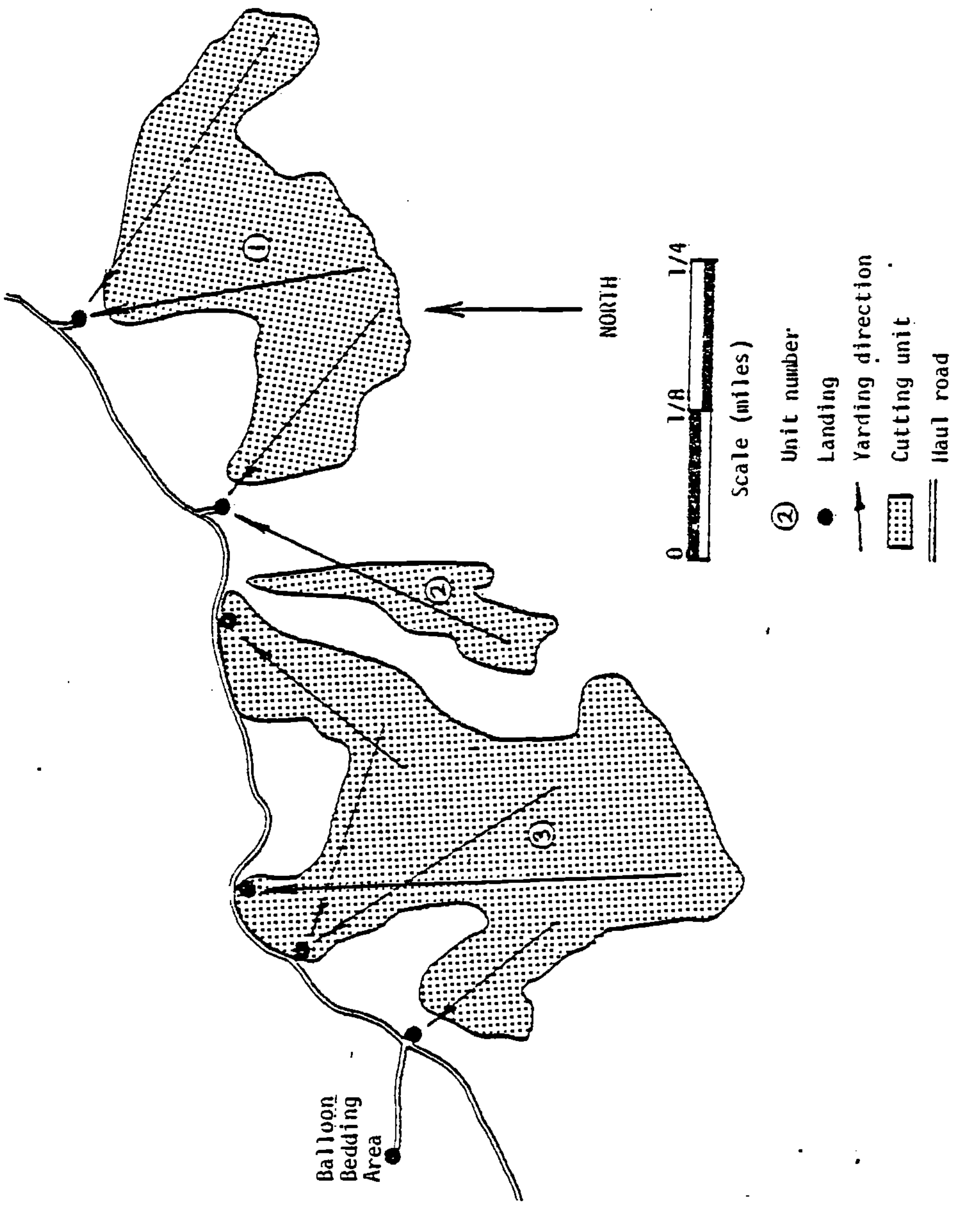


Figure 3. Pansy Basin balloon units.
(Source: Dykstra, 1977)

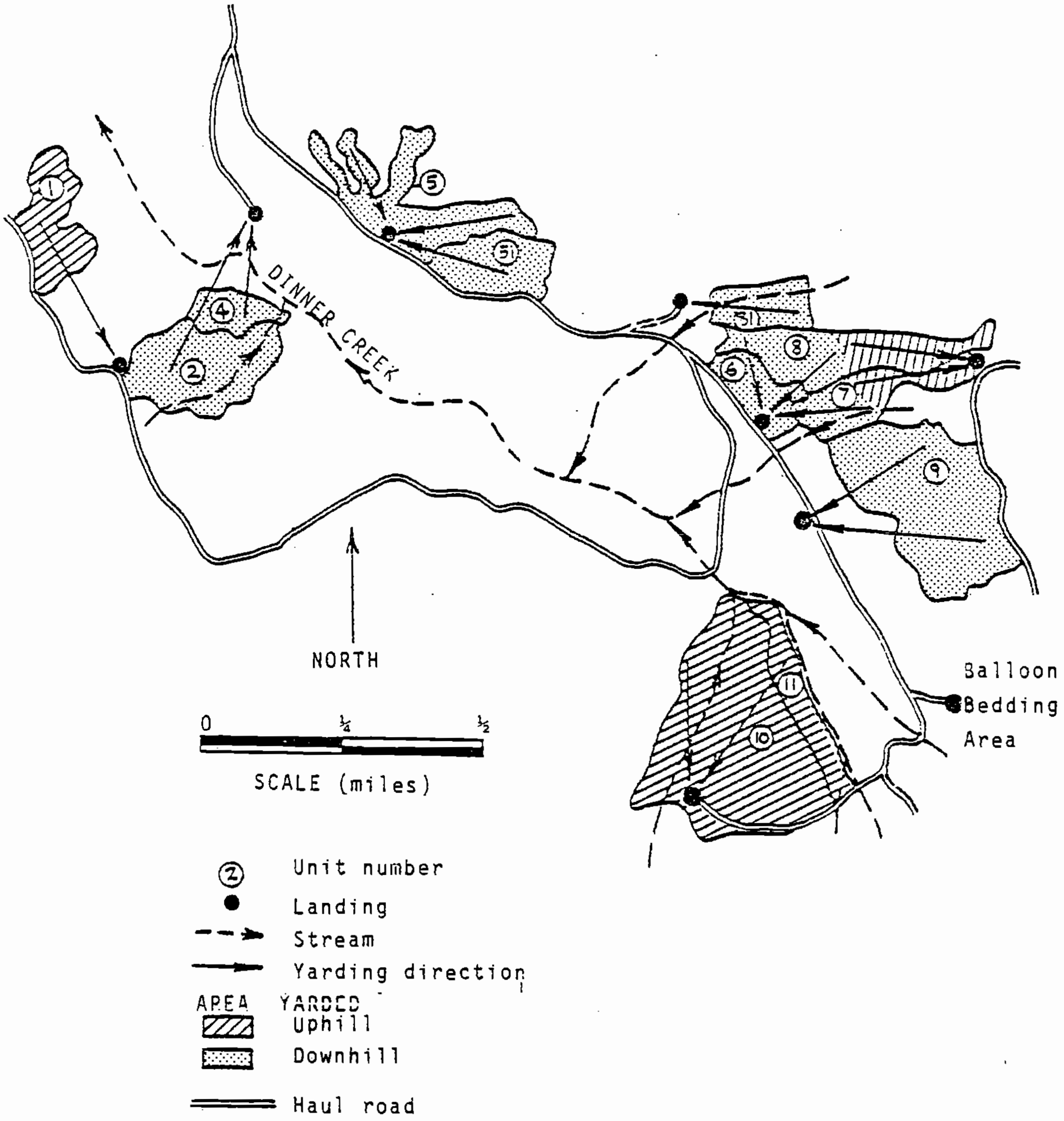


Figure 4. Dinner balloon units.

(Source: Dykstra, 1977)

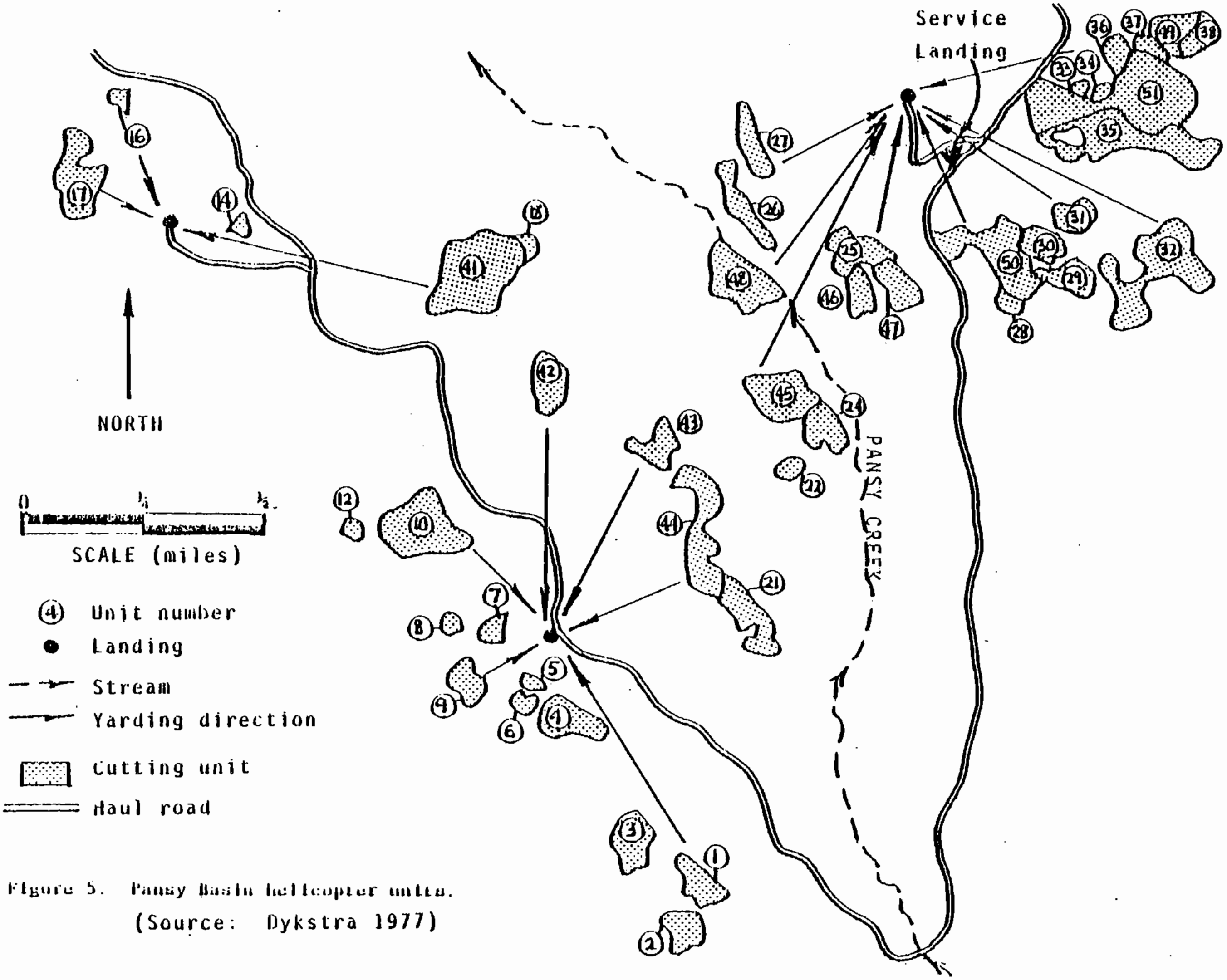


Figure 5. Pansy Basin helicopter units.
(Source: Dykstra 1977)

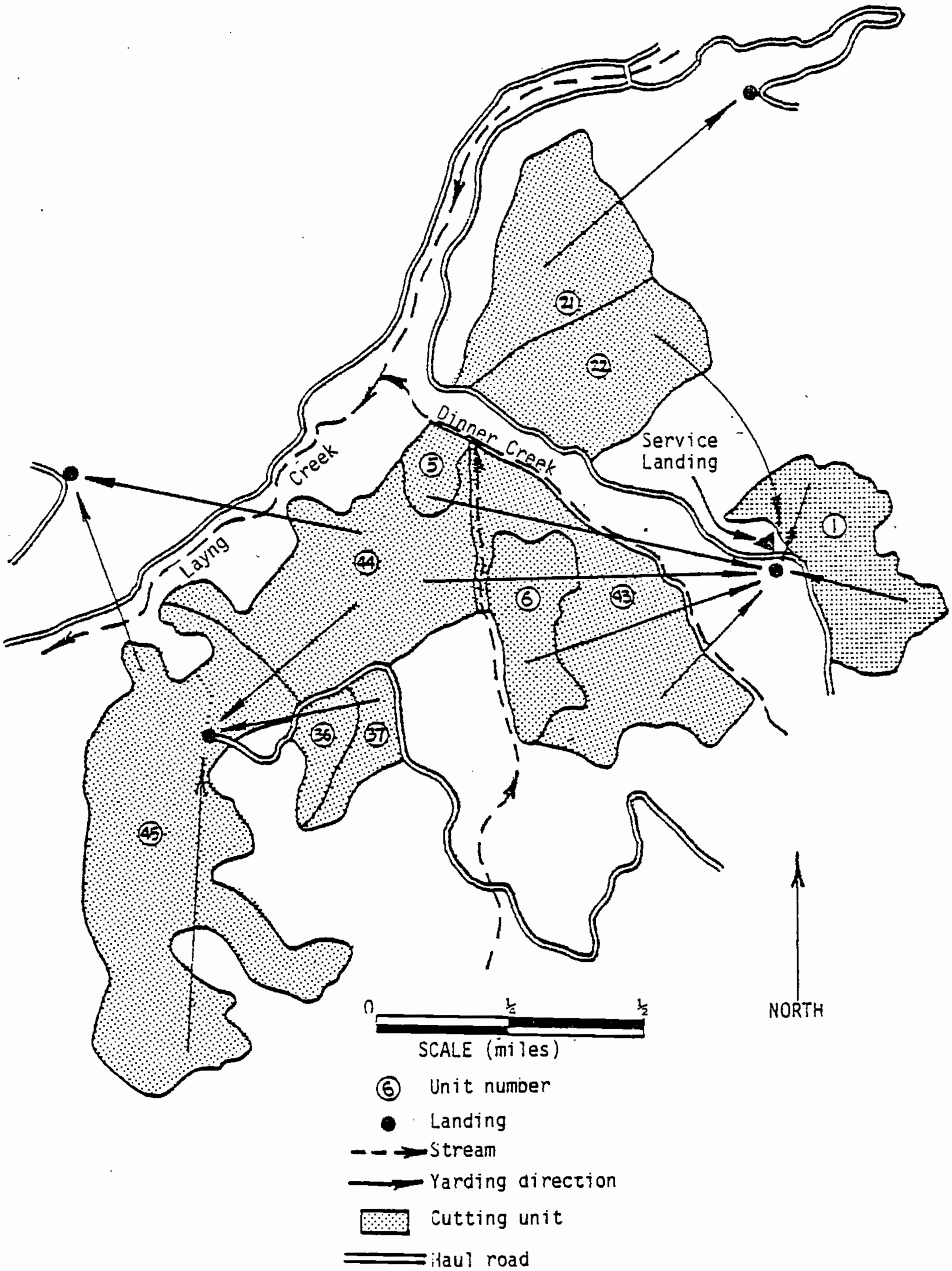


Figure 6. Dinner Creek helicopter units.
(Source: Dykstra, 1977)

Table 3. Average Volume per Log for the Systems Studied

System	Gross MBF/Log	Net MBF/Log
Short-span skyline[a]	.269	.229
Long-span skyline[a]	.269	.229
Single-yarder balloon	.342	.294
Yo-Yo highlead	na	.300
Yo-Yo highlead uphill	na	.404
Yo-Yo inverted skyline	na	.313
Heavy helicopter	.360	.275
Medium helicopter	.408	.326

na indicates that the data were not available

[a] These skyline systems were used on different cutting units but in same timber sale. Log volume records were not segregated within the timber sale..

Table 4. Logging season, by type of activity, for the study areas

Item	Pansy Basin Skyline		Pansy Basin Balloon	Dinner Balloon	Pansy Basin Helicopter	Dinner Helicopter
	Short-span	Long-span				
Cutting Season:						
1973	AUG-OCT	--	JUN-OCT	SEP	AUG-OCT	DEC
1974	JUL-OCT	AUG-NOV	MAR-APR	FEB-DEC	MAY-OCT	JAN-DEC
1975	SEP-OCT	AUG-OCT	--	MAR-DEC	--	JAN-MAR
1976	--	--	--	JAN-MAY	--	--
Yarding Season:						
1973	SEP-NOV	--	AUG-NOV	--	--	--
1974	JUN-NOV	OCT-NOV	APR-AUG	SEP-DEC	JUL-NOV	{JAN-JUN NOV-DEC
1975	AUG-SEP	JUN-OCT	--	APR-DEC	JUN-AUG	JAN-APR
1976	--	MAY-NOV	--	MAY-SEP	--	--

LITERATURE REVIEW

Most previous logging production studies have used detailed time study analysis. The following variables have typically been determined to be important factors influencing yarding productivity: number of logs per turn, yarding distance, chordslope, groundslope, lateral yarding distance, percent of trees cut per acre, number of chokersetters, and type of cut (Aulerich, et al., 1974; Cottell, et al., 1976; Dykstra, 1975, 1976b; Sinner, 1973).

In the analysis of detailed time study data, Dykstra (1974, 1975, 1976a, 1976b, 1976c) has addressed yarding system efficiency and the effect of landscape design on production rates. He did not find that cutting unit design had a significant effect on production rates for those particular studies, but concluded that cutting units could be designed which would impair yarding efficiency. His results also suggested that cutting intensity does influence yarding rates for cable systems because of increased road change times in partial cuts.

Brandstrom (1933) pointed out, while detailed time studies are mainly designed for evaluation of operating system efficiency, they also provide information that is useful for cost appraisal of logging systems. However, these studies tend to miss seasonal influences and lengthy downtimes because data are collected over a short time period. It has been suggested that the gross time study method may be more appropriate for making an appraisal of long-run production rates and costs, since it more accurately reflects total downtime (Dykstra, 1976).

In recent years, the gross time study method has gained wider acceptance for logging research (Cottell and Winer, 1969; Cottell, et al., 1971; Bradley and Biltonen, 1972; Dykstra and Froehlich, 1976; Cottell, et al., 1976; Schnare, 1978; and Scherer, 1978). The only published cable yarding study using gross data combined shift-level data with turn-level data taken on a sampling basis to determine the production rates of various systems studied (Cottell, et al., 1976). While only a few formal reports of gross time studies done by companies have been published (Donnelly, 1962; Pearce and Stenzel, 1972), Conway (1976) reported that this method is probably the one most commonly used in the forest industry.

YARDING SYSTEMS AND EQUIPMENT

Short-span Skyline

North Bend

An Interstate West Coast Tower operating in the North Bend configuration yarded to uphill landings (Figure 7). It was only used during the fall of 1973.

The yarder characteristics were as follows:

Engine	Detroit Diesel 6-71
Rated engine power	239 bhp at 2,100 rpm
Undercarriage	Terex C-6 crawler tractor
Tower type	Square, steel box section
Tower height	49 feet (fully extended)
Weight	72,780 pounds without line
Drum capacities:	
Skyline	2,000 feet of 1-inch diameter
Mainline	1,200 feet of 3/4-inch diameter
Haulback	2,700 feet of 1/2-inch diameter
Strawline	2,500 feet of 3/8-inch diameter
Guylines	Three (3/4-inch diameter)
Line speed	2,120 feet per minute (main drum, full, third gear)
Line pull	67,000 pounds (main drum, bare, third gear)
Interlock	None

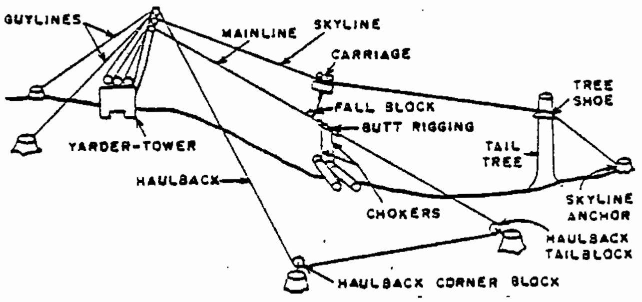


Figure 7. North Bend skyline yarding system

(Source: Dykstra, 1975)

Running Skyline

The Skagit GT-3 was used in a running skyline configuration with a slackpulling carriage and chokers (Figure 8). This machine worked the short-span sale from 1974 until completion in 1975.

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

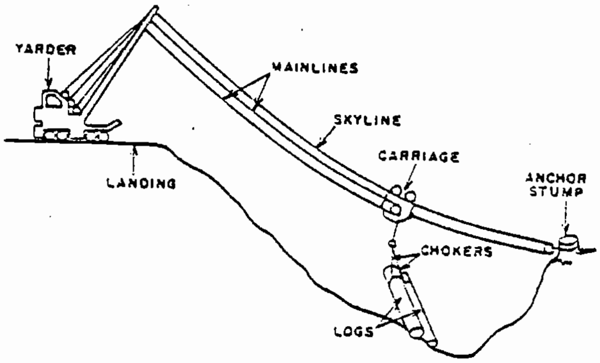


Figure 8. Running skyline system in slackpulling configuration with a three-drum carriage
(Source: Dykstra, 1976b)

Long-span Skyline

A long-span standing skyline was rigged with a 115 foot spar tree. (Figure 9). The yarder was a three-drum, trailer-mounted, logger-fabricated unit which operated with a Skagit RCC-15 carriage. The RCC-15 is a radio-controlled, diesel-powered, clamping carriage. The diesel engine in the carriage provides power to the skidding drum (Figure 10). This skidding drum is used for lateral yarding. The carriage is sent out until the rigging slinger signals a stop. He then clamps the carriage by using a radio signal and signals the skidding drum to lower the skidding line and chokers to the chokersetting crew. After they hook the turn, it is skidded to the carriage and held there. The skyline clamp is then released (via radio) and the yarder operator brings the carriage and turn to the landing by reeling in the mainline. The logs are unhooked at the landing and the cycle is repeated.

The long-span yarder had the following characteristics (Anderson, 1978):

Engines	
Skyline drum	275 Cummins, 275 hp
Other drums	12V71 GMC, 359 hp
Undercarriage	55-foot homebuilt trailer
Weight with lines	200,000 pounds
Drum Capacities	
Skyline	4,500 feet of 1 3/4-inch diameter
Mainline	4,000 feet of 1-inch diameter
Haulback	7,000 feet of 3/4-inch diameter
Strawline	4,500 feet of 7/16-inch diameter
Guylines	8 top and 4 buckle guys
Line speeds	
Mainline	1,200 feet per minute, average maximum
Haulback	1,500-1,800 feet per minute, average maximum

Line pulls	
Mainline	90,000 pounds, maximum
Haulback	45,000 pounds, maximum
Interlock	none
Drum set	Unknown, believed to be a Washington 303 highlead drumset, built about 1940

The Skagit RCC-15 specifications are:

Control	radio
Skyline	1 3/8 to 2-inch diameter
Sheaves	24-inch pitch diameter
Engine	Detroit Diesel 4-53, 95 hp
Dropline drum	reversible-load-line drum
Capacity	440 feet of 7/8 inch diameter
Speed	315 feet per minute, no load
Skyline clamp	hydraulic
Load capacity	44,000 pounds
Weight	6,900 pounds

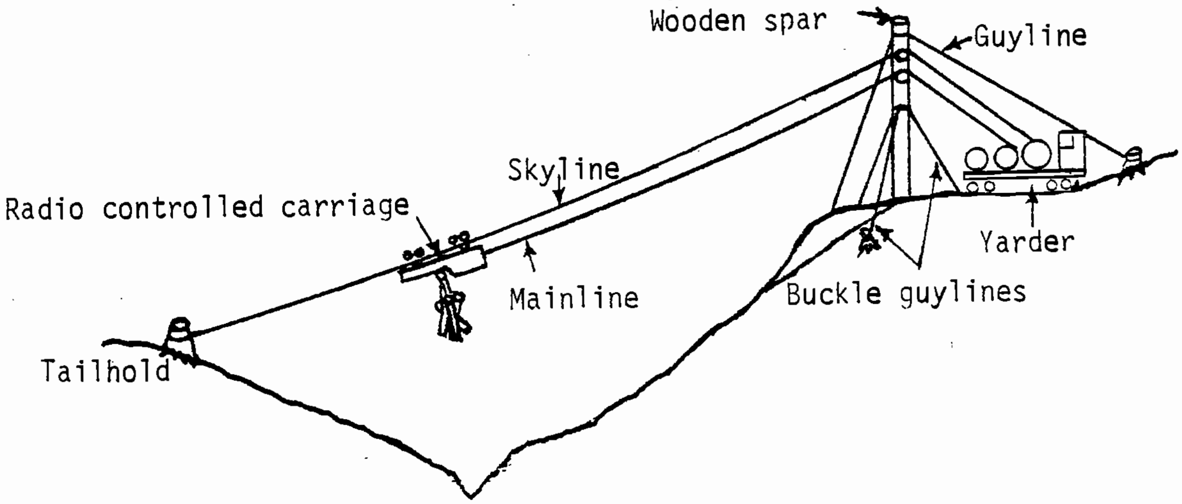
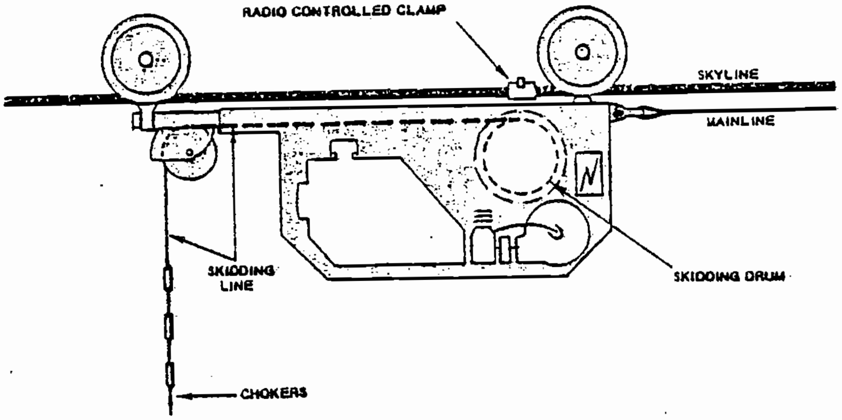


Figure 9. Long-span standing skyline



FOR SELECTIVE OR CLEARCUT LOGGING—
UPHILL OR DOWNHILL.

Figure 10. Skagit RCC-15 carriage
(Source: Studier and Binkley, 1975)

Single-yarder Balloon

Inverted Skyline

The inverted skyline balloon system (Figure 11) was employed with a Washington Iron works prototype yarder designed for a 250,000 cubic-foot capacity balloon which is no longer in production. This yarder was only used in 1973 because it was underdesigned for the 530,000 cubic-foot capacity balloon which was used to log the sale.

Yarder and balloon specifications were as follows:

Balloon volume	530,000 cubic feet
Lifting gas	Commercial helium
Net design lift	25,000 pounds (sea level, 90 percent inflation)
Envelope diameter	105 feet
Balloon height	113 feet
Yarder engine	Cummins VT 12700C diesel
Rated engine power	725 bhp
Undercarriage	Military tank
Drum capacities:	
Skyline	5,500 feet of 1-inch diameter
Mainline	7,000 feet of 1-inch diameter
Strawline	7,500 feet of 7/16-inch diameter
Tieback lines	2 (1 1/8-inch diameter)
Line speeds:	
Skyline	1,750 feet per minute (maximum)
Mainline	2,000 feet per minute (maximum)
Line pull:	
Skyline	67,000 pounds (maximum)
Mainline	34,000 pounds (maximum)
Interlock	Hydraulic (not used in this configuration)

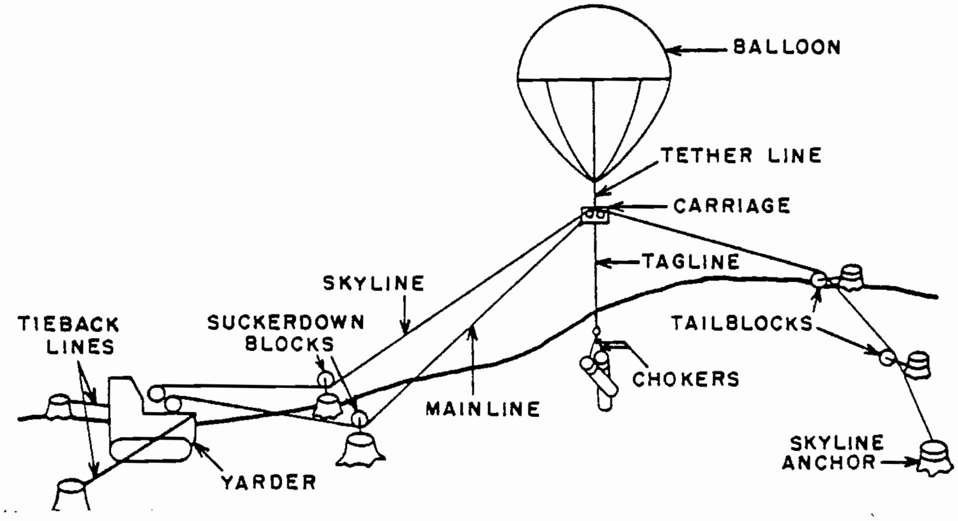


Figure 11. Inverted skyline balloon yarding system (limited to downhill yarding) (Source: Dykstra, 1975)

Highlead

The highlead balloon system (Figure 12) was used in 1974 with a Washington Iron Works Aero Yarder, Model 608A, designed for the 530,000 cubic-foot capacity balloon.

Yarder characteristics were as follows:

Yarder engine	Detroit Diesel 12V-71N65
Rated engine power	700 bhp
Undercarriage	Caterpillar 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

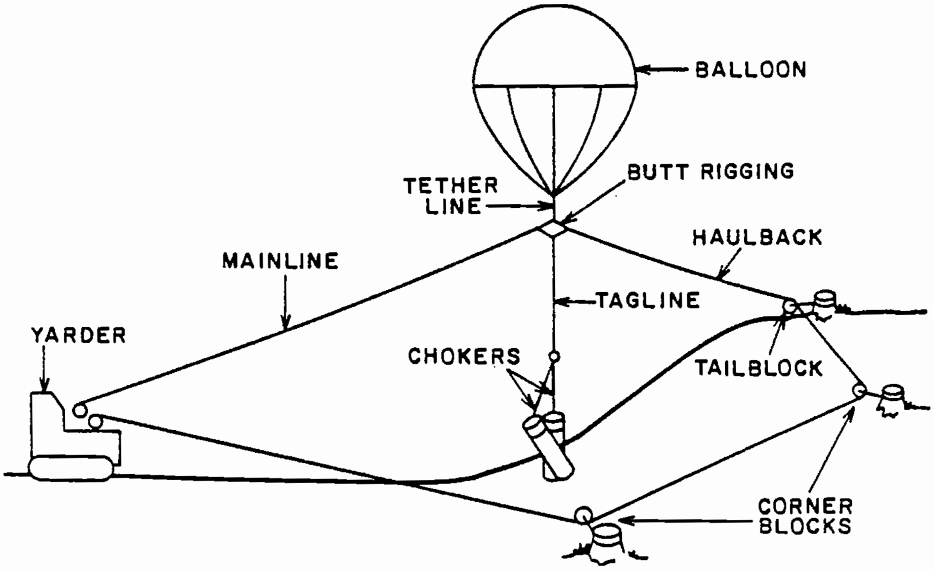


Figure 12. Balloon yarding system in highlead configuration (Source: Dykstra, 1976b)

Yo-Yo Balloon

The yo-yo balloon systems incorporate two yarders which work in tandem via a radio link between the yarder operators. This eliminates the costly (and mechanically troublesome) interlocks required with the single-yarder balloon systems. The yo-yo yarders can operate either on parallel roads or side by side. Yo-yo balloon systems were used in two configurations: "highlead" yarding to downhill or uphill landings (Figure 13), and "inverted skyline" yarding to a downhill landing (Figure 14).

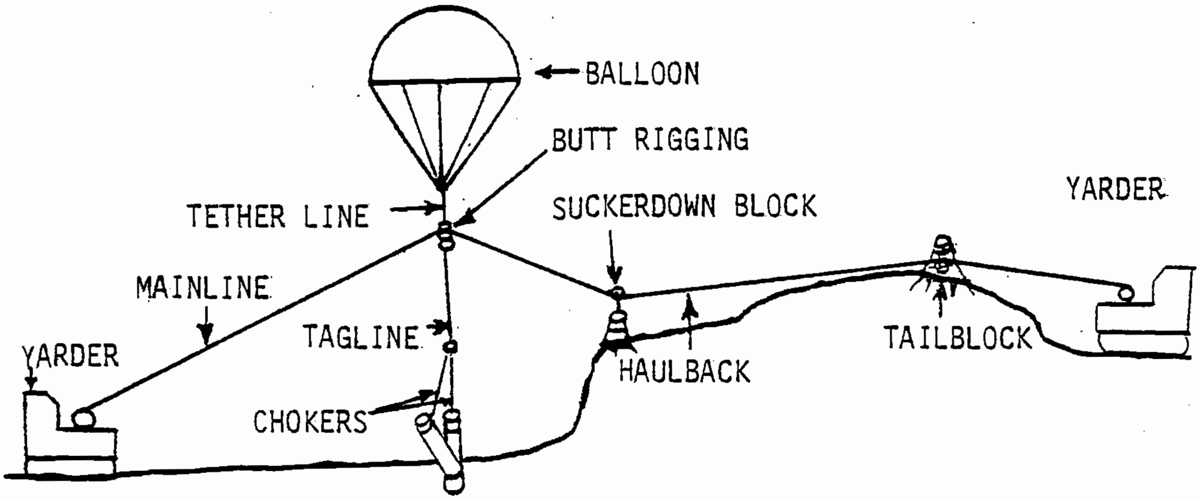


Figure 13. Yo-Yo highlead yarding system

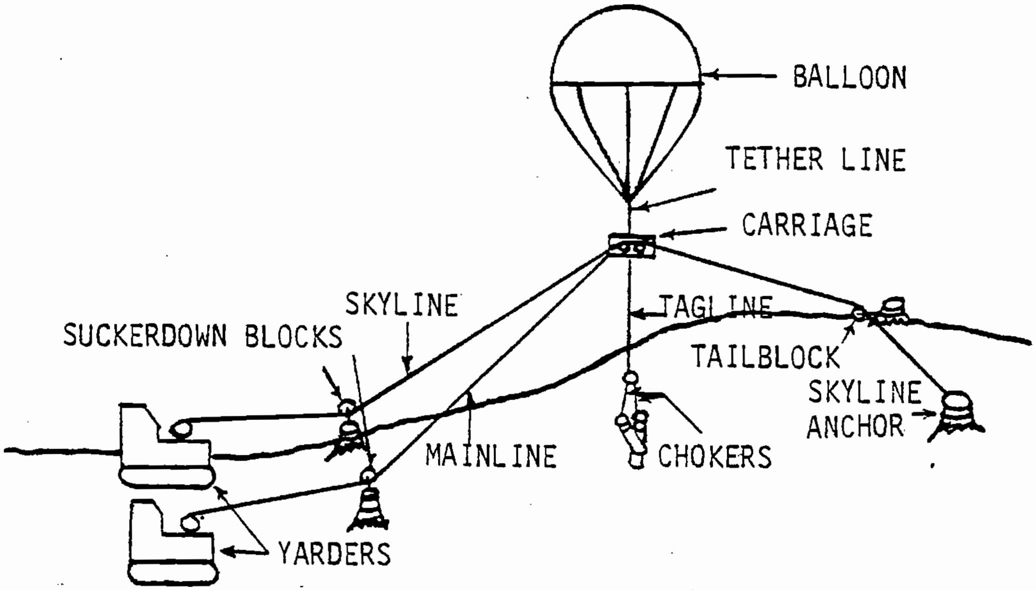


Figure 14. Yo-Yo inverted skyline balloon yarding system

The yarders were Smith-Berger single-drum hoists mounted on a TD-24 undercarriage. The same type of balloon was used as with the single-yarder systems. The individual yarder specifications are as follows:

Yarder engine	Cummins V12 Diesel
Rated engine power	1000 bhp
Undercarriage	TD-24
Weight with lines	100,000 pounds
Drum capacities:	
Mainline	5,000 feet of 1-inch diameter
Strawline	7,000 feet of 7/16-inch diameter
Tether line	250 feet of 7/8-or 1-inch diameter
Tieback line	None
Mainline line speed	1,800 feet per minute (maximum)
Mainline line pull	100,000 pounds (maximum)
Interlock	Radio communications between operators

Helicopters

Helicopter logging has the greatest mobility of any logging system because it is not limited to cableways and is virtually unhampered by terrain. The helicopter flies from the landing to the pickup area. It hovers over the hooker while he attaches the preset chokers by inserting the choker sliprings into the hook (Figure 15) and retreats a safe distance from the turn. The aircraft climbs vertically until the load is airborne, and then flies to the landing. The turn is set down and released electronically by the pilot, and immediately the helicopter returns for the next turn. At the landing, the chasers remove the chokers from the logs and bundle them for eventual return to chokersetting crew.

Medium and heavy helicopters were studied, both using preset chokers. On the heavy helicopter operation, a small utility helicopter was used to deliver the bundles of chokers to the chokersetting crew. In the medium helicopter operation , the same helicopter both yarded the logs and delivered the bundles of chokers.

Heavy Helicopter

The heavy helicopter was a Sikorsky S64E Skycrane (Figure 15) 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 (Jet A aircraft turbine fuel)
Vertical rate of climb at MCP	1,330 feet per minute at sea level
Net external load, hover out of ground effect at 4,000 feet and 60°F (McGonagill, 1977)	17,180 pounds

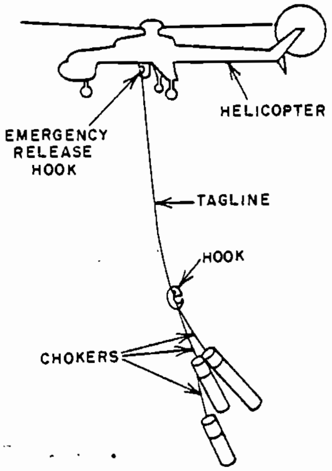


Figure 15. Heavy helicopter in logging configuration (Source: Dykstra, 1976b)

Medium Helicopter

The medium helicopter was a Boeing-Vertol 107 Model II (Figure 16) with the following specifications:

Engines	Two General Electric CT58-110-2 gas turbine
Takeoff power (TOP)	1,250 shaft hp (each engine)
Maximum continuous power (MCP)	1,050 shaft hp (each engine)
Rated rotorspeed	264 rpm
Maximum forward airspeed at MCP	148 knots (170 mph) at sea level
Average cruise speed	134 knots (154 mph) at sea level
Fuel consumption	180 gal per hour (Jet A aircraft turbine fuel)
Forward rate of climb at MCP	1,700 feet per minute at sea level
Vertical rate of climb at TOP	1,240 feet per minute at sea level
Fuselage length	44 feet, seven inches
Fuselage width	7 feet, 3 inches

Length overall (including rotors)	83 feet, 4 inches
Height	16 feet, 10 inches
Rotor sweep diameter	50 feet
Wheel base	24 feet, 11 inches
Net external load, hover out of ground effect at 1950 foot elevation and 60°F (McGonagill, 1977)	10,250 pounds

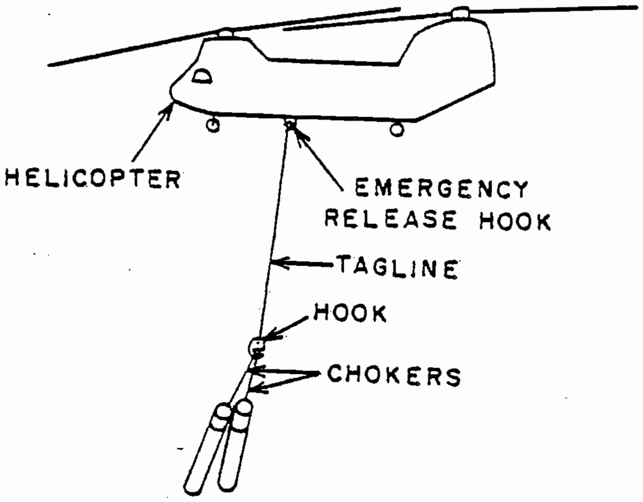


Figure 16. Medium helicopter in yarding configuration
(Source: Dykstra, 1975)

MEASUREMENTS

The data analyzed in this paper were collected by two sources: Forest Service and loggers. The loggers recorded daily logging production data, and the Forest Service collected pre-sale and post-sale data for each cutting unit. These data were compiled and organized for the analysis, and in some cases new variables were developed by combining data from the two sources. The variables used and their sources are identified in Table 5.

Logger-measured Variables

The Forest Service contracts for these administrative study sales specified that the purchaser would maintain certain daily records on forms supplied to them (Clarke, 1973). Data collected on these forms included a timber sale code, date, cutting unit number, yarding system code, landing number, yarding road number, crew size, gross work time, groundslope code, average yarding distance, number of turns, number of merchantable logs yarded, number of unmerchantable logs yarded, duration of delays (by type of delay), number of aborted turns for the helicopters (by type of abort), tagline length, and hook point elevation. The loggers were also required to record their daily work location on a topographic map. The variables listed below were obtained from these data, which were keypunched by the Forest Service. Each variable is identified by a mnemonic (abbreviation) which will be used in the remainder of this report.

TABLE 5. SOURCES OF VARIABLES USED IN THIS STUDY

Variable	Skyline	Single Balloon	Large Helicopter	Yo-Yo Balloon	Medium Helicopter
LOGS/HR	L	L	L	L	L
PCS/TURN	L	L	L	L	L
RATIO	L	L	L	--	L
SLOPE	L	L	L	L	L
AYD	L	L	L	F	F
LNDSIZE	F	F	F	F	F
TOC	F	F	F	F	F
ITPA	F	F	F	F	F
TCPA	R	R	R	R	R
CREW	L	--	L	L	L
SLASH	F	F	F	F	F
LDSCAPE	F	F	F	F	F
ASPECT	F	F	F	F	F
ASPMO	R	R	R	R	R
CHDSLP	R	R	--	--	--
RDS/LNDG	R	R	na	--	na
PROFILE	R	R	--	--	--
ABORTS	na	na	L	na	L
ELEV	na	--	--	F	F
TAGLINE	--	--	--	L	L
HTRESID	--	--	--	F	--
NRDCHGS	R	R	na	R	na

"L" indicates that the variable was recorded by the logger.

"F" indicates that the variable was recorded by the forester.

"R" indicates that the variable was developed by the researcher.

Dashed lines indicate that the data were not recorded

na = not applicable

LOGS/HR (logs per hour): the total number of logs yarded during the day divided by the number of productive hours (gross work hours minus delay hours) worked during the day.

PCS/TURN (pieces per turn): the total number of logs yarded during the day divided by the total number of turns yarded for the day.

NRDCHGS is the number of cable road changes for the day.

RATIO is the total number of merchantable logs yarded for the day divided by the total number of logs yarded for the day. The segregation of logs yarded into merchantable and unmerchantable classes was made by the logging crew.

SLOPE is an estimate of the average ground slope for the area yarded each day, measured perpendicular to the contours and recorded in the following classes: 1 = 0 to 30 percent; 2 = 30 to 60 percent; 3 = more than 60 percent.

AYD is the average yarding distance for the day, recorded in hundreds of feet. AYD was estimated by the logging crew for the Pansy Basin Sales, but was estimated by the Forest Service for the Dinner Creek Sales. The latter estimates were made from the loggers' daily work maps.

CREW is the total number of men working on the yarding operation during the day.

ABORTS is the number of aborted helicopter loads per day.

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

Forester-measured variables

The variables listed below were developed from records maintained by the Forest Service for each cutting unit or timber sale.

LNDSIZE (landing size): the area occupied by each landing, in acres.

TOC (type of cut): the cutting prescription for the unit: 0 = partial cut; 1 = clearcut.

ITPA is the initial number of trees per acre for each cutting unit (obtained from timber cruise data).

SLASH is a dummy variable relating requirements for the yarding of unmerchantable material (YUM) that has a gross volume of 50 board feet or greater: 0 = YUM not required; 1 = YUM required.

ASPECT is the average aspect of the cutting unit: 0 = northeast to northwest; 1 = east or west; 2 = southeast to southwest.

ELEV is average hook point elevation for the day, estimated from the loggers' daily work maps.

HTRESID is the average height of residual timber in the cutting unit, in feet.

LDSCAPE corresponds to the Forest Service landscape management classification (Forest Service, 1974) for the cutting units: 0 = preservation (management activities allow only ecological changes); 1 = retention (management activities are not visually evident); 2 = partial retention (management activities remain visually subordinate to the characteristic landscape); 3 = modification (management activities visually dominate the original characteristic landscape); 4 = maximum modification (management activities of vegetative and landform alternations dominate the characteristic landscape).

Researcher-developed Variables

The following variables were developed from both sources' data.

TCPA is the number of trees cut per acre (obtained from timber fellers' records).

CHDSLP is the slope of a chord running from the landing to the base of the tailhold as shown on the loggers' daily work maps, measured in percent (negative for uphill yarding).

RDS/LNDG is the number of cable roads used at a landing (obtained from the loggers' maps).

PROFILE is an index describing the shape of the ground profile along the cable road (Figure 17), based on the loggers' maps: 0 = concave; 1 = constant; 2 = convex.

ASPMO is an index derived in an effort to measure environmental working conditions. The index combines the aspect of the work site with the season of work. Its derivation (Figure 18) is an attempt to estimate the interaction between aspect and the time of year. As an example, ASPMO explicitly recognizes the fact that working conditions should be easier on a north-facing slope in the summertime (ASPMO = 0) than on the same slope in the wintertime (ASPMO = 4). The actual values used in this index would vary with local climatic conditions.

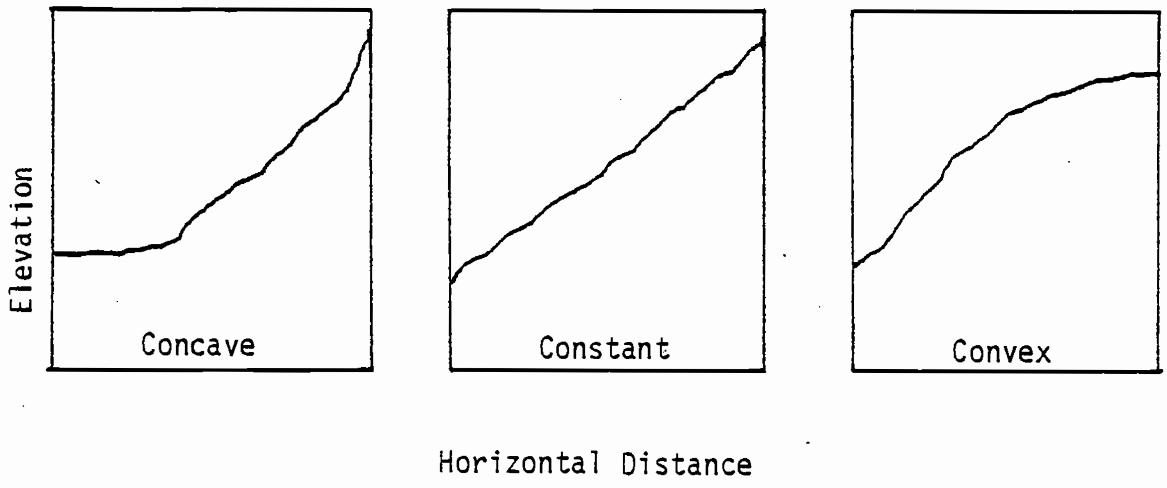
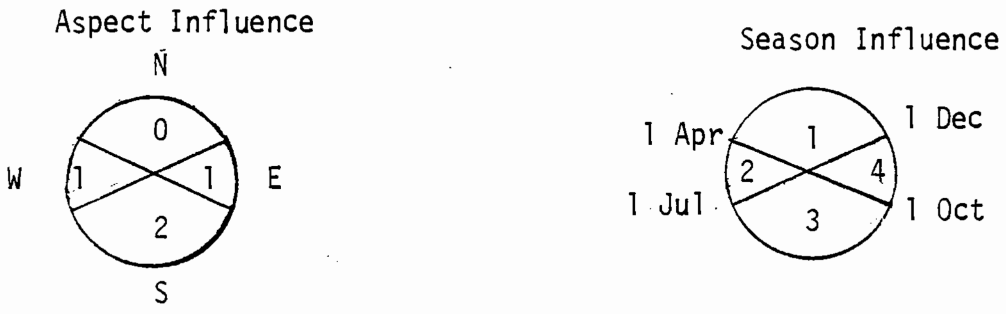


Figure 17. Derivation of PROFILE Index



Aspect-Month Index
(Working Conditions)

		Good → Poor				
Aspect	Season	0	1	2	3	4
0	1					x
1	1				x	
2	1			x		
0	2				x	
1	2			x		
2	2		x			
0	3	x				
1	3		x			
2	3				x	
0	4				x	
1	4			x		
2	4		x			

Example: North aspect, month of May.
Aspect=0, Season=2
Aspect-Month Index = 3

Figure 18. Derivation of the Aspect-Month Index.

YARDING DATA SUMMARY

The yarding data for the 11 operations have been summarized in Tables 6, 7, and 8. These tables were compiled from data summaries for each of the cutting units. These data were then allocated to individual yarding systems depending upon the number of acres each system was used in each cutting unit.

These tables are useful only as a general summarization of the study data. They cannot be used to compare yarding productivity because of differences in yarding conditions, timber stand characteristics, crew experience, and operating season.

Delay time has been segregated into delays, road change time, and landing change time (Table 7). Delays have been further categorized into operational and non-operational delays on a percentage basis of gross work time (Table 8).

The summary in Table 8 indicates the importances of delays in a comparison of yarding systems. The helicopter systems are a good example of this fact. If helicopters were compared on "delays", the medium helicopter would appear less efficient because it operated more in the winter season (Table 3). When the helicopters' operational delays were compared, they had about the same efficiency.

The running skyline system, with an inexperienced crew (Schnare, 1978) and a new machine, experienced about the same percentage of operational delays as the North Bend system with an experienced crew but an older machine. The relative inefficiency of the running skyline crew was compensated by the limited number of equipment delays due to the newer machine.

Table 6. Summary of Yarding Data

Item	Pansy Basin Skyline				Pansy Basin Balloon		Dinner Balloon (Yo-Yo)			Pansy Basin Heavy Helicopter	Dinner Medium Helicopter
	Short-span		Long-span								
	Running Skyline	North Bend	Uphill	Downhill	Inverted Skyline	Haulback	Highlead Downhill	Highlead Uphill	Inverted Skyline Downhill		
Silvicultural prescription:											
Partial cut area, ac.	46	0	144	30	0	0	68	21	8	118	400
Clearcut area, ac.	18	22	67	0	37	68	75	67	6	93	74
Total	64	22	211	30	37	68	143	88	14	211	474
Yarding crew-days	108	36	204	54	63	95	199	174	24	107	244
Gross yarding crew-hours	901.7	296.2	2,165.0	297.2	543.5	757.0	1,391.8	1,168.6	178.4	793.4	2,317.3
Nonproductive crew-hours	285.7	165.8	372.7	53.0	168.4	223.3	374.0	321.4	46.7	196.9	874.0
Net productive crew-hours	616.0	130.4	1,792.3	244.2	375.1	533.7	1,017.8	847.2	131.7	596.5	1,443.3
Average gross crew-hours per day	8.4	8.2	10.6	5.5	8.6	8.0	7.0	6.7	7.4	7.4	9.5
Average nonproductive crew-hrs per day	2.7	4.6	1.8	1.0	2.7	2.4	1.9	1.8	1.9	1.8	3.6
Average productive crew-hours per day	5.7	3.6	8.8	4.5	5.9	5.6	5.1	4.9	5.5	5.6	5.9
Number turns yarded	6,922	1,708	12,245	1,906	2,311	3,793	7,122	6,546	930	12,076	25,532
Number pieces yarded -- cull	3,354	826	12,376	2,541	0	0	0	0	0	3,750	1,757
--merchantable	10,853	2,714	37,051	5,032	6,158	9,959	17,328	13,201	2,185	40,148	30,765
--total	14,207	3,540	49,427	7,573	6,158	9,959	17,328	13,201	2,185	43,898	32,522
Estimated gross vol. yarded, Mfbm	2,919	732	9,970	1,354	2,108	3,409	--	--	--	14,520	13,269
Estimated net vol. yarded, Mfbm	2,487	622	8,491	1,153	1,799	2,910	5,234	5,369	687	11,042	10,565
Average production per prod. crew-hr:											
No. turns yarded per hour	11.2	13.1	6.8	7.8	6.2	7.1	7.0	7.7	7.1	20.2	17.6
No. pieces yarded per hour	23.1	27.2	27.6	31.0	16.4	18.7	17.0	15.6	16.6	73.6	22.4
Gross vol. yarded, Mfbm per hour	4.7	5.6	5.6	5.5	5.6	6.4	--	--	--	24.3	9.1
Net vol. yarded, Mfbm per hour	4.0	4.8	4.7	4.7	4.8	5.5	5.1	6.3	5.2	18.5	7.3

Dashed lines indicate that the data were not recorded.

Table 7. Summary of landing change times and road change times

System	Landing Average Time (Crew-hours)	Landing Number of Changes	Road Average Time (Crew-hours)	Road Number of Changes
Short-span Skyline				
North Bend	13.8	6	0.8	34
Running Skyline	3.4	29	1.0	61
Long-span Skyline				
Uphill	16.4	2	2.3	49
Downhill	0.0	0	2.8	12
Single-yarder Balloon				
Inverted skyline	--	--	1.4	22
Highlead	--	--	0.4	32
Yo-Yo Balloon				
Highlead Downhill	--	--	0.9	130
Highlead Uphill	--	--	1.0	76
Inverted Skyline	--	--	1.4	8
Helicopter				
Heavy	--	--	na	na
Medium	--	--	na	na

Dashed lines indicate that data not recorded.

na = not applicable.

TABLE 8. YARDING DELAYS AS PERCENT OF GROSS TIME[a]

	Skyline				Single-yarder Balloon		Yo-Yo Balloon			Heavy Helicopter	Medium Helicopter
	Short-span		Long-span								
	Running Skyline	North Bend	Uphill	Downhill	Inverted Skyline	Highlead	Highlead Downhill	Highlead Uphill	Inverted Skyline		
Operational											
Equipment	4.2	12.8	3.6	2.5	22.9	4.3	11.2	13.5	9.3	21.0	15.8
Planning	--	--	--	--	3.2	12.9	4.2[b]	5.1[b]	4.7[b]	0.0	1.7
Crew	2.3	1.8	1.8	1.5	0	0	0.2	0	0.4	0.1	1.0
Operator	14.5	3.5	6.8	6.3	--	--	--	--	--	--	--
Landing	6.0	8.3	0.7	0.8	--	--	--	--	--	--	--
Refuel	--	--	--	--	--	--	0.0	0.0	0.0	--	3.3
Misc.	1.1	2.6	1.1	0.9	0.9	10.1	1.1	0.5	2.9	0.6	2.1
Total Operational Delays	28.1	29.0	14.0	12.0	27.0	27.3	16.6	19.1	17.3	22.7	23.9
Non-operational											
Weather	--	--	--	--	0	0.7	3.2	2.8	2.7	1.5	14.1
Fire call	--	--	--	--	0	0	0.0	0	0	0	0.0
Total 'delay' time	28	29	14	12	27	28	20	22	20	24	38

[a] Delays were recorded to nearest 0.1 hour

[b] includes moving balloon.

Dashed lines indicate that such delays were recorded in other categories.

A comparison between short-span and long-span landing delays shows that the short-span experienced about 7 percent more delay time per hour in this category. Most of the short-span landings were on the haul road itself, whereas the long-span system operated from large, fixed landings. This suggests that a larger number of landing-related delays should be expected with mobile yarders operating from roadtop landings.

The inverted skyline yarder had problems holding the balloon at times because of the undersized yarder. This is clear from an inspection of Table 8, which shows that it experienced five times as much equipment delay time as the highlead balloon yarder, which was correctly sized for the type of balloon being used.

METHOD OF MULTIPLE REGRESSION ANALYSIS

The Statistical Interactive Programming System (SIPS) on the Oregon State University CDC 3300 computer was used to analyze the data via stepwise regression.

Multiple regression equations were developed by examining the output from the SIPS stepwise regression program and selecting the equation for which the last variable entered added at least .01 to R^2 and was significantly different from zero at the 0.20 probability level. The mean square error (MSE) for this equation also had to be no greater than the minimum MSE of the preceding equations. Significant variables were subsequently dropped from the equation if it appeared they would not be useful for cost appraisal purposes or if their associated regression coefficients carried the wrong sign.

MULTIPLE REGRESSION ANALYSIS

The purpose of this portion of the analysis was to develop a method of predicting yarding production rates and to determine the factors (variables) which influence them. These factors should be easily estimated from available information prior to logging. Factors which may influence yarding production but were not measured in this study were excluded from the analysis, such as average lateral yarding distance. Table 9 summarizes the variables used in the regression analysis.

The data were first analyzed for each individual yarding system, and then the data for similar systems were combined and analyzed collectively. These "individual" and "combined" equations are presented according to the general categories of skyline, balloon, and helicopter logging systems. When ASPMO was statistically significant for a system, it was reported in the system's equation. (In addition, the system equation was reported without ASPMO for those who might prefer not to use this variable.)

In the regression summaries which follow,

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

*** indicates that the regression coefficient was significantly different from zero at the 0.05 probability level but not at the 0.01 level;

** indicates that the regression coefficient was significantly different from zero at the 0.10 probability level but not at the

Table 9. Summary of independent variables used in the yarding regression analysis.

Variable (min max mean)	Pansy Basin Skyline				Pansy Basin Balloon		Dinner Balloon (Yo-Yo)			Pansy Basin--Heavy Helicopter	Dinner--Medium Helicopter
	Short-span		Long-span								
	Running Skyline	North Bend	Uphill	Downhill	Inverted Skyline	Haulback	Highlead Downhill	Highlead Uphill	Inverted Skyline Downhill		
Logs yarded per productive hour	9.0 50.8 23.9	18.9 41.0 26.2	8.8 108.0 26.9	9.1 53.1 33.7	2.0 32.5 17.3	3.0 37.2 17.8	3.7 38.0 17.6	2.0 34.6 15.0	4.4 13.0 9.6	23.6 186.7 76.1	1.5 73.3 24.5
Pieces yarded per turn	1.3 3.1 2.0	1.5 2.7 1.9	1.7 6.1 4.1	2.1 5.2 3.8	1.0 4.1 2.8	1.5 4.5 2.5	0.6 4.6 2.6	0.4 3.1 2.0	1.3 1.9 1.6	1.1 7.2 3.7	0.9 2.9 1.3
Number road changes per day	0 5 0.9	0 6 2.1	0 2 0.3	0 2 0.3	0 2 0.3	0 2 0.2	0 1 0.9	0 3 1.7	-- -- --	-- -- --	-- -- --
Ratio, merch. logs to total logs yarded	0.3 1.0 0.7	0.5 1.0 0.8	0.4 1.0 0.8	0.3 1.0 0.6	1.0 1.0 1.0	1.0 1.0 1.0	1.0 1.0 1.0	1.0 1.0 1.0	1.0 1.0 1.0	0.2 1.0 0.9	0.3 1.0 1.0
Slope class	1 2 1.2	1 2 1.4	1 2 1.8	1 2 2.0	1 2 1.2	1 2 1.9	1 3 2.0	2 3 2.6	2 3 2.1	1 3 1.6	1 3 2.1
Average yarding distance, ft*100	2 9 5.0	2 7 3.2	6 20 12.7	5 14 8.4	0 12 4.0	9 17 3.6	2 22 11.6	1 19 9.4	10 17 14.0	8 76 26.7	5 54 24.6
Landing size, acres	0.0 0.1 0.0	0.0 0.1 0.0	0.9 0.9 0.9	0.9 0.9 0.9	0.9 2.3 1.0	0.9 1.6 0.9	0.1 0.7 0.3	0.1 0.7 0.3	0.6 0.6 0.6	0.1 2.0 0.7	0.2 1.4 0.4
Initial no. of trees per acre (cruise data)	60 88 82.0	75 85 77.8	85 85 85.0	85 85 85.0	76 76 76.0	76 76 76.0	6 102 59.3	9 52 43.0	11 38 34.6	58 88 75.7	4 48 15.5
Trees removed per acre (actual)	51 252 110.6	102 182 115.3	92 117 104.7	101 101 101.0	105 110 109.1	89 105 102.5	21 145 97.5	35 145 79.4	46 145 132.6	21 219 102.5	14 120 38.3
Slash code: 0 = no YUM 1 = YUM	1 1 1.0	1 1 1.0	0 1 1.0	1 1 1.0	0 0 0.0	0 0 0.0	0 1 0.4	0 1 0.1	0 0 0.0	0 1 0.7	0 0 0.0
Landscape management class	2 4 2.7	3 4 3.6	2 3 2.4	2 2 2.0	3 5 3.4	4 5 4.8	1 5 4.1	5 5 5.0	5 5 5.0	1 4 2.8	2 5 3.4

(continued)

Table 9 continued

	Pansy Basin Skyline				Pansy Basin Balloon		Dinner Balloon (Yo-Yo)			Pansy Basin--Heavy Helicopter	Dinner--Medium Helicopter
	Short-span		Long-span								
Variables min max mean	Running Skyline	North Bend	Uphill	Downhill	Inverted Skyline	Haulback	Highlead Downhill	Highlead Uphill	Inverted Skyline Downhill		
Aspect: 0=north; 1=east 1=west; 2=south	0 2 0.5	0 1 0.6	0 2 0.9	0 0 0.0	0 0 0.0	0 0 0.0	0 2 0.1	0 2 0.3	0 0 0.0	0 2 0.6	0 2 0.6
Aspect-month Index	0 3 0.9	1 3 2.2	0 3 1.4	3 3 3.0	0 3 1.2	0 3 1.7	0 3 1.2	0 3 2.0	0 0 0.0	0 3 1.6	1 4 3.0
Chordslope, % (negative=uphill yarding	-50 -14 -26.7	-47 -10 -26.9	-36 -1 -14.4	3 16 10.9	0 38 24.3	0 52 33.9	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --
Number yarding roads per landing	1 13 6.6	0 11 4.9	9 32 19.2	32 32 32.0	14 18 15.7	4 18 11.8	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --
Profile shape: 0=concave; 1=constant; 2=convex	0 2 0.9	0 2 0.8	0 2 0.4	0 2 1.1	0 2 1.1	0 2 1.1	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --
Number in the yarding crew	4 8 5.7	5 6 6.0	7 12 9.9	7 11 8.8	-- -- --	-- -- --	4 12 9.6	3 12 9.5	10 11 10.6	-- -- --	12 27 20.4
Number aborted loads per day	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	0 24 4.9	* * *
Height of residual trees, feet	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	18 175 140.7	75 125 120.0	75 75 75.0	-- -- --	-- -- --
Tagline length, feet	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	200 275 200.5	200 400 201.6	200 200 200.0	-- -- --	100 250 172.5
Hook point Elevation, feet	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	1190 2900 2403	1800 2900 2439	2100 2400 2225	-- -- --	1424 2442 1950
Number of observations recorded	107	27	204	54	67	76	141	136	8	107	201

Dashed lines indicate that the data were not recorded.

*Only recorded on four days; sample too small for statistical analysis.

	0.05 level;
*	indicates that the regression coefficient was significantly different from zero at the 0.20 probability level but not at the 0.10 level;
n.s.	indicates that the regression coefficient was not found to be significantly different from zero at the 0.20 probability level, but its sign was correct and a strong theoretical reason exists for believing the variable is functionally related to the dependent process;
R^2	is the coefficient of determination, a measure of the fraction of the variation in the data which is explained by the regression equation;
n	is the number of observations in the sample.

Skyline

The skyline regression hypothesis was as follows:

LOGS/HR = f(PCS/TURN, NRDCHGS, SLOPE, AYD, LNDSIZE, RDS/LNDG, PROFILE,
CREW, TOC, ASPMO, ITPA, TCPA, CHDSLP, SLASH, LDSCAPE, RATIO)

North Bend--short-span

LOGS/HR = -5.5364 + 17.981 (PCS/TURN) **** $R^2 = .43$
- 0.77521 (AYD) n.s. n = 26

Running Skyline--short-span

LOGS/HR = 10.283 + 15.157 (PCS/TURN) **** $R^2 = .67$
- 2.5147 (AYD) **** n = 91
+ 0.18561 (CHDSLP) ****

or with ASPMO

LOGS/HR = 9.8623 + 14.863 (PCS/TURN) **** R^2 = .68
- 2.3679 (AYD) **** n = 91
- 0.74545 (ASPMO) *
+ 0.14766 (CHDSLP) ***

Short-span Combined

LOGS/HR = 5.4818 + 16.328 (PCS/TURN) **** R^2 = .64
- 2.2472 (AYD) **** n = 117
+ 0.13699 (CHDSLP) ****

Downhill Long-span

LOGS/HR = 11.138 + 7.1774 (PCS/TURN) **** R^2 = .29
- 0.59976 (AYD) n.s. n = 54

Uphill Long-span

LOGS/HR = 23.755 + 2.7776 (PCS/TURN) **** R^2 = .13
- 0.63694 (AYD) **** n = 201

Long-span Combined

LOGS/HR = 26.741 + 3.0159 (PCS/TURN) **** R^2 = .18
- 0.89579 (AYD) **** n = 258

Balloon

The balloon regression hypothesis was as follows:

LOGS/HR = f (PCS/TURN, NRDCHGS, SLOPE, AYD, LNDSIZE, PROFILE, CREW, TOC, ASPMO, ITPA, TCPA, ELEV, TAGLINE, HTRESID, CHSLP, SLASH, LDSCAPE, RATIO)

Inverted Skyline--Single Yarder

LOGS/HR = -2.0181 + 7.0619 (PCS/TURN) **** R^2 = .56
+ 1.3068 (NRDCHNG) * n = 67
- 0.83756 (PROFILE) *

Highlead--Single Yarder

LOGS/HR = 7.8180 + 4.9988 (PCS/TURN) **** R^2 = .28
- 2.4464 (PROFILE) *** n = 76

Single Balloon Yarder Combined

LOGS/HR = 4.1414 + 5.5036 (PCS/TURN) **** R^2 = .33
- 1.1156 (PROFILE) *** n = 143

Uphill Highlead Yo-Yo

LOGS/HR = 3.4125 + 7.4462 (PCS/TURN) **** R^2 = .48
- 0.36635 (AYD) **** n = 136

Highlead Yo-Yo

LOGS/HR = 8.7162 + 5.7980 (PCS/TURN) **** R^2 = .64
- 0.47300 (AYD) **** n = 119

Inverted Skyline Yo-Yo

No regression was attempted because the sample size was only 8.

Combined Uphill Highlead and Highlead Yo-Yo

LOGS/HR = 6.4360 + 6.2898 (PCS/TURN) **** $R^2 = .58$
- 0.41208 (AYD) **** $n = 255$

All Balloon Combined, Except Yo-Yo Inverted Skyline

LOGS/HR = 5.0006 + 5.338 (PCS/TURN) **** $R^2 = .43$
- 0.13129 (AYD) **** $n = 398$

Helicopter

The helicopter regression hypothesis was as follows:

LOGS/HR = f(PCS/TURN, SLOPE, AYD, LNDSIZE, CREW, TOC, ASPMO, ITPA,
TCPA, ELEV, TAGLINE, HTRESID, ABORTS, SLASH, LDSCAPE, RATIO)

Heavy Helicopter

LOGS/HR = 18.304 + 17.953 (PCS/TURN) **** $R^2 = .70$
- 0.33125 (AYD) *** $n = 105$

or with ASPMO

LOGS/HR = 21.691 + 18.224 (PCS/TURN) **** $R^2 = .71$
- 0.31603 (AYD) *** $n = 105$
- 2.9267 (ASPMO) ***

Medium Helicopter

LOGS/HR = 2.3885 + 21.798 (PCS/TURN) **** $R^2 = .37$
- 0.21143 (AYD) **** $n = 201$

Combined Helicopters

LOGS/HR = 5.5505 + 19.931 (PCS/TURN) **** $R^2 = .87$
- 0.25495 (AYD) **** $n = 306$
+ 3.7567 (TOC) ****

Test of Individual System Equations vs. Combined System Equation

The purpose of combining similar systems into one equation was to determine if the combined equation would explain the data as well as the respective individual equations. If so, an appraiser could use the combined equation to determine the production rate without having to appraise for a specific logging system. The following statistic was used to compare the individual equations with each combined equation:

$$\text{(chi-square)} \quad \chi^2 = \sum_k \frac{(f_i - F_i)^2}{F_i}$$

where:

f_i = estimate of yarding production (LOGS/HR) from individual equation using the individual system data

F_i = estimate of yarding production (LOGS/HR) from combined equation using the individual system data.

k = number of observations in the individual data set.

Example of calculating f_i and F_i

The independent variables associated with first day observation of the heavy helicopter were the following: PCS/TURN = 5.1

AYD = 25

TOC = 1

These values were put into the equations to calculate f_1 and F_1.

$$f_1 = 18.304 + 17.953\,(PCS/TURN) - 0.33125\,(AYD) = 101.58$$

$$F_1 = 5.5505 + 19.931\,(PCS/TURN) - 0.25495\,(AYD) + 3.7567\,(TOC) = 104.58$$

This procedure was followed for the complete set of observations. Then the values (f_i & F_i) were entered into the chi-square equation to calculate the chi-square statistic.

The following hypothesis was formulated to test each combined equation:

H_0: The data are described as well by the combined equation as by the set of individual equations, within a given level of statistical tolerance.

The null hypothesis could not be rejected for any of the combined equations at $\alpha = .95$ (Table 10).

TABLE 10. CHI-SQUARE TEST RESULTS--INDIVIDUAL EQUATIONS COMPARED AGAINST RESPECTIVE COMBINED EQUATIONS

Item	n	χ^2	χ^2 Table[b] at α		Result
Short-span Skyline Combined					
Running skyline	91	1.45	60.00	99.5	NR
North Bend	27	13.40	14.60	97.5	NR
Long-span Skyline Combined					
Uphill yarding	201	9.46	153.00	99.5	NR
Downhill yarding	54	25.67	30.98	99.5	NR
Single-yarder Balloon Combined					
Inverted skyline	67	12.63	40.94	99.5	NR
Highlead	76	8.81	48.00	99.5	NR
Yo-Yo Balloon Combined					
Uphill Highlead	136	4.22	97.27	99.5	NR
Highlead	141	3.72	101.50	99.5	NR
All Balloon Combined[a]					
Inverted skyline	67	24.61	40.94	99.5	NR
Highlead	76	12.27	48.00	99.5	NR
Yo-yo uphill highlead	136	23.40	97.27	99.5	NR
Yo-yo highlead	141	25.32	101.50	99.5	NR
Helicopter Combined					
Heavy helicopter	107	80.12	80.17	95.0	NR
Medium helicopter	201	18.27	153.00	99.5	NR

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[a] Except the yo-yo inverted skyline for which the sample size was too small to permit a statistically valid test.

[b] Table values from Beyer, 1971.

NR means the test failed to reject the null hypothesis that the data were described as well by the combined equation as by the set of individual equations, within the level of statistical tolerance shown.

DISCUSSION OF REGRESSION RESULTS

Variables

Past studies have shown that the following affect yarding production: the number of pieces per turn, yarding distance, percent of trees removed per acre, lateral yarding distance, groundslope, chordslope, the number of chokersetters, and type of cut. Of these factors, only lateral yarding distance was not measured and a study needs to be designed to test it. Analysis of data obtained for this study showed that the variables which most strongly influenced productivity of the yarding systems studied were pieces per turn and average yarding distance.

AYD was not found to be statistically significant for either the North Bend or the downhill long-span skyline systems because of little variation in the variable and in the single-yarder balloon systems because of inaccurate estimates of the variable. The single-yarder balloon AYD was believed poorly estimated because the overall reported AYD was about 400 feet (Table 9). An examination of its harvest units (Figure 3) suggests that the actual overall AYD was most likely around 900 feet. Other studies have generally shown yarding distance to be the single most influential independent variable. Two possible serious shortcomings of the gross time study method are relying on loggers to estimate daily averages, and the fact that using daily averages in itself removes much of the variability.

The number of road changes per day is believed to be related to the AYD and volume of timber removed and, because of this collinearity with AYD, it tended to be significant only when AYD was not. The number of roads per landing was thought to reflect the effect of many roads coming into one landing on yarding productivity. It was not found to be significant.

Chordslope and PROFILE were estimated for the skyline and single-yarder balloon systems. Chordslope was a significant variable in all cases except the North Bend and uphill long-span skyline systems. Multicollinearity between chordslope and AYD in the downhill long-span operation caused the coefficient associated with the latter variable to have a positive sign. Therefore, chordslope was dropped from the equation. PROFILE proved to be a better predictor than chordslope for the single-yarder balloon systems. It was not significant for the skyline systems because they were designed to use tail trees in cases where the PROFILE would have affected production.

SLOPE was recorded as an index, so that numerous slopes were averaged into a single value. It turned out to be an insignificant variable in this study, but might have proven significant if it had been measured over the continuum. Dykstra (1976b) found ground slope to be significant when it was measured to the nearest ten percent.

ASPECT was found to be significant for most systems, but its influence varied markedly; in some cases the coefficient was positive, and in others it was negative. This led to further examination which showed that the operating seasons varied among different systems. The variable ASPMO was derived in an effort to measure the suspected difficulty of working conditions as imposed by the combination of aspect and season. To a certain extent, ASPMO was admittedly arbitrary. Furthermore, no tests were made to determine whether it was the optimum index for predicting the number of logs yarded per hour. The index would have to be adjusted for various regional and local weather conditions and is thus of limited use as presented here. I believe the idea has merit and it was therefore included in this report. ASPMO was determined to be statistically significant only for the running skyline, the heavy helicopter, and the combined helicopter operations. This was possibly because the other operations did not have enough variation in aspect and season, it was not optimum index, or it does not work. ASPMO was dropped from the combined helicopter equation because it did not add .01 to R^2.

Type of cut was not found to be significant for most systems due to the fact that the partial-cut prescriptions were so heavy they created a near-clearcut condition. This agrees with Dykstra's (1976b) findings. The scattered timber and heavy understory on the medium helicopter overstory-removal units may have caused the pilot difficulties in finding the hooker. Certainly, the scattered timber contributed to the fact that the helicopter was often underloaded. Type of cut was not statistically significant for the heavy helicopter except when combined with medium helicopter data.

The initial number of trees per acre was obtained from cruise data and the number of trees cut per acre was obtained from timber fellers' records. Table 9 shows that ITPA was generally less than TCPA. This suggests that the cruise data were in error and points to the shortcomings of variables gathered from small sample sizes unless they are measured accurately. Neither ITPA nor TCPA were found to be statistically significant and they could not be transformed into percent of trees cut per acre because of sampling error. Sinner (1973) found that the percent of trees cut per acre was an important variable and I think it should be considered in future studies.

The time loss by an aborted helicopter load was not recorded as delay time. Therefore, ABORTS would affect the yarding production rate. ABORTS was not found to be a statistically significant variable for this study, apparently because the crew responsible for presetting turns rarely overloaded the helicopter.

TAGLINE was only measured for the yo-yo balloon systems and the medium helicopter system. The tagline length was mostly constant in the yo-yo systems and thereby did not affect production. In the medium helicopter system, it was not significant enough to remain in the final equation. However, its coefficient showed that as tagline length increased the production increased. This agrees with Dykstra's (1975) findings.

Height of residual trees, crew size and landing size were not found to be significant variables. Height of the residual timber was estimated by field crews for the yo-yo balloon systems but the sample size was too small to draw statistical inferences. Crew size and landing size were measured on most systems but they were not strong enough factors to statistically influence production.

Elevation above sea level was not found to be statistically significant, possibly because of little variation within or between units (Table 9). Balloon lifting capacity is only reduced by about 3 percent per 1000 feet of elevation gain above sea level (McGonagill, 1977). From Table 9, the range of ELEV was 1100 feet, which would only reduce lifting capacity by about 700 pounds. An examination of Table 11 suggests that on the average the balloons had between 4000 to 9550 pounds of unused lifting capacity. The small variation over any one unit would not be expected to affect production. But ELEV will affect the volume per turn and so the timber appraiser must determine the balloon lifting capacity for each unit.

RATIO was significant for every system in which it was measured, but it was dropped from the equations because of perceived difficulties in estimating the variable prior to logging. The RATIO coefficient was positive for the skyline systems and negative for the helicopter systems. The signs of these two coefficients make sense. For the skyline systems, Dykstra (1978) observed that hooking a cull log took longer and this supports a positive coefficient. In the helicoper operations, preset chokers were used so the type of log would not influence hooking time. In addition, many of the cull logs were whips. Whips weigh less than merchantable logs because they have less gross volume per log. This would allow more logs per turn and thus a large measure of "productivity" (logs per hour). All of this supports the negative RATIO coefficient for the helicopter system.

SLASH and LDSCAPE were measured, but there were not enough replications of treatments to test them statistically. Some units had no SLASH requirements whereas every unit had landscape design considerations. Therefore, the equations developed in this study reflects the yarding production rate on landscape designed units.

TABLE 11. UNUSED BALLOON LIFTING CAPACITY

Case 1: Maximum distance between yarders, yo-yo uphill highlead

Assumptions:

(1) 5000 feet of line out, line weighs 1.85 pounds per foot
(2) Net volume per log = 404 board feet (Table 3)
(3) Net volume = .81 * gross volume
(4) Average pieces per turn = 2 logs (Table 9)
(5) One board foot (bf), gross scale, weighs 10 pounds
(6) Net balloon design lift at 2400 foot elevation (McGonagill, 1977) = 23250 pounds
(7) Neglect the weight of rigging

Calculations:

weight of logs = logs * gross bf/log * pounds/bf = 10,000 pounds
weight of lines = pounds/foot * length = 9,250 pounds
potential lifting capacity = net design lift - weight of lines = 14,000 pounds
unused lift capacity = potential lift - weight of logs = 4,000 pounds

Case 2: Minimum line out, yo-yo uphill highlead

Assumptions:

(1) 2,000 feet of line out
(2) Everything else the same as for Case 1

Calculations:

weight of lines = 3,700
potential lift capacity = 19,550 pounds
unused lift capacity = 9,550 pounds

Table 11 continued

Highlead balloon

Assumptions:

(1) 3,000 feet of line suspended

(2) Gross volume per log (Table 3) = 342 bf

(3) Pieces per turn (Table 9) = 2.50

(4) Net balloon design lift at 4,000 foot elevation = 22,000 pounds

(5) All other assumptions the same as for Case 1

Calculations:

weight of logs = 8,550 pounds

weight of lines = 5,550 pounds

potential lift capacity = 16,450 pounds

unused lift capacity = 7,900 pounds

Equations

Past studies have usually analyzed yarding data on an individual-system or combined-system basis. This study did both and tested the hypothesis that the combined system equation explains the data statistically as well as the respective set of individual equations. This hypothesis could not be rejected at $\alpha = .95$ for any of the combined equations (Table 10). This result holds true only for the conditions of this study and the short-span skyline systems will illustrate this point.. The North Bend had an experienced crew whereas the running skyline had inexperienced crew (Schnare, 1978). Even though no statistically significant difference in production rate was found, I believe the running skyline would be expected to have a better production rate than the North Bend if the crew was experienced.

No statistically significant difference was found between uphill and downhill yo-yo balloon yarding production rates, probably because they operated on the average with a surplus lifting capacity (Table 11). This uplifting force prevented ground leading on the uphill yarding operation, which would have slowed the production rate. Conversely, when yarding downhill on convex slopes, an uplifting force would also be required to prevent ground leading. The combined single-balloon equation showed that a convex slope would reduce production rate by 2.2 logs per hour as compared to a concave slope.

The helicopter yarding production rates were not found to be statistically different from each other. If they carried the same number of logs per turn, the heavy helicopter's logs could have more volume than the medium helicopter's logs because it has a greater lifting capacity for any given elevation.

This study has brought to light the importance of crews' experience, machine, delays, and system in estimating the time required to yard a landscape-designed harvest unit. These interactions need to be examined further.

ESTIMATING VALUES FOR INDEPENDENT VARIABLES

The following is a suggested procedure for estimating values for independent variables. The intent is to aid the appraiser in using the equations developed in this study.

1. The average yarding distance (in hundreds of feet) can be determined for each road from the logging plan. The average yarding distance (AYD) for the harvest unit can be determined by summing the AYD of the roads and dividing by the number of roads. This method assumes that the area covered by each road is fairly uniform, if not use a weighted average.
2. The chordslope can be found the same way as the average yarding distance.
3. The average number of logs per turn by system:
   - a. short-span skyline -- 2.0 logs per turn (average found in this study)
   - b. long-span skyline -- 4.0 logs per turn (average found in this study)
   - c. balloon -- determine net payload of balloon for the elevation of harvest unit (McGonagill, 1977), subtract the weight of lines, and then multiply by 0.60 (based upon Table 11) to get the expected average weight of logs per turn. The average number of logs per turn is calculated by dividing log weight per turn by the pounds per board foot for the timber species and divide that number by board feet per log (obtained from timber cruise data).

d. helicopters -- determine the net external load for a helicopter hovering out of ground effect[1] for an elevation of 300 feet above the highest point in the in flight path at the average temperature expected during operations (McGonagill, 1977). The average payload is calculated by multiplying net external load found times 0.78 but use 0.52 if the unit is an overstory removal. (0.52 and 0.78 were determined from results of this study.) The average number of logs per turn is average payload divided by average weight per log.

4. Average volume per log can be determined from the timber cruise data using local experience on bucking practices.

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[1] To hover "out of ground effect" is defined as hovering more than one-half the rotor sweep diameter above the ground. "Ground effect" is the packing of air between the ground and the helicopter's rotors when the helicopter hovers near the surface. This "ground effect" increases lifting capacity for low-level hovering, but has no influence in helicopter yarding because helicopter operates out of ground effect.

SUMMARY OF MULTIPLE REGRESSION EQUATIONS

The LOGS/HR found using these equations are the number of logs yarded per productive hour on landscape designed units. A productive hour does not include delays, road change time or landing change time. Care should be exercised when estimating the variables to insure that they are within the range of data presented in Table 9, otherwise erroneous results may occur.

These equations are really only sound for the operators, machines, and crews studied. Since the study was conducted, I have learned that some operators have made changes in their equipment. The long-span yarder has been modified (Anderson, 1978) and the balloon studied here has been replaced with a 620,000 cubic-foot balloon (Stewart, 1978). Also, crew members can change and gain more experience with time. The regression equations derived in this study are presented only as an aid for comparing different alternatives. They should be useful for making initial estimates of yarding production rates for the types of logging systems considered.

Skyline

Short-span combined

$$\begin{array}{llll} \text{LOGS/HR} = 5.4818 & + 16.328\ \text{PCS/TURN} & **** & R^2 = .64 \\ & - 2.2472\ \text{AYD} & **** & n = 117 \\ & + 0.13699\ \text{CHDSLP} & **** & \end{array}$$

Long-span combined

$$\begin{array}{llll} \text{LOGS/HR} = 26.741 & + 3.0159\ \text{PCS/TURN} & **** & R^2 = .18 \\ & - 0.89579\ \text{AYD} & **** & n = 258 \end{array}$$

Balloon

Ballon combined

$$\begin{aligned} \text{LOGS/HR} &= 5.0006 + 5.338\ \text{PCS/TURN} && \ast\ast\ast\ast && R^2 = .43 \\ &\quad - 0.13129\ \text{AYD} && \ast\ast\ast\ast && n = 398 \end{aligned}$$

Helicopter

Helicopter combined

$$\begin{aligned} \text{LOGS/HR} &= 5.5505 + 19.931\ \text{PCS/TURN} && \ast\ast\ast\ast && R^2 = .87 \\ &\quad - 0.25495\ \text{AYD} && \ast\ast\ast\ast && n = 306 \\ &\quad + 3.7567\ \text{TOC} && \ast\ast\ast\ast && \end{aligned}$$

These equations have been plotted with LOGS/HR vs. AYD in Figure 19. Other independent variables were fixed at the mean value for each system (Table 9). The curves in Figure 19 are useful for making comparisons among systems because they are representative of the mean conditions encountered during the study. Since the curves are derived for only one set of conditions, the equations should be used for deriving estimates of LOGS/HR with the relevant independent variables. The skylines curves show that the long-span skyline system had a better production rate and was less sensitive to yarding distance than the short-span skyline system. The long-span skyline was more sensitive to yarding distance than the helicopter. The balloon curve was not as sensitive to yarding distance as Dykstra's (1975, 1976b). I suspect this is related largely to the apparently poor job of estimating AYD for inverted skyline and highlead balloon systems as mentioned earlier.

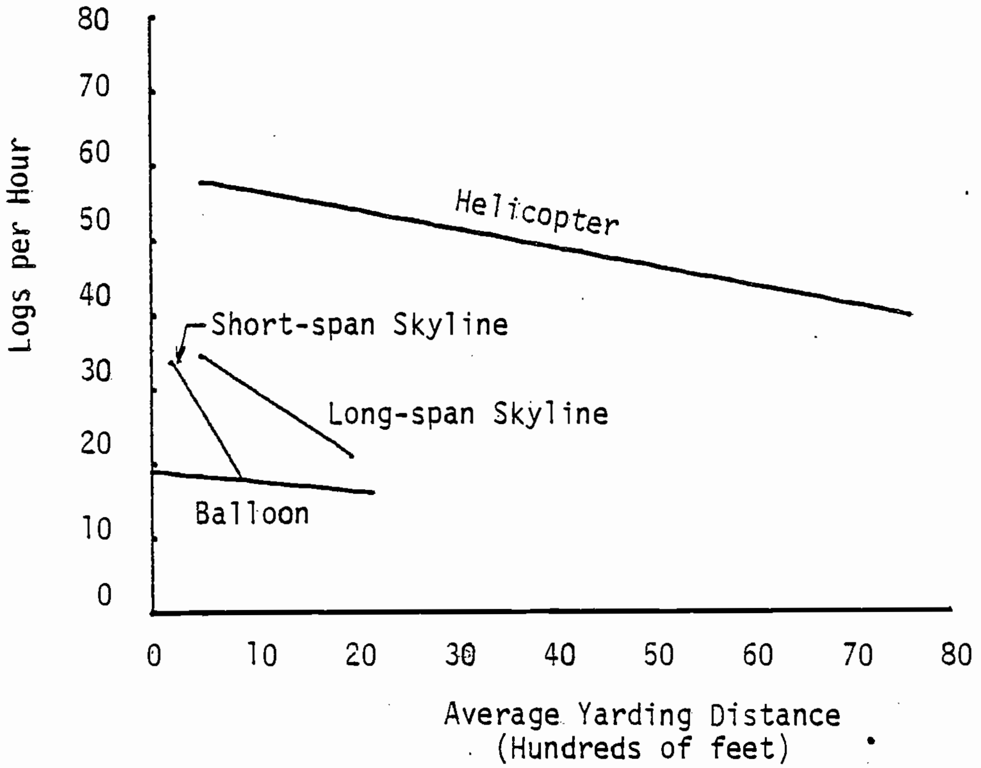

Figure 19. Logs Per Hour as a Function of Average Yarding Distance

COMPARISON OF YARDING PRODUCTION RATES FOR GROSS VS. DETAILED TIME STUDIES

Dykstra (1974, 1975, 1976b) conducted detailed time studies on the running skyline, inverted skyline balloon, highlead balloon, and heavy helicopter systems which are analyzed in this paper. This provides a unique opportunity to compare detailed time study yarding production rates determined from data collected over a short time period with gross time study yarding production rates determined from data collected over a long time period. Dykstra (1976b) has suggested that gross time studies may be more appropriate for making appraisals of long-run production rates since the data obtained with such studies may more accurately reflect total downtime. The yarding production rates based on total hours worked have been reported in Table 12 for both methods. The rates measured by the gross time study method are consistently lower than those measured by the detailed time study method. Thus, it appears that the gross time study more accurately reflected the total downtime. Therefore, the gross time study method would be better suited for developing information that is useful for appraisal purposes or any other purpose which requires accurate, long-run production data.

TABLE 12. COMPARISON OF DETAILED AND GROSS TIME STUDY YARDING PRODUCTION RATES INCLUDING DELAYS

System	Yarding production rate (gross volume) Detailed time study[1] (MBF per hour)	Gross time study[2] (MBF per hour)
Running skyline	3.6	3.2
Inverted skyline balloon	5.5	3.9
Highlead balloon	5.5	4.5
Heavy helicopter	29.9	18.3

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[1] From Dykstra, 1975, 1976b

[2] Calculated as follows:

(gross volume yarded)/(gross yarding hours),
The values came from Table 6.

SUGGESTIONS FOR FUTURE RESEARCH

The gross time study method can best be used in studies where information required is for appraisal purposes whereas detail time study method can be best used in evaluation of system efficiency.

This study has shown that requiring loggers to collect a lot of data gives quantity and not quality. The data collected by the logger should be kept to a minimum. I would suggest these variables:

date
location
system code
gross time
delay time
number of turns yarded
number of logs yarded
average yarding distance
average lateral yarding distance
chordslope from landing to tailhold
percent trees cut per acre
road change time
landing change time
move distance

A new entry should be made for each new day, road change, landing change or system used because daily averages lose the uniqueness of these factors. The logger also should show his work location on a topographic map and turn these records in daily. The records should be checked for completeness and whether the estimates of distances appear reasonable.

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