PRODUCTION AND COST ANALYSIS OF A HELICOPTER THINNING OPERATION IN THE OREGON COAST RANGE AND COMPARISON TO HELIPACE PRODUCTION ESTIMATES

by

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ABSTRACT OF THE PAPER OF

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With increasing environmental concerns, short harvesting seasons, salvage logging needs, and limited road access, helicopter yarding is becoming attractive to many land managers. Most helicopter yarding has occurred on clearcut or even-aged management areas containing large, valuable timber. Very little helicopter yarding has occurred in stands of smaller, less valuable timber which are often inaccessible or have other limiting factors which preclude logging by conventional methods. There has been little research on the use of small to medium-lift helicopters in harvesting of first thinnings of small diameter timber. The purpose of this study was to determine whether the use of small to medium-lift helicopters can be an economical alternative for commercial thinning of young timber stands in steep, mountainous terrain, and whether the HELIPACE software program accurately estimates production of a helicopter yarding system.

The study area consists of several stands of second-growth Douglas-fir requiring an initial thinning. The stands were thinned using a Sikorsky S-58T helicopter (with an external lift of 5000 pounds) to yard a total of 457 MBF over a period of four weeks. The average yarding distance was 775 feet and the average

slope was about 30%. The diameter of the trees removed averaged 11.3 inches, and the average piece size was approximately 40 board feet (net).

A detailed time study was conducted and the results are used to estimate yarding production and costs for the Wildcat Thin sale for comparison to HELIPACE computer program estimates and cable estimates from a concurrent study on the same sale. Regression equations were developed and used to predict total turn time and evaluate the effects of yarding distance and weight per board foot on yarding cost. The detailed time study data was also used in comparing the actual turn times (and production) from 13 individual study areas to predicted turn times from the HELIPACE program.

The results of the study indicate that there was no significant difference between HELIPACE estimates of turn times and actual turn times observed. The average difference in turn time was approximately 6%. The results also indicate that using the Sikorsky S-58T can apparently be an economically feasible alternative for commercial thinning. An average yarding cost of $258.32 per thousand board feet was estimated for the helicopter operation, while HELIPACE estimated $242.85 per MBF for yarding. Average total logging costs for the helicopter operation were estimated to be $354.35 per MBF; total logging costs estimated by HELIPACE were $339.08 per MBF; and the total cable logging costs from the concurrent study on the same sale were $234.94 per MBF. The cable cost estimates were significantly lower than for the helicopter but at current timber values, helicopter yarding can be profitable. Helicopters should be considered when there are other concerns than strictly economics, such as environmental concerns, time constraints, limited access, and physical limitations of other systems.

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INTRODUCTION

Background

Due to increasing environmental concerns, limited road access, salvage logging needs, and short harvesting seasons, helicopter yarding is becoming attractive to many land managers in all regions of the United States but particularly in the western states where there are extensive areas of steep, mountainous terrain. In the past, most helicopter yarding has occurred on clearcut or even-aged management areas containing large, valuable timber due to higher costs associated with helicopter logging. Very little, if any, helicopter yarding has occurred in stands of smaller, less valuable timber which are often inaccessible or have other limiting factors which preclude logging by conventional methods.

As forests available for timber management become scarce, as the current trend in the Pacific Northwest indicates, timber values generally increase making helicopter yarding of thinnings and partial cuts more practical or at least an economically viable alternative. Much of the future harvesting on public lands will be limited to second growth thinnings, often initial thinnings of young stands. Harvest of small diameter class trees (less than 15 inches) will become a large percentage of the annual cut in the Pacific Northwest in the future (Tedder, 1979). With the recent reductions in harvesting of mature timber on federal lands, thinning of young, immature timber stands will become an even more important source of fiber.

Literature Review

Helicopter Yarding

Helicopters were first used for logging in the United States during the early 1970's when a joint venture by the U.S. Forest Service, Erickson Lumber Company, Columbia Construction Helicopters, and Sikorsky Aircraft Company brought about an evaluation of the S-64E Skycrane for harvesting timber (Binkley, 1973). Since that time, the helicopters most often used for logging have been the Sikorsky S-64, S-61, and S-58T, the Boeing Chinook 234, the Boeing Vertol 107, the Aerospatiale Llama, and the Bell 204 and 214. The external payloads of these aircraft range from 2,500 to 28,000 pounds (see Table 1 for comparison of helicopter specifications).

Very little research has been completed on the various aspects of production efficiency associated with helicopter logging of thinnings in immature timber stands. There has been much research to evaluate the most effective methods of harvesting small wood in thinning operations (Aulerich, 1975; Kellogg, 1980), but this research concentrated on ground vehicles and cable systems. Flatten (1991) examined the use of a small helicopter with an external payload of only 2,500 pounds for thinning in steep terrain, and Dykstra (1975, 1976, and 1978) evaluated medium to heavy-lift helicopters with payloads of 6,700 to 20,000 pounds for partial cutting. Most other studies have involved large helicopters working in clearcut areas and very little information has been collected on helicopter logging of any type in recent years.

Table 1 - Comparison of Helicopter Specifications

Characteristics of Helicopters Commonly Used for Logging*

Characteristic	Helicopter Model: Chinook	S-64	BV-107	S-61	Bell 214	K-MAX	S-58T	Bell 204	Llama
Performance:									
Cruising Speed (mph)	140	95	120	120	80	100	120	120	100
Fuel Consumption (gal/hr)	400	395	180	150	200	85	110	110	60
Engines									
Number	2	2	2	2	1	1	2	1	1
Max. Horsepower (per engine)	4,500	4,500	1,350	1,500	2,930	1500	910	1,100	858
Weights (lbs):									
Gross Weight	55,000	42,000	19,000	19,000	16,000	11,000	13,000	9,500	4,300
Approx. Payload** (external lift @ sea level)	28,000	20,000	11,500	11,000	7,400	6,000	5,000	4,500	2,500
Dimensions (nearest ft.):									
Fuselage Length	52	70	45	61	45		39	43	34
Overall Length (w/rotors)	99	89	83	73	61	52	66	57	42
Main Rotor Diameter	60	72	50	62	50	48	56	48	36
Overall Height	19	25	17	18	14		16	13	10

* Taken from USDA Forest Service Publication, 1993, and records compiled by Don Studier, Logging Systems Specialist, USDA Forest Service, Region 6.

** The external lifts or payloads are estimates at sea level and will vary with individual helicopter.

There is no past research literature on initial commercial thinning of young timber stands or plantations with helicopters. In the past, yarding small timber (less than 15 inches in diameter) by helicopter would have been uneconomical due to low timber values. With the recent increase in stumpage values in the Pacific Northwest for Douglas-fir and other species, helicopter logging may be an economical alternative for thinning young timber stands in the future.

There are numerous factors which have been shown to affect production rates and costs of helicopter yarding. Dykstra (1974, 1975, and 1976) found that yarding distance, number of logs per turn, board-foot volume (or weight) per turn, and change in elevation from the hook point to the landing, all significantly affected total turn time (and thus production rates and costs). Earlier studies by Campbell (1972) and Studier (1973) identified the same four variables as being significant. All three researchers found that turn times increased as each of the four variables (number of logs per turn, weight per turn, chordslope, and yarding distance) increased.

One variable which is thought to affect productivity but has not been studied, or at least not documented with past research, is the amount of remaining canopy left in the residual stand. Remaining canopy or crown closure is thought to directly affect turn times and thus production and cost (USDA Forest Service, 1993).

With operating costs generally much higher for helicopters than other yarding equipment, significantly higher hourly production rates are necessary to allow helicopters to compete with cable systems. The ability to piece together optimal turn sizes is critical in making a helicopter operation economically feasible. The difficulty in achieving optimal turn sizes in thinnings or other partial cuts, while protecting the residual stand, has been a primary reason why large helicopters have not been widely used for commercial thinnings (USDA Forest Service, 1993). In a thinning on the Siskiyou National Forest, Dykstra, Aulerich, and Henshaw (1978) estimated that prebunching with horses to allow optimal turn sizes decreased yarding costs with a medium-lift helicopter by as much as 40%.

Small to medium-lift helicopters with lower payload capacities are more suited to logging small piece sizes typically found in thinnings of second-growth timber. In a partial cut on the Willamette National Forest, Flatten (1991) found that yarding with a small helicopter with a payload of 2500 pounds was profitable and damage to the residual stand appeared to be less than typically found with cable systems.

HELIPACE Computer Program

In 1990 the Helicopter Logging Association and USDA Forest Service jointly developed a software program (HELIPACE) to estimate production and costs associated with helicopter logging (Aerial Forest Management Foundation and USDA Forest Service, 1993). A new version of this program is released annually and includes cost estimates based on information collected from USDA Forest Service helicopter sales of the previous year. This program was developed for planning purposes to help determine the feasibility of possible helicopter sales.

The USDA Forest Service uses the program to determine whether specific timber sales can be logged economically by helicopter, to compare helicopter cost and production to other harvest methods, and to estimate helicopter logging costs for use in timber sale appraisals. Since this software program is relatively new, there has been no validation of the program by comparing the estimates from HELIPACE to the results of a detailed time study.

Giles and Marsh (1994) used HELIPACE to estimate yarding costs and maximum yarding distances which would be profitable for salvage logging on the Boise National Forest but no analysis of actual production or costs was attempted. The authors (Giles and Marsh, 1994) attempted to compare the HELIPACE estimates with actual yarding distances by the operator based on optional salvage timber offered at varying distances, but the comparison was hindered due to significant increases in timber values between the purchase date and time of logging. This resulted in the operator yarding optional material at longer distances than had the timber values remained constant during the timber sale harvest period.

The only other literature available on the HELIPACE program is the User Guide which accompanies the latest version (2.0) of the software (Aerial Forest Management Foundation and USDA Forest Service, 1993).

The HELIPACE program requires several input variables relating to the sale area, stand condition, wood availability, and weight/volume relationship. From the input variables, HELIPACE estimates the average turn time, daily production, and yarding costs on a per MBF and daily basis.

PURPOSE OF THE STUDY

The purpose of this study was: 1) to determine whether the use of small to medium-lift helicopters (such as the Sikorsky S-58T) can be an economically viable alternative for commercial thinning of young timber stands in the Oregon Coast Range, 2) to identify factors that affect productivity of the helicopter system, and 3) to determine whether the HELIPACE software program accurately estimates production of a helicopter yarding system.

The first objective was met by comparing the results of a completed thinning operation using a Sikorsky S-58T to the estimated costs of a cable yarding operation on the same sale. The cable yarding costs were obtained from skyline thinning studies conducted on the Wildcat Thin sale (King, 1994). Logging cost rates were compared with typical small log values in the Oregon Coast Range.

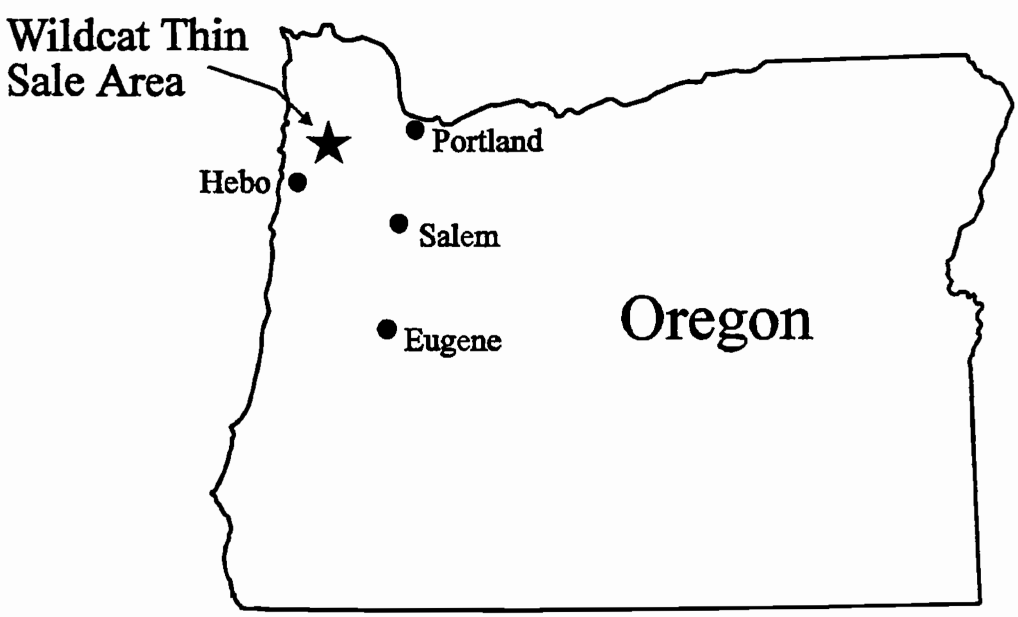
The second objective was met by analysis of the results from a detailed time study of a helicopter yarding operation. Statistical analysis was used to identify the factors that most affect each part of the yarding cycle. In addition to variables studied in past research, an attempt was made to determine the effect of the remaining canopy on production.

In order to satisfy the third objective, data collected from the helicopter thinning operation were input into the HELIPACE software program. The HELIPACE production estimates were compared to the actual results of the completed thinning operation.

SALE AREA DESCRIPTION

The study area consisted of five thinning units totaling 75 acres which were part of the Wildcat Thin Timber Sale on the Hebo Ranger District of the Siuslaw National Forest (see Figure 1 for general vicinity map). This sale contained a total of six thinning units of which five units were completely or partially yarded by helicopter, with the remainder of the sale yarded by cable systems. Leave trees were marked by the Forest Service to insure the proper number and spacing of residual stems.

Figure 1 - General Vicinity Map



The timber stands, which were second growth, even-aged plantations, ranged in age from 31 to 33 years old. Average slope within the sale area was approximately 30% and ranged from level to 40%. The units were located at an elevation of 600 to 1500 feet and were generally on western aspects (southwest, west and northwest).

Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) was the primary species comprising almost 90% of the volume on the site. Other major species included Western hemlock (Tsuga heterophylla (Raf.) Sarg.) and Sitka spruce (Picea sitchensis (Bong.) Carr.), which resulted from natural regeneration within the planted stands of Douglas-fir.

According to an initial stand examination and a subsequent cruise, there were an average of approximately 230 merchantable trees per acre of which about 100 trees per acre were designated (marked) as leave trees. The remaining 130 trees per acre were designated for cutting. Merchantability limits were: minimum 7 inches diameter at breast height, minimum top of 5 inches diameter inside bark, and minimum piece length of 12 feet. Prior to thinning there were 15.9 MBF per acre and a basal area of 206 square feet. There were 7.0 MBF per acre (90 square feet of basal area) designated for removal. The average diameter at breast height was 11.3 inches for cut trees and 14.6 inches for leave trees. The average height of the residual stand was estimated to be approximately 70 to 75 feet. Total stand defect was estimated to be about 2%.

The silvicultural prescription for this area called for an initial commercial thinning, followed by subsequent thinnings as needed to allow for maximization of diameter growth of the crop trees. The thinning was also meant to increase stand diversity by varying the leave tree spacings between 80 and 120 trees per acre in the various stands, with 100 trees per acre being the optimal for timber production. Trees to be left were marked from the healthy dominant and codominant Douglas-fir and Western hemlock. Trees to be removed were from the suppressed, intermediate, and codominant tree classes, as well as diseased, damaged, poorly formed, or otherwise unhealthy trees.

HELICOPTER DESCRIPTION

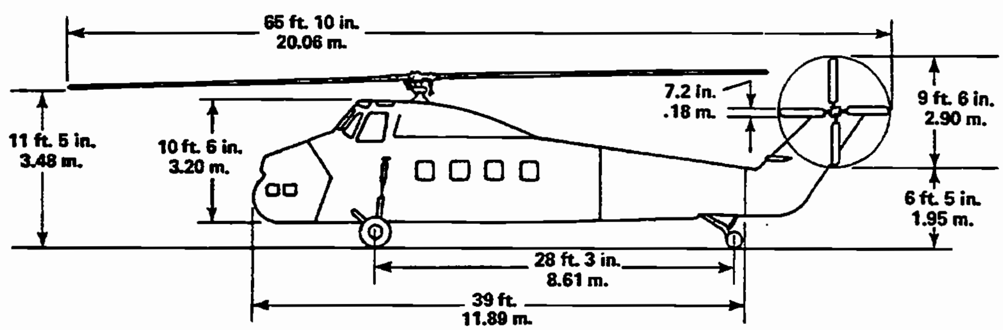
The purchaser of the timber sale involved in this study was Western Timber Company of Philomath, Oregon, which contracted Columbia Construction Helicopters of Portland, Oregon to log the helicopter units. Yarding of the helicopter units was subcontracted to Scenic River Logging, Inc. of Sandy, Oregon. This company had only been in business for approximately one year, though the owner/pilot had been employed as a pilot with another logging company and flew the same model of helicopter (Sikorsky S-58T) for several years.

The S-58T was manufactured by Sikorsky Aircraft Division of United Aircraft Corporation (see Table 2 for specifications). This model is no longer manufactured but there are many of these ships in operation today with approximately ten actively used for logging in the western U.S. The S-58T is a small to medium-lift helicopter with relatively low hourly costs when compared to the larger helicopters more commonly utilized for logging. With a payload capacity well-suited for yarding small piece sizes, the S-58T has been used primarily for logging smaller second growth timber in clearcut and salvage operations. The operator of this sale had not logged a first thinning of young even-aged, small diameter timber prior to this sale.

Table 2 - Performance Specifications of the S-58T

Weight Empty, lbs	7,577
Useful Load, lbs	5,423
Gross Weight, lbs	13,000
Performance (sea level, standard day, maximum gross weight)	
Maximum Speed, mph	143
Cruise Speed, mph	127
Fuel Consumption, gal/hr	110
Range (no reserve), miles	300
Hover Ceiling, IGE, ft	10,400
Hover Ceiling, OGE, ft	8,600
Service Ceiling, ft	15,000
Maximum External Load, lbs	5,000

SIKORSKY S-58T



HELICOPTER OPERATION

Yarding Distances and Roads

The five units of the sale yarded by helicopter were logged during March and April of 1994. The units were yarded to three landings (see map in Appendix A). Since the sale was originally planned for yarding by cable systems and most of the units were located along Forest Service system roads, access to each landing was already in place and no road construction or major improvement was required.

Average yarding distance for the helicopter portion of the sale (five units) was approximately 775 feet. The maximum yarding distance was about 1850 feet, and the minimum yarding distance was approximately 50 feet due to landings being located within or adjacent to some units. Most of the yarding was uphill but one unit had some downhill yarding. The change in elevation from the hook point to the landing ranged from +320 feet to -80 feet, with the average estimated to be around 100 feet.

Equipment

In addition to the Sikorsky S-58T helicopter described earlier, other equipment included a fuel tank trailer, a mechanics truck and trailer with spare parts, a Fiat-Allis 745-B front-end loader, and a swing boom loader.

The fuel tank trailer was located at the service landing and was used instead of a fuel truck since the same service landing was used for all helicopter operations on the sale. Other equipment included chokers, radios, and pickups for crew transportation.

Crew

The crew for the helicopter operation consisted of 8 to 10 people. A single pilot and one mechanic were used to fly and service the helicopter. The pilot was the owner/operator and served as the project manager, with a woods boss supervising on the ground activities during actual flight time. Two people worked at the landing removing chokers from incoming turns, wrapping chokers, and hooking chokers for delivery to the woods. The number of choker setters in the woods varied from three to five people, with four choker setters on most days. The woods boss set chokers if the crew was short for any reason. An additional person was needed to operate the front-end loader used during the yarding operation to keep the drop zone clear and deck logs. The truck drivers operated the swing boom loader used to load the trucks.

Method of Operation

Due to the relatively short yarding distances encountered on this sale, multiple choker setters were required to keep pace with the helicopter and avoid unnecessary delays. The choker setters (normally four) were widely spaced within the unit being yarded and the helicopter rotated among the locations to allow the choker setters time to have a turn of logs ready for transport. The helicopter returned chokers to the woods during outhaul at varying intervals depending on when choker setters needed more chokers and the availability of chokers collected at the landing from previous turns. The landing crew wrapped or bundled chokers removed from the logs delivered to the landing and hooked the bundles to the tag line for return to the woods.

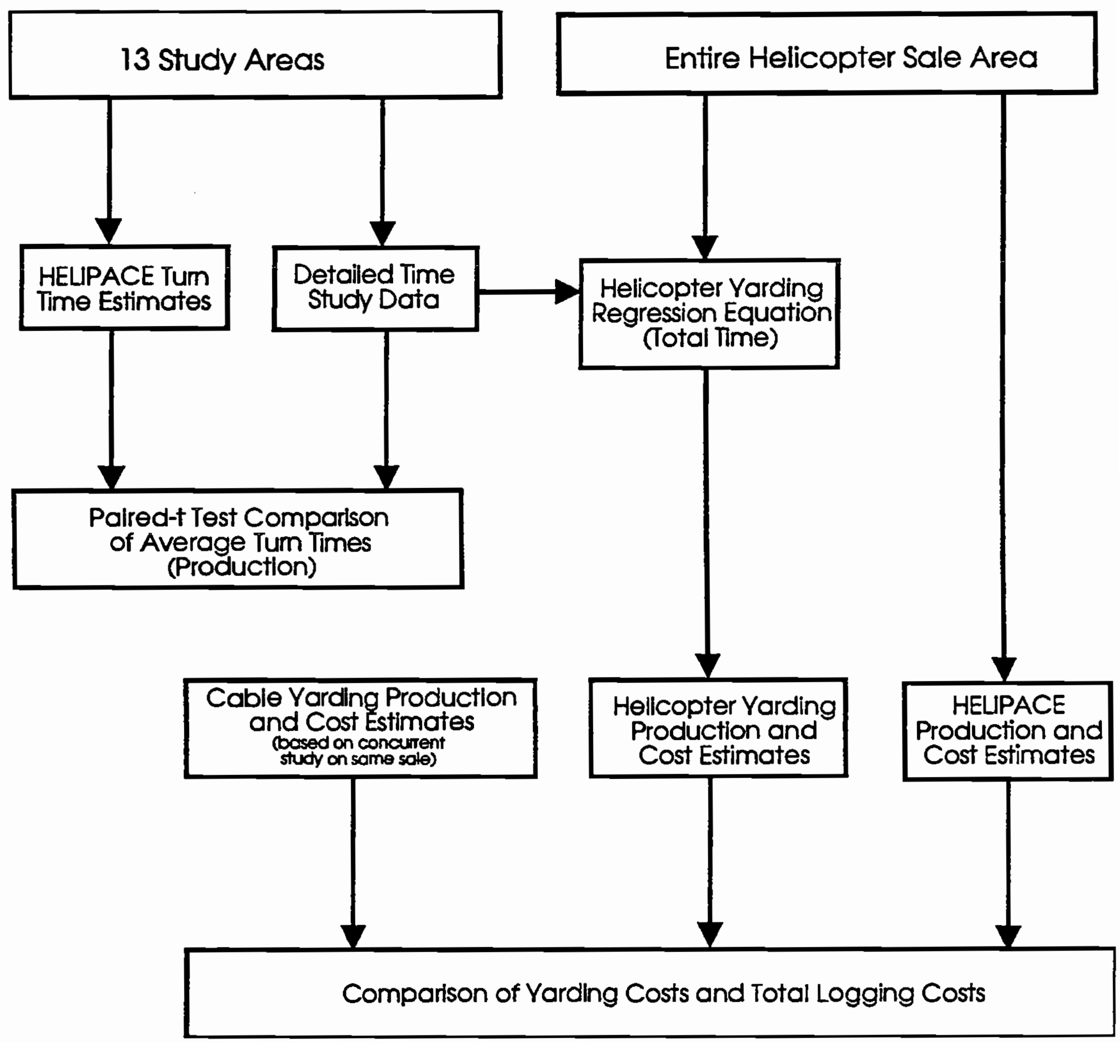
The typical flight cycle, or period between fueling and servicing of the helicopter, was about one hour and fifteen minutes. The service/refueling landing was located at a road intersection about one quarter mile south of sale unit 5. The various sale units were between one quarter mile and one mile from the service landing.

STUDY METHODS

The circumstances surrounding this study were such that the researcher had very little control over the study area or the helicopter operation. The timber sale was originally planned for cable yarding but the purchaser decided to yard part of the units by helicopter. The primary reason the purchaser decided to utilize a helicopter for yarding was that the logging season was coming to a close in a matter of weeks (March 31) due to required protection of endangered species habitat. If the timber on this sale was not removed prior to this time, logging would not be allowed to resume for approximately six months. The sale could not be completed prior to the seasonal closure with the planned cable systems but most likely could be completed with the typically much faster helicopter system. This decision was made only a few weeks prior to the beginning of harvest operations, so the sale had been prepared and sold by the Forest Service long before this study opportunity materialized.

This study includes two parts which are very different, so the study methods of each are described separately. The helicopter yarding time study is described first, and then the HELIPACE computer program analysis since this was the order they were performed. The chart in Figure 2 identifies the relationships of the various parts of this study which are described in detail in the following sections.

Figure 2 - Chart of Study Procedure



Helicopter Yarding Detailed Time Study

Since accurate production data and the ability to establish a relationship between turn time and other variables affecting production were desired, a detailed time study was used in analysis of the helicopter yarding system (Olsen and Kellogg, 1983). The time study data was collected between March 14 and April 4 of 1994 and required ten days. Data from this time study was used to determine an average turn time or yarding cycle time for this project and to develop a predictive equation for delay-free cycle time with the given stand conditions and equipment.

The time study separated the yarding operation into its procedural components which were timed to the nearest deciminute (100th minute) and recorded. All data was collected using the Husky Hunter field data recorder with the SIWORK3 time data collection program. Three workers were required to collect the necessary information. Two workers followed separate hookers to observe while the third worker stayed at the landing to observe and record data. The actual number of hookers working at any one time varied from three to five people but only two were timed at any given time during data collection. The workers were in contact by hand-held radio, allowing the recorder to know precisely when activities at each hook point started and ended. Timed components of the yarding cycle were:

- <u>Outhaul</u>: time began when the helicopter left the landing and ended when the pilot found the hooker and began a vertical descent.

- Descent (for hook): time began at the end of outhaul and ended when vertical descent stopped for the hooking operation.
- Hook: time began with the end of vertical descent and ended with the beginning of vertical ascent.
- Ascent (after hook): time began with the start of vertical ascent after hooking and ended with the start of forward flight.
- Inhaul: time began at the start of forward flight back to the landing and ended with the start of vertical descent at the landing.
- Unhook: time began at the start of vertical descent at the landing and ended with the start of forward flight (after the load was released and vertical ascent ended).
- Delays: Delays were recorded by the following categories:
    1. Loader - the loader being in the drop zone causing the helicopter to wait until clear.
    2. Chaser - the chaser being in the drop zone collecting chokers.
    3. Fuel - fueling of the helicopter.
    4. Maintenance - planned maintenance to the helicopter.
    5. Helicopter - repair or unplanned maintenance to the helicopter.
    6. Hook - repair or adjustment of the hooking mechanism or tag line.
    7. Abort - drop of the load due to excessive weight, hang-ups, etc.

8. Hindrance - delays due to obstructions or hang-ups such as standing trees, brush, etc.

9. Personal - delays such as lunch or rest breaks.

10. Miscellaneous - transport of supplies, water, etc.

Other recorded components (non-timed) were:

- Logs: number of logs in the turn.
- Weight: total weight of the turn which was determined by an on-board (helicopter) weighing mechanism and communicated to the recorder by radio.
- Chokers: indicator variable (0 or 1) denoting whether chokers were returned to the hooker during outhaul.

The above information was recorded for thirteen small study areas within the five units of the sale which were yarded by helicopter (see map in Appendix A for location of study areas and landings). The areas were not determined prior to the data collection but were marked on the ground by the data collectors after yarding was completed in an area. This procedure allowed for data to be collected in continuous or solid blocks so stand and yarding information could be collected from the specific, defined sites involved in the detailed time study. This method of study area selection also allowed the study to encompass the range of yarding conditions in this sale.

The following site and stand information was collected from each of the thirteen study areas after the yarding was completed:

- Yarding Distance: slope distance between the landing drop point and the hook point as determined from field measurements.
- Chordslope: the slope (percent) of a line segment between the hook point and the landing drop point.
- Canopy Closure: the percentage of canopy coverage for the residual stand was estimated by tree counts and crown area measurements on each area. Crown areas were measured on at least 20% of the residual trees in each area to estimate average crown area which was used along with total number of trees per area and size of area to estimate crown closure. For each site: Canopy closure = (average crown area sq.ft. * number of trees in area / total land area sq.ft.)

Collected data were either downloaded from the Husky Hunter data recorder to a personal computer or entered manually for analysis with spreadsheet and statistical software programs. Yarding cycle time elements were determined by averaging the individual cycle components and summing them for an average total cycle time for the site conditions and equipment used for this yarding operation. An average total cycle time for each of the thirteen study areas was determined to allow for comparison with predicted average cycle times obtained from the HELIPACE software program.

A step-wise regression analysis process yielded predictive equations which described delay-free time for the total yarding cycle and each of the yarding cycle components (outhaul, hook, inhaul, unhook) as a function of the six possible non-timed operational components (logs, weight, chokers, yarding distance, chordslope, and crown closure) defined above. Using average sale values for the independent variables, the total yarding time regression equation was used to predict an average yarding cycle time for the sale area (all five units yarded by helicopter).

Except for the paired-t analysis of average cycle times, all production and cost estimates used for comparisons between the helicopter operation, HELIPACE, and cable system were based on the entire sale area yarded by helicopter. The reason for basing production and cost estimates on the entire sale was to allow for estimates which reflected average sale conditions (as opposed to the thirteen small study areas).

HELIPACE Computer Program Analysis

The HELIPACE software program (version 2.0) runs on a personal computer under Microsoft Windows™. The program has mainly been used to estimate production and costs based on sale and stand information which has been obtained from stand prescriptions or cruises. Often the information entered into HELIPACE has not been measured and is a "best guess" estimate of the sale planner. The input information entered into the program for this study was measured to allow for comparison to the actual results from the detailed time study and cost estimates.

The program allows analysis by unit or area, and each of the thirteen study areas from the detailed time study were analyzed separately with each being treated as a unit. This allowed for direct comparison of the average cycle times from the detailed time study to the estimated cycle times calculated by HELIPACE. A paired t-test using a statistical software program was used to determine whether there was a difference in the HELIPACE estimates and the detailed time study measurements for the thirteen areas.

All of the input variables required to run the HELIPACE program were collected as part of the detailed time study or measured after yarding was completed. Table 3 shows a sample of the inputs and calculations from HELIPACE. As shown, some inputs are required while others are optional, depending on the information available and which variables the user prefers the program to calculate. Most of the required inputs for this study were readily determined from site measurements, cruise information, and observation of the helicopter operation. The most difficult inputs to estimate were the remaining crown closure and the weight per gross board foot. The method of estimating remaining crown closure of the residual stand was described in the previous section. The weight per board foot estimate was based on scale records for this sale and average turn weight and number of logs per turn from the detailed time study (see Appendix E for calculation of weight per board foot).

The program requires the user to select one of the six helicopter models which are listed. The relatively small number of helicopters available for selection is one of the limitations of the current program. The reason for only six ships being in the program is that the cost information is updated annually from cost figures obtained from Forest Service sales, and these helicopters are the ones most commonly used for logging and operated frequently enough to provide adequate cost records. The S-58T which was used for the operation analyzed by this study is not one of the current helicopter model options in the program, but this does not affect the average cycle time calculation since the same formula is used for all small to medium-lift helicopters in the program.

For this study, the Bell 204 was used in running the program since the external payload and costs are very similar to those of the S-58T (Aerial Forest Management Foundation, 1994). The external payload for the S-58T is approximately 5,000 pounds compared to 4,500 for the Bell 204, and the fuel consumption rates and average speed are the same for both ships (See Table 4 for a comparison of the specifications of these two helicopters). Obviously, the cost information for the Bell 204 will not be correct for the S-58T, but these costs were the best estimates available through HELIPACE and they provide a reasonable estimate of yarding costs.

Table 3 - Sample HELIPACE Inputs and Displayed Calculations

UNIT	11	(R)	WOOD AVAILABILITY		
Sale	Wildcat	(O)	Cut Trees/acre	111	(R)
Acres	11	(R)	Cut Logs/acre	154	(R)
Unit Centroid: Easting		(O)	Tree Avg Gross Scale (BF)	63	(D)
Northing		(O)	Log Avg Gross Scale (BF)	45	(D)
Elevation	760	(R)	Avg Tree Weight (lbs)	1191	(D)
Log Landing: Number	1	(R)	Avg Log Weight (lbs)	859	(D)
Easting		(O)	Avg Number UM (pieces/acre)	0	(O)
Northing		(O)	Avg UM Piece Weight (lbs)	0	(O)
Elevation	840	(R)	Mean Target Load (lbs)	3402	(D)
Unit to Landing Elev. Change	80	(D)	Plausibility Test: Trees/Turn	2.96-4.23	(D)
Include Service Flight Time?	N	(O)	Logs/Turn	3.21-4.59	(D)
Service Landing: Number	N/A	(O)	Average Available Load	2381-3402	(D)
Easting	N/A	(O)	Load Factor	0.70-1.00	(R)
Northing	N/A	(O)			
Elevation	N/A	(O)	PRODUCTION RATE		
			Avg Residual Tree Height	73.00	(R)
AIRCRAFT	Bell 204	(R)	Additional Turn Time	0.20	(R)
Design Load	3402	(D)	Mean Minutes/Turn	1.96	(D)
Mean Flight Path Length	450	(D*)	Mean Turns/Effective Hour	30.69	(D)
LL to SL Flight Path Length	N/A	(O)	Effective Yarding Hours/Day	7.00	(D)
SL to Unit Flight Path Length	N/A	(O)	Yarding Workdays	2.84-1.99	(D)
			Board Foot/Cubic Foot Ratio	N/A	(O)
STAND			Production Rate Gross (MBF/day)	27.1-38.7	(D)
Stand Data File	N/A	(O)	Production Rate Net (MBF/day)	23.6-33.7	(D)
% Remaining Canopy Closure	60	(R)			
Gross Scale (MBF/acre)	7.00	(R)	PRODUCTION COST		
Scaling Defect %	13	(O)	Total Payunit Net Merch MBF	66.99	(D)
Net Scale (MBF/acre)	6.09	(D)	Pounds/Net BF	21.71	(D)
Yard Unmerchantable Material?	N	(O)	Aircraft Fixed $/Day	3700	(D)
Add Weight % for Intended UM	0	(O)	Aircraft Variable $/Day	2380	(D)
Add Wt % for Unintended UM	0	(O)	Yarding System $/Day	6080	(D)
Pounds/Gross (BF)	18.89	(R)	Aux Support Aircraft $/Day	N/A	(O)
Average Scaling Defect %	N/A	(O)	Sawyers	0	(R)
Total Weight to Yard (lbs/acre)	132230	(D)	Rigging and Landing Crew	5-6	(R)
Includes UM Weight (lbs/acre)	0	(D)	Loaders with Operators	1-2	(R)
% of Butt Logs to be Ripped	0	(D)	Additional Ripping $/Day	0	(D)
			Support System $/Day	1050-1260	(D)
			Ground Support Fixed $/Day	460	(D)
			Production Cost $/Net MBF	385-311	(D)

(R) = Required Input (D) = Displayed Calculation
(O) = Optional Input (D*) = Displayed Calculation which may be changed

Table 4 - Comparison of S-58T and Bell 204 Helicopters

	S-58T	Bell 204
Performance:		
Cruising Speed (mph)	120	120
Fuel Consumption (gal/hr)	110	110
Engines		
Number	2	1
Max. Horsepower (per engine)	910	1,100
Weights (lbs):		
Gross weight	13,000	9,500
Approx. Payload*	5,000	4,500

* Payloads are estimates at sea level and will vary by individual helicopter.

In order to estimate average sale production and costs, a second HELIPACE analysis was performed. The entire sale (five units) yarded by helicopter was analyzed in the program and a sale summary was compiled for the sale. HELIPACE provides a summary which lists production and cost information by unit and sale. The summary provides total volume, acreage, work days, and cost, as well as average yarding distance, volume per day, cost per MBF, and weight per turn.

Using information collected for the entire helicopter sale area (as opposed to the 13 study areas) for cost estimation in HELIPACE provided an estimate of average cost per MBF more reflective of the entire sale than the information from the thirteen study areas. Analysis of the entire sale area yarded by helicopter more accurately reflected the sale average yarding distances, crown closure percentages, elevation changes, and other sale information used by HELIPACE to estimate average unit and sale costs per MBF.

RESULTS

Detailed Time Study

Statistics

Site information for each of the thirteen study areas sampled during the detailed time study is shown in Table 5. The weighted average yarding distance for these sampled settings was 695 feet, slightly less than the estimated sale average of 775 feet.

Table 6 displays a statistical summary of the times for the various components of the yarding cycle, as well as data pertaining to the independent variables measured. As noted previously, hook time was broken down into three separate components which are shown in the table along with total hook time.

Table 5 - Site Information for Detailed Time Study Areas

Study Area	Unit Location	Acres	Yarding Dist (ft)	Chord-slope(%)	Crown closure(%)	Number of turns
1	11	0.20	325	16	62	16
2	11	0.15	460	18	59	10
3	12	0.69	880	26	35	26
4	12	1.39	865	24	59	34
5	12	0.23	1245	15	49	12
6	2	0.19	940	3	59	12
7	2	0.11	870	-9	55	6
8	2	0.64	760	-8	49	22
9	2	0.96	510	-4	57	87
10	3	0.28	705	9	57	23
11	3	0.71	260	8	66	40
12	3	0.36	1300	9	63	13
13	3	0.80	1225	8	52	21

Table 6 - Statistical Summary

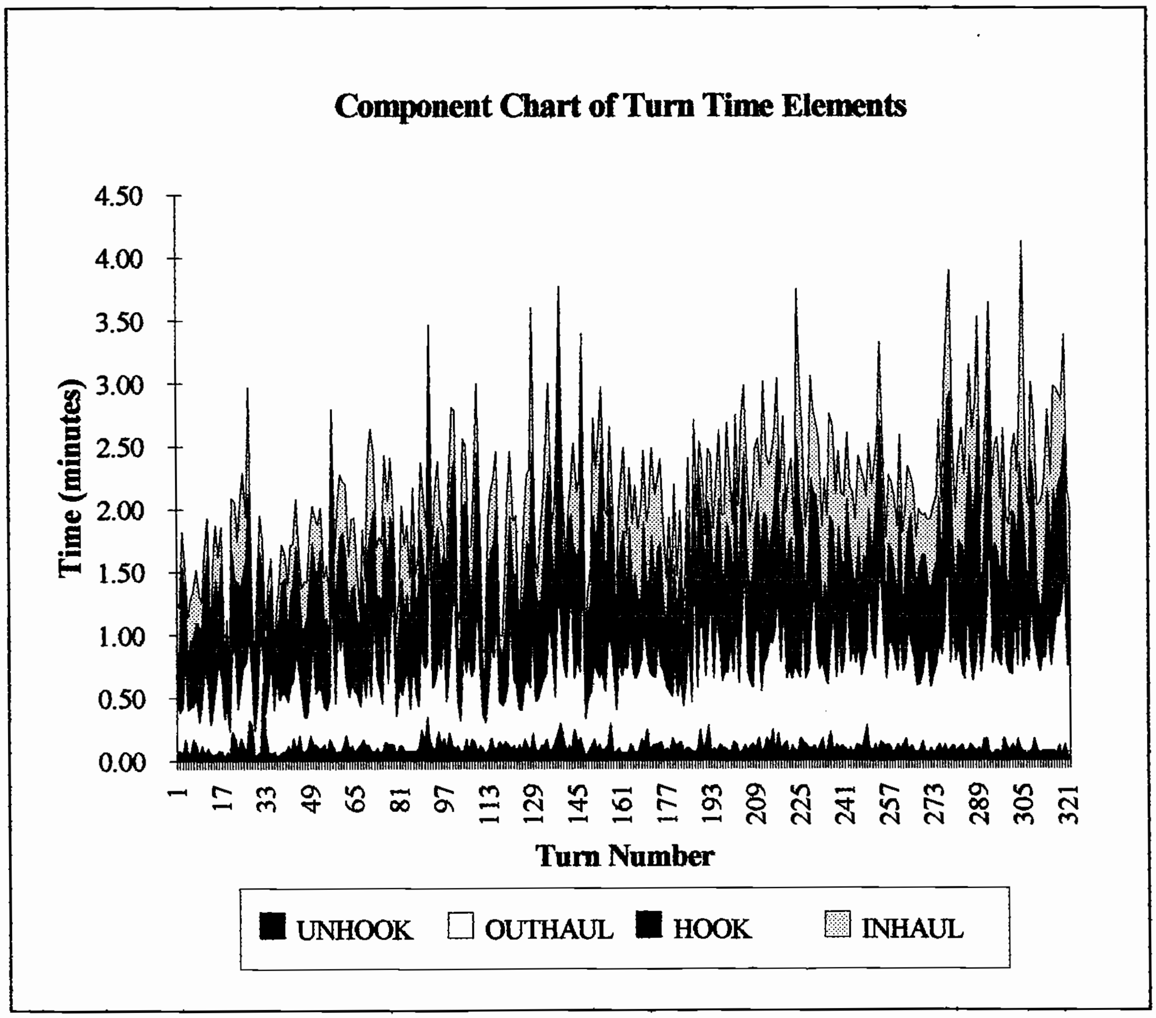
Statistical Summary of Detailed Time Study Data

Sample size = 322 turns

	Turn Time Elements (minutes)								Independent Variables				
		Hook Element											
Variable:	Outhaul	Descent	Hook	Ascent	Total Hook	Inhaul	Unhook	Total Time	Logs	Weight (lbs)	Yarding Dist (ft)	Chord-slope(%)	Crown closure(%)
Average	0.67	0.29	0.28	0.26	0.83	0.50	0.11	2.11	4.30	3701	695	7.4	55.97
Median	0.62	0.28	0.25	0.23	0.80	0.52	0.10	2.09	4	3700	705	8	57
Variance	0.08	0.02	0.02	0.01	0.07	0.05	0.00	0.35	1.54	183540	94560	123.75	59.94
Standard dev.	0.29	0.14	0.14	0.11	0.27	0.22	0.06	0.59	1.24	428	308	11.12	7.74
Standard error	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.03	0.07	23.87	17.14	0.62	0.45
Minimum	0.15	0.03	0.08	0.07	0.33	0.07	0.03	0.74	1	2000	260	-9	35
Maximum	1.90	1.29	1.35	0.87	2.16	2.12	0.62	4.13	10	5600	1300	26	66
Range	1.75	1.26	1.27	0.80	1.83	2.05	0.59	3.39	9	3600	1040	35	31

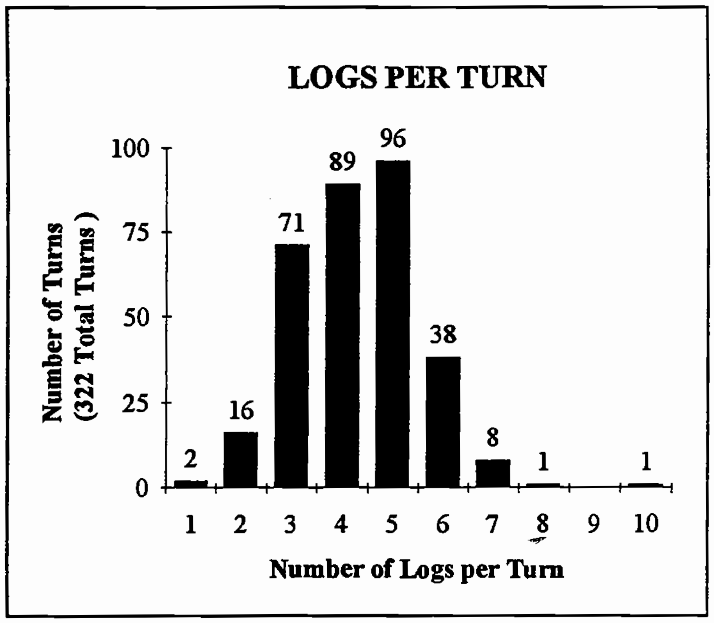
A component chart showing the relative amounts of each of the main cycle elements (outhaul, hook, inhaul, unhook) and the source of variability for total turn times is shown in Figure 3.

Figure 3 - Component Chart of Turn Time Elements



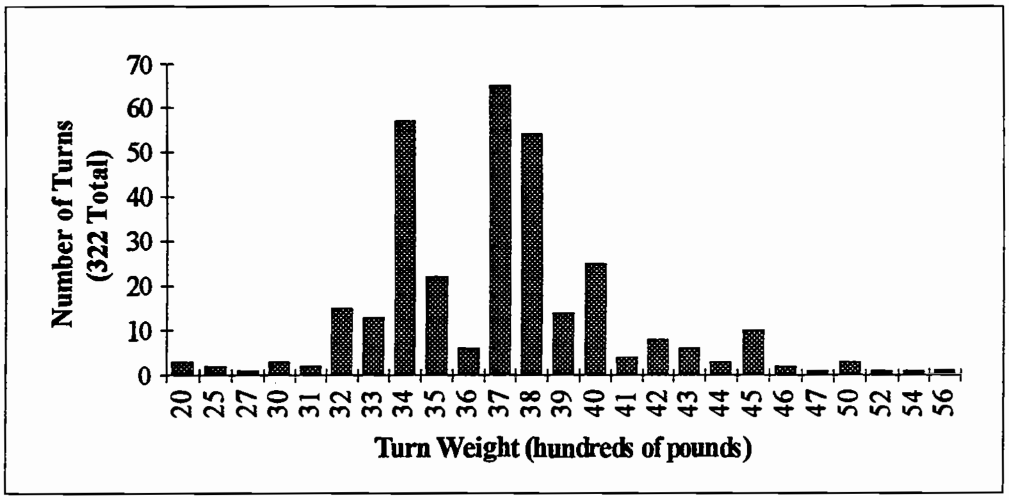
The average number of logs per turn was 4.3, and the turn size varied from 1 log to 10 logs. Figure 4 shows the distribution of turn sizes based on the number of logs per turn.

Figure 4 - Number of Logs per Turn



The weight per turn was obtained by a measuring device on the helicopter. The average weight per turn was 3,701 pounds which was 74 percent of lifting capacity. The turn weights varied from 2,000 pounds to 5,600 pounds. Figure 5 shows the distribution of turn sizes based on weight.

Figure 5 - Distribution of Turn Weights



The average crown closure estimate for the study areas was 56 percent with a minimum of 35 percent and maximum of 66 percent. The average chordslope (measured from the hook point to the landing) was 7 percent. The least chordslope was -9 percent (downslope to the landing) and the maximum was 26 percent (upslope to the landing).

<u>Outhaul Time Regression</u>

Multiple linear regression (stepwise regression process) was used to determine the relationship between chordslope, crown closure, slope yarding distance, choker delivery (a zero/one variable), and outhaul time. Chordslope and crown closure dropped out of the analysis. All remaining variables were significant at the 0.05 level. The equation is as follows:

Outhaul time = 0.323532 + 0.000364 SYD + 0.388252 Chokers

Sample size = 322
R^2 = 0.51

where:
Outhaul time (minutes) = see STUDY METHODS for description
SYD = slope yarding distance in feet (range of 260 to 1300 feet)
Chokers = are chokers delivered during cycle, (1 = yes, 0 = no)

Chokers were delivered to the hooker an average of 2.3 turns out of every 10 turns. In previous studies, choker delivery has been found to be significant in relation to hook time but not outhaul time. The reason for this could be the pilot having to search for the specific hooker in need of chokers. When chokers were not being delivered, the pilot could go to any of the four hookers having a turn ready. Another possible reason could be that chokers were delivered to one location but the next turn of logs was yarded from a different location.

Hook Time Regression

As described in a previous section, total hook time was broken into three separate elements for which detailed data were collected. Regression equations were developed for each of these individually. The three elements of total hook time were descent, hook, and ascent. The time study data was used to determine a relationship between: descent time, chokers, and crown closure; hook time, logs per turn, and crown closure; and ascent time, turn weight, and logs per turn.

Since the regression equations for descent time and hook time explained little of the time variation for these two elements of the yarding cycle (R^2 values were

0.03 and 0.02, respectively), the mean times are presented here. Mean descent time was 0.29 minutes, and mean hook time was 0.28 minutes.

For ascent time, logs per turn dropped out of the analysis. Weight per turn was significant at the 0.05 level. The resulting regression equation for ascent time is shown below:

Ascent time = -0.221537 + 0.000129 Weight

Sample size = 322
$R^2 = 0.24$

where:
Ascent time (minutes) = see STUDY METHODS for description
Weight = weight of turn in pounds (range of 2000 to 5600 pounds)

Inhaul Time Regression

The independent variables used in the regression analysis for inhaul time were weight per turn, number of logs per turn, slope yarding distance, and chordslope. Logs per turn dropped out of the analysis. The other three variables were significant at the 0.05 level. The resulting regression equation for inhaul time is shown below:

Inhaul time = -0.282818 + 0.000144 Weight + 0.000344 SYD + 0.001875 Chordslope

Sample size = 322
$R^2 = 0.39$

where:
Inhaul time (minutes) = see STUDY METHODS for description
Weight = weight of turn in pounds (range of 2000 to 5600 pounds)
SYD = slope yarding distance in feet (range of 260 to 1300 feet)
Chordslope (%) = slope from hook point to landing (range of -9 to 26%)

Unhook Time Regression

The independent variables analyzed in the regression analysis for unhook time were number of logs per turn, weight per turn, and choker delivery. Weight per turn and choker delivery dropped out of the analysis. Although the number of logs per turn was significant at the 0.05 level, the resulting regression equation explained less than three percent of the variation in unhook time and the mean time is presented here. Mean unhook time was 0.11 minutes.

Total Turn Time Regression

The regression model for total turn time is the result of a step-wise regression process which analyzed all six of the independent variables described previously. Percent crown closure and chordslope did not vary with each turn (and varied little by study area) and as anticipated dropped out of the analysis. Each of the variables remaining in the equation were significant at the 0.01 level. The resulting equation for total turn time is shown below:

$$\text{Total time} = 0.082144 + 0.000917\ \text{SYD} + 0.419075\ \text{Chokers} + 0.092694\ \text{Logs} + 0.000241\ \text{Weight}$$

Sample size = 322
$R^2 = 0.47$

where:
Total time (minutes) = see STUDY METHODS for description
SYD = slope yarding distance in feet (range of 260 to 1300 feet)
Chokers = are chokers delivered during cycle, (1= yes, 0 = no)
Logs = number of logs in turn (range of 1 to 10 logs)
Weight = weight of turn in pounds (range of 2000 to 5600 pounds)

The only independent variable significant in any of the elemental regression equations but not significant in the total turn time equation was the chordslope variable. Chordslope was significant in the inhaul time equation at the 0.05 level but not at the 0.01 level.

HELIPACE Computer Program

Statistics

The HELIPACE computer program was used to estimate average turn times for each of the thirteen study areas from the detailed time study. All HELIPACE inputs were based on actual sale data and field measurements. The average turn times computed by HELIPACE and average turn times from the detailed time study are given by yarding distance in Table 7.

Table 7 - Average Turn Time From HELIPACE and Time Study

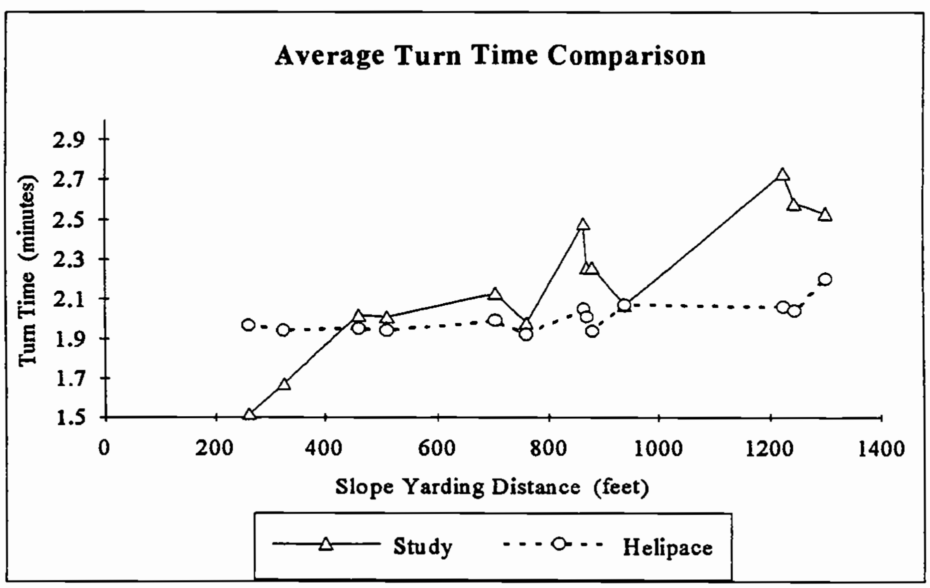
Yard Dist (ft)	Time Study (min/turn)	HELIPACE (min/turn)	Difference (min/turn)	Percent Difference
260	1.52	1.97	0.45	29.6
325	1.67	1.94	0.27	16.2
460	2.02	1.95	-0.07	-3.5
510	2.01	1.94	-0.07	-3.5
705	2.13	1.99	-0.14	-6.6
760	1.98	1.92	-0.06	-3.0
865	2.48	2.05	-0.43	-17.3
870	2.26	2.01	-0.25	-11.1
880	2.26	1.94	-0.32	-14.2
940	2.07	2.07	0.00	0
1225	2.73	2.06	-0.67	-24.5
1245	2.58	2.04	-0.54	-20.9
1300	2.53	2.20	-0.33	-13.0

Comparison of Turn Time (HELIPACE and Time Study)

The average turn time (weighted by area size) calculated by HELIPACE for the thirteen study areas was 1.99 minutes compared to 2.11 minutes for the detailed time study. The average turn time from HELIPACE was 6% less than for the detailed time study. This indicated that actual production based on the time study (28.4 turns per hour or 122.3 logs per hour) was 6% less than that estimated by HELIPACE (30.2 turns per hour or 129.6 logs per hour).

The difference was not significant at a 95% confidence level on the basis of a paired-t test. Results of the paired-t test are listed in Appendix C. The differences between the time study results and the HELIPACE estimates are illustrated in Figure 6. HELIPACE estimates are higher than the time study results at shorter yarding distances but lower than the time study results at longer yarding distances.

Figure 6 - Comparison of Average Turn Time



Cost Evaluation

Ideally, costs would be calculated for the specific helicopter used on the study area, but this was not possible due to the secrecy of the helicopter industry and the S-58T being out of production. Attempts to obtain information needed to determine detailed costs on this ship were unsuccessful. Helicopter hourly costs from HELIPACE were therefore used to estimate yarding costs for this study and then compared to yarding costs estimated from HELIPACE production estimates and cable yarding cost estimates.

HELIPACE uses costs based on information collected from actual helicopter operations on Forest Service sales, and the average costs for the Bell 204 should closely reflect those of the S-58T. HELIPACE costs are updated annually and the costs should reflect adequate estimates for this study. Costs from HELIPACE were used to compute hourly costs for the helicopter system which can be found in Table 8. See Appendix E for a detailed explanation of the cost items displayed in the table. The costs were adjusted to reflect the actual sale conditions (crew size, number of loaders, etc.).

Table 8 - Helicopter System Hourly Costs

Cost Item	Cost/hour*
Aircraft Fixed Cost	$ 528.57
Aircraft Variable Cost	$ 340.00
Support System	$ 180.00
Ground Support	$ 65.71
Loader w/operator**	$ 102.39
Total Hourly Cost***	$1216.67

* all costs are in 1993 dollars

** front-end loader required for yarding operation

*** based on an effective 7 hour day (considered by the industry to be the norm) including delays

The cost of delays is included in the cost estimates from HELIPACE. The costs were obtained by the Forest Service from accounting records of helicopter logging companies and reflect all operation costs, including crew costs incurred when the helicopter is on the ground. For aircraft operations it is common for all costs other than labor to be tied directly to actual flight hours. The costs take into account delays for refueling, travel time, and maintenance. Using costs including delays with production estimates require no reduction in efficiency (effective hour equals 60 minutes).

HELIPACE assumes an effective seven hour day (actual flight hours) based on a ten hour work day. This accounts for delays and all non-flight time and was determined from studies of previous helicopter yarding operations. Since there appeared to be much variation in actual flight hours per day on this sale (based on personal observation), this figure may or may not be reflective of actual conditions for this sale. No gross production data was collected during this study and the effective day was assumed to be seven hours.

Production

Helicopter

The helicopter system yarded an average of 4.71 MBF (net scale) per flight hour. This production was based on the average total turn time calculated by using the average sale conditions in the total time regression equation derived from the detailed time study. The average turn time of 2.18 minutes resulted in 27.52 turns per hour and the average turn was 171 board feet.

HELIPACE

The production rate estimated by HELIPACE was 5.01 MBF (net scale) per flight hour. The five units of the sale were entered separately into HELIPACE and a (volume) weighted average of turns per hour was used to compute estimated hourly production. The average turn time was 2.05 minutes resulting in 29.27 turns per hour. HELIPACE allows the sale planner to adjust the average turn size (weight) to reflect log availability using a load factor ranging from 0 to 100 percent of the maximum target load of the helicopter. The turn size used for the HELIPACE estimates was the same as that determined by the time study (3701 pounds or 171 board feet). This equated to about 93% of the 4000 pound target load for the S-58T.

Cost/MBF Comparison

Yarding Cost

The case study yarding cost for the helicopter system was $258.32 per MBF (based on net scale). The yarding cost estimated by HELIPACE was $242.85 per MBF, about 6% lower than costs estimated from the time study due to the higher production rate estimated by HELIPACE. The estimated yarding cost for a cable system on this sale was $101.08 per MBF. The cable system cost estimate was obtained from a skyline thinning study conducted on the same sale (King, 1994). The cable operation utilized a Thunderbird TMY40 yarder with a mechanical slackpulling carriage, and the logs were loaded with a Thunderbird 838 hydraulic heel boom loader.

Yarding this sale with cable systems would have required additional road improvements and landing construction which were not necessary with helicopter yarding. The additional total cost for the road and landing construction required for the cable system was estimated to be $5000 (Forest Service estimate). This would have resulted in an additional cost of $10.95 per MBF for cable yarding, increasing cable system costs to $112.03 per MBF.

Total Cost

Estimates of total helicopter logging costs for this sale, as well as estimated total costs from HELIPACE and for the cable system, can be found in Table 9. All of the cable costs were obtained from the skyline thinning study on the same sale (King, 1994). HELIPACE yarding costs were obtained from the sale summary report provided by the program. Felling cost estimates were obtained from the concurrent study by King. Daily loading costs from the King study were utilized along with daily production rates for each system to estimate loading costs. The transportation costs for each of the three cost estimates were based on the Forest Service timber sale appraisal for the Wildcat Thin Sale. A representative of the timber purchaser stated that the total helicopter logging costs for this sale were reasonable estimates of costs incurred on this sale but would not provide detailed cost information on the helicopter operation.

Table 9 - Total Logging Cost Summary

Cost Type	Helicopter $/mbf	HELIPACE $/mbf	Cable $/mbf
Felling	$ 51.35	$ 51.35	$ 51.35
Yarding	$ 258.32*	$ 242.85*	$ 101.08
Loading	$ 14.17	$ 14.17	$ 40.85
Transport	$ 30.71	$ 30.71	$ 30.71
Road			$ 10.95
Total Cost	$ 354.55	$ 339.08	$ 234.94

* Includes front end loader required for yarding operation.

Total logging cost for the helicopter operation was $15.47 per MBF more than estimated by HELIPACE. This cost difference was due to the slightly higher (6%) production rate predicted by HELIPACE than determined by the case study. HELIPACE allows for calculation of yarding costs only or stump-to-truck costs which includes felling, yarding, and loading costs. Table 9 shows HELIPACE yarding cost estimates but felling and loading costs were not obtained from the program since most sale planners have access to data more reflective of local conditions.

Total cost for the helicopter operation was $119.61 per MBF more than the estimated total cost for the cable operation. This was much less than the difference in yarding costs ($157.24) due to higher loading costs and additional cost of roads for the cable operation. The higher loading cost was attributed to the much lower production rates for cable systems as compared to helicopter systems. The net production estimate for helicopter yarding was 4.71 MBF per hour compared to 1.65 MBF per hour for the cable yarding system studied by King (1994).

DISCUSSION OF RESULTS

HELIPACE as a Planning Tool

Even though the paired-t test showed no statistical difference in production (number of logs per hour) between the helicopter operation and the HELIPACE estimates, a relatively small difference in daily production could represent a significant amount in terms of estimated logging costs and profit. In the comparison made here, HELIPACE over-estimated production on the thirteen study areas. Actual turn times varied much more than those predicted by the program, but the average turn time differed by only about six percent.

The program also over-estimated production and thus under-estimated yarding costs for the entire sale by about six percent. After adding in felling, loading, and transportation costs, the difference in total logging cost estimates for the case study and HELIPACE were closer (4%). Since all helicopter operations are different and production rates obviously vary due to numerous factors, some differences in production and cost estimates would be expected.

As a sale planning tool for estimating production and costs, HELIPACE should provide adequate projections. In most pre-sale planning situations, the information required to determine precise costs is not available or is at best a "rough" estimate. For pre-sale planning, the HELIPACE program calculations are probably more accurate than the information entered into the program.

The program is commonly used to determine yarding costs for use in Forest Service timber sale appraisals. This is one of the major reasons for development of the program and this study indicates that HELIPACE is probably adequate for this purpose. There are many factors to consider when running the program and knowledge of helicopter operations and sale area conditions are critical. HELIPACE allows yarding time adjustments for varying stand conditions and these cannot be estimated without some knowledge of sale area conditions and helicopter operating characteristics. HELIPACE can be an effective planning and sale appraisal tool when used correctly by knowledgeable users.

Evaluation of Economic Feasibility

As shown previously, estimated total logging costs for this sale were $354.55 per MBF. Pond (delivered to mill) values for small diameter logs at the time of this sale ranged from $625 per MBF for Douglas fir down to $425 per MBF for Sitka spruce (Jeffries, 1994). Taking species mix into account (87.1% Douglas fir, 12.1% western hemlock, and 0.8% Sitka spruce), the weighted average timber value would be $605.25 per MBF. This leaves $250.70 per MBF for stumpage and profit.

The costs for logging this sale were greatly affected by the large percentage of defect (12.97%), which was not anticipated or adequately accounted for during the Forest Service appraisal process. The defect reduced the net board foot production by almost thirteen percent (0.7 MBF/hour) and increased costs by about $40 per MBF.

Based on personal observations by myself, representatives of the Aerial Forest Management Foundation, and Forest Service personnel, the helicopter operation on this sale did not appear to be as productive as the typical helicopter operation. The operator seemed to be somewhat disorganized at times, and as a result production was probably less than what could have been obtained on this sale. During the first several days of operations, there was no loader (for loading trucks) on site and the landings quickly became filled with logs and the yarding operation either ceased for the day or time was lost while moving to a different unit and landing. The apparent disorganization and resulting lower production could possibly be attributed to the relatively new operator (less than one year), the owner being the pilot as well as attempting to run the operation, and the operator's inexperience with thinnings in small, heavy timber (per net board foot).

The cable logging cost estimate of $234.94 per MBF was $119.61 per MBF (about 33.7%) less than the helicopter logging cost estimate. The timber purchaser had bids from cable operators in addition to Scenic River Logging, Inc. According to the purchaser, the bids for helicopter yarding were within 10% of the bids for cable yarding but as stated previously, time constraints influenced the purchaser's decision in selecting Scenic River Logging (through Columbia Helicopters). Cable system production would not allow completion of this sale prior to the end of the designated harvesting season while higher production helicopter yarding could meet the deadline.

While cable logging may have been a cheaper alternative in this instance (with little road improvement required), helicopter logging was feasible considering the high timber values and time constraints. When there are high road construction or improvement costs involved, helicopter logging could often prove to be the most economical method of harvest.

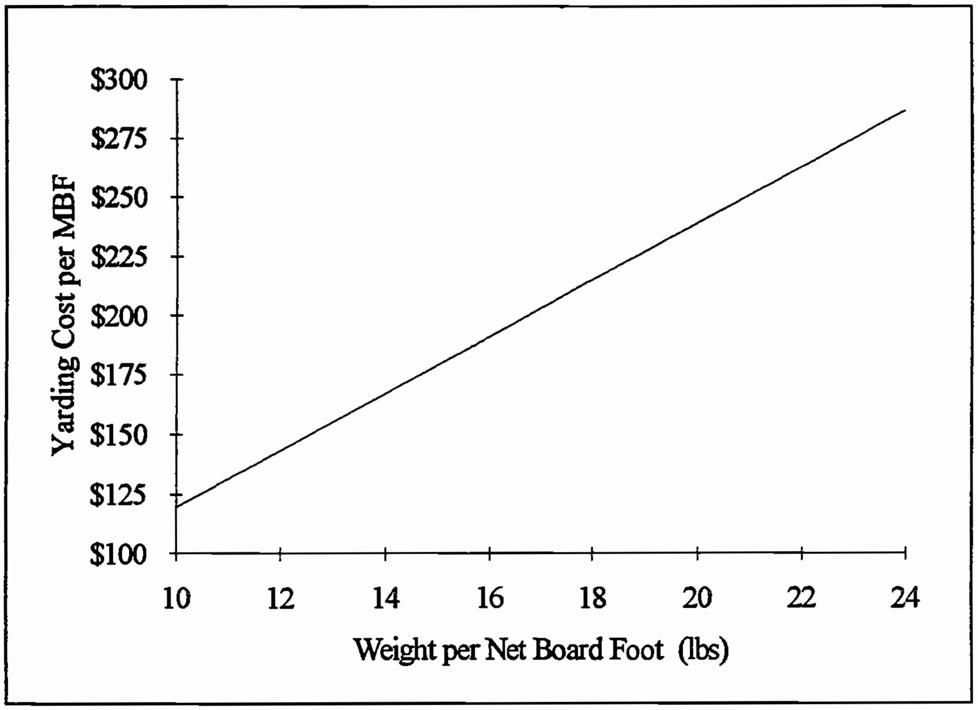
Effect of Weight/BF on Production and Costs

The weight per board foot of the timber being yarded greatly affects the production and cost of helicopter yarding. The weight per net board foot yarded is dependent on several factors, including timber species, location, wood density, season, size of timber, and amount of slash and unmerchantable timber yarded to the landing (Bell and Dilworth, 1988). Poor bucking and yarding of unmerchantable and defect material can reduce or even eliminate profitability of helicopter operations.

The weight per net board foot of timber yarded on this sale was very high (over 20 lbs/BF) due to the large amount of slash yarded, high percentage of defect (13%), and small diameter logs (average small end diameter was 6.4"). See Appendix E for weight calculations. Douglas fir typically weighs between 9 and 16.5 pounds per board foot but this does not consider defect, slash, or unmerchantable material yarded.

Based on the data from this study, Figure 7 shows the effect of weight per board foot on yarding costs.

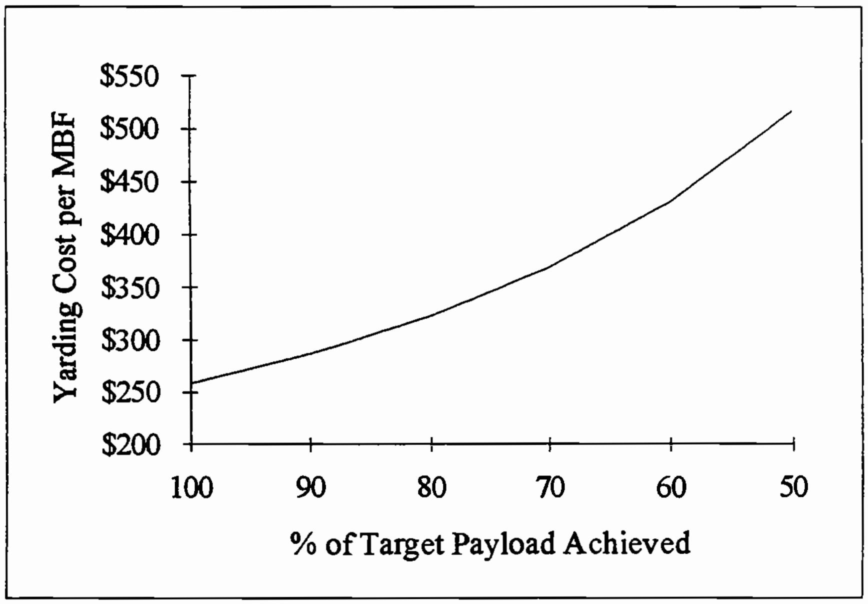
Figure 7 - Effect of Weight/BF on Helicopter Yarding Cost



In situations where the weight per board foot is typically lower, such as in somewhat larger timber or logs containing less defect, the yarding cost would be significantly less due to increased net volume production. As can be seen in Figure 7, with an average weight of 16 pounds per board foot the average yarding cost drops to approximately $191.00 per MBF compared to the sale average of $258.32 per MBF.

In some instances a lower weight per board foot may increase helicopter yarding costs. Very light timber such as dry salvage logs may not weigh enough to allow the helicopter to achieve target payloads and the number of logs in a turn may be the limiting factor. Figure 8 shows the effect of limited payloads on yarding costs in terms of the average percent of target load achieved. The chart was based on the data from this study with the target load (100%) assumed to be the average load achieved (3700 pounds).

Figure 8 - Effect of Percent of Target Payload Achieved on Yarding Cost



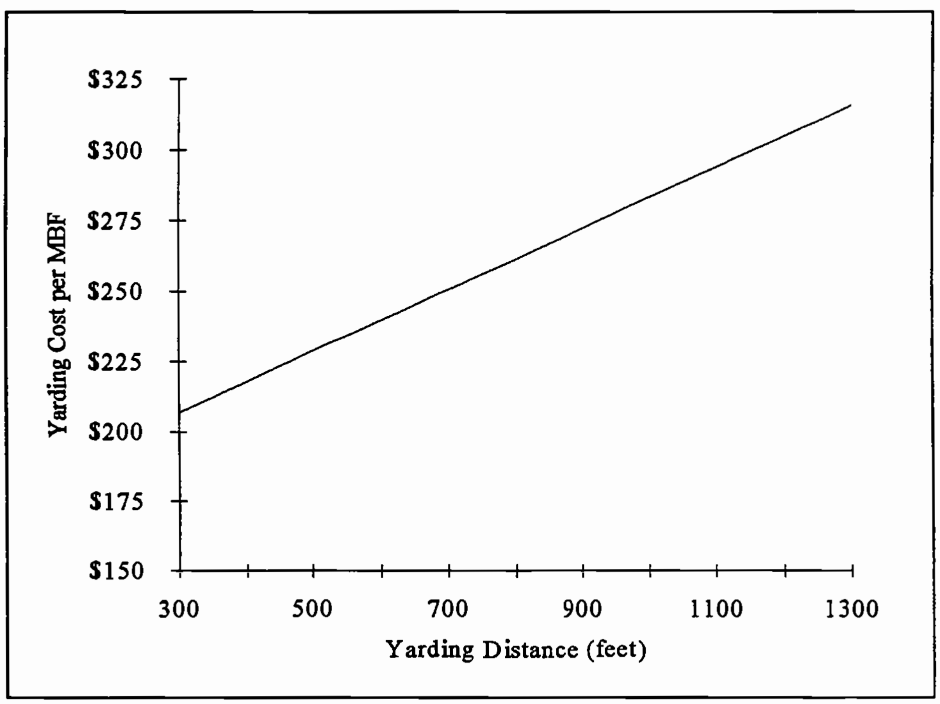
As shown in Figure 8, yarding cost per MBF increases rapidly with even moderate decreases in the percent of average payload achieved (below the target level).

Effect of Yarding Distance on Production and Costs

Due to the short yarding distances (average of 775 feet) encountered on this sale, the effect of yarding distance on total turn time was probably amplified since the helicopter often did not travel far enough to reach normal flight speed. This means that a greater percentage of time was necessary for outhaul and inhaul than in typical helicopter operations with average yarding distances in excess of one quarter mile and often greater than one mile. Roads to each unit were existing and this sale was planned for cable yarding, so yarding distances were very short.

Based on the study data for the range of yarding distances encountered on this sale, the effect of yarding distance on yarding costs is shown in Figure 9. The costs were determined by estimating production based on total turn times calculated at the various yarding distances using the regression equation presented previously. Average values for the independent variables other than yarding distance were inserted in the regression equation for total turn time.

Figure 9 - Effect of Yarding Distance on Yarding Cost



As shown in Figure 9, yarding distance greatly effects production and costs over the range of distances encompassed by this study. The effect of variation in yarding distance would not be expected to be as great at longer average yarding distances due to the helicopter's ability to reach average flight speed. This is properly accounted for in the HELIPACE program which computes outhaul and inhaul times based on average aircraft flight speed.

Road Considerations

With this sale planned for harvesting by cable systems and an adequate road system in place, planning a transportation system for future entries was not an issue. The only additional road improvements planned but not completed were temporary roads for access to cable landings.

Typically, planning for multiple entries would be an important consideration because often the economic and environmental benefits of helicopter yarding are in the form of reduced or no road improvement. A sometimes forgotten cost involved with helicopter yarding is the lack of road access for possible future harvests, but both present and future access needs and costs must be considered when making harvesting decisions.

CONCLUSIONS

The Wildcat Thin Sale created a unique and difficult logging situation for helicopter logging systems. The extremely small diameter timber and high weight to board foot ratio created conditions which resulted in increased yarding costs as compared to larger timber having a more typical (lower) weight to board foot ratio. Average yarding distance was unusually short for helicopter operations due to the existing road system, requiring the use of up to four hookers for most of the sale. Despite these difficulties, the S-58T was able to yard five units of this sale at a reasonable cost which should allow for a profit based on current market values for timber. Since the helicopter operation probably cost somewhat more than a cable system, and the Forest Service based the minimum contract prices on cable system cost estimates, the sale price of this timber was likely higher than the purchaser would have paid knowing yarding would be by helicopter. High production yarding and timely delivery of timber to the mill may have been an added benefit not normally considered in analyses of logging costs.

Even though first thinnings of young timber stands using helicopter systems can apparently be economical when timber values are fairly high as in today's market, there are some important considerations before deciding to thin young timber by helicopter. Small timber will typically weigh more per unit volume than large timber resulting in lower volume production per hour. Defect will increase the weight per net unit volume. Crown closure of the residual stand will likely have some effect on production due to varying levels of visibility interfering with the pilot seeing hookers (not shown by this study but certainly reasonable to anticipate some undetermined effect).

The HELIPACE software program appears to provide adequate yarding production estimates based on a comparison with actual production rates on this sale. Even though there was more variation in production at various yarding distances for this sale than predicted by HELIPACE, the average production for the sale was very similar. Since cost estimates are based on information collected from actual sales for the previous year, HELIPACE should provide reasonable cost estimates when based on reasonable production estimates. Effective use of this program requires users to have knowledge of sale area conditions and experience with helicopter systems in order to provide accurate inputs that reasonably reflect the yarding system, stand conditions, turn size availability, and other factors affecting production.

Possible Future Research

Since this study developed on short notice, there was no opportunity to design the study to adequately investigate the effects of crown closure of the residual stand on helicopter production. The helicopter industry, and also HELIPACE, attempts to make adjustments to production (turn times) when estimating helicopter production and costs for thinnings. HELIPACE assumes little effect below 50% crown closure but increases turn times (and decreases production) sharply between 50% and 100% crown closure.The crown closure in this study averaged just under 56% with little variation for the sale area.

Determining crown closure effects on production would help determine thinning densities required to make helicopter yarding feasible.

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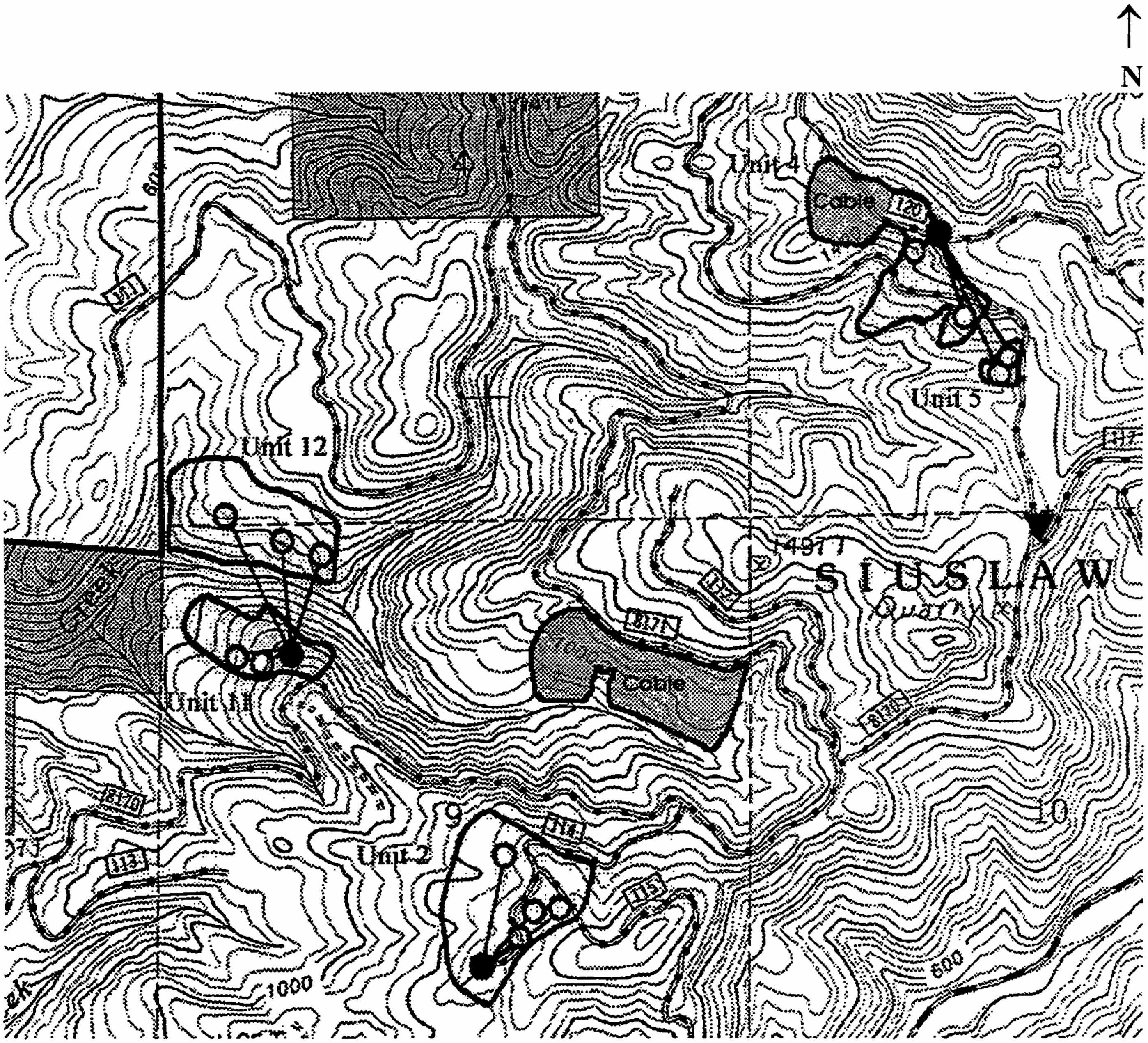
APPENDICES

Appendix A - Sale Area Map with Unit and Study Area Locations

Figure A1 - Sale Area Map with Unit and Study Area Locations



LEGEND

Study Areas ○
Landings ●
Service Landing ▼
Mean Flight Path ○——●

MAP SCALE

1 in. = 1350 feet

Appendix B - Regression Analysis Documentation

The following regression outputs are from the Statgraphics program, a statistical software package used for the stepwise regression analysis in this study. The final model fitting result for each time (dependent) variable is shown. The RESULTS section of this paper identifies which independent variables dropped out of the analysis.

Outhaul Time Regression

Model fitting results for: REGRESS6.OUTHAUL

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	0.323532	0.028101	11.5131	0.0000
REGRESS6.CHKERS	0.388252	0.026705	14.5384	0.0000
REGRESS6.SYD	0.000364	0.000037	9.9622	0.0000

R-SQ. (ADJ.) = 0.5050 SE= 0.201237 MAE= 0.143294 DurbWat= 1.940
Previously: 0.0000 0.000000 0.000000 0.000
322 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Hook Time Regression

Hook time was divided into three elements (descent, hook, and ascent) which were analyzed individually.

Descent

Model fitting results for: REGRESS6.DOWN

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	0.277621	0.008921	31.1182	0.0000
REGRESS6.CHKERS	0.062649	0.01861	3.3664	0.0009

R-SQ. (ADJ.) = 0.0312 SE= 0.140496 MAE= 0.103310 DurbWat= 1.703
Previously: 0.0000 0.000000 0.000000 0.000
322 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Hook

Model fitting results for: REGRESS6.HOOK

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	0.193092	0.027279	7.0784	0.0000
REGRESS6.LOGS	0.019628	0.006094	3.2210	0.0014

R-SQ. (ADJ.) = 0.0284 SE= 0.135681 MAE= 0.091293 DurbWat= 1.788
Previously: 0.0312 0.140496 0.103310 1.703
322 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Ascent

Model fitting results for: REGRESS6.UP

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	-0.221537	0.047263	-4.6874	0.0000
REGRESS6.WEIGHT	0.000129	0.000013	10.1759	0.0000

R-SQ. (ADJ.) = 0.2421 SE= 0.097532 MAE= 0.072983 DurbWat= 1.918
Previously: 0.0284 0.135681 0.091293 1.788
322 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Inhaul Time Regression

Model fitting results for: REGRESS6.INHAUL

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	-0.282818	0.082385	-3.4329	0.0007
REGRESS6.WEIGHT	0.000144	0.000022	6.4707	0.0000
REGRESS6.SYD	0.000344	0.000032	10.7254	0.0000
REGRESS6.CHORDSLOPE	0.001875	0.000879	2.1328	0.0337

R-SQ. (ADJ.) = 0.3920 SE= 0.168792 MAE= 0.118650 DurbWat= 1.590
Previously: 0.2421 0.097532 0.072983 1.918
322 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Unhook Time Regression

Model fitting results for: REGRESS6.UNHOOK

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	0.075184	0.011934	6.2999	0.0000
REGRESS6.LOGS	0.009033	0.002666	3.3884	0.0008

R-SQ. (ADJ.) = 0.0316 SE= 0.059359 MAE= 0.040155 DurbWat= 1.812
Previously: 0.3920 0.168792 0.118650 1.590
322 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Total Turn Time Regression

Model fitting results for: REGRESS6.TOTAL

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	0.082144	0.210806	0.3897	0.6970
REGRESS6.WEIGHT	0.000241	0.000066	3.6630	0.0003
REGRESS6.LOGS	0.092694	0.022456	4.1278	0.0000
REGRESS6.CHKERS	0.419075	0.056964	7.3569	0.0000
REGRESS6.SYD	0.000917	0.000079	11.6280	0.0000

R-SQ. (ADJ.) = 0.4686 SE= 0.428998 MAE= 0.318596 DurbWat= 1.611
Previously: 0.0316 0.059359 0.040155 1.812
322 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Appendix C - Paired-t Test Documentation

The paired-t test analysis was used to test for a difference between actual production based on the detailed time study and estimated production by HELIPACE. The test was run using three different forms of the production data (average turn time, turns per hour, and logs per hour) with no significant difference found at the 95% confidence level. Outputs for all three tests follow Table C1 which shows the data by average turn time, turns per hour, and logs per hour for the detailed time study and the HELIPACE program estimates.

Table C1 - Comparison of Production Data for Study Areas

Avg Yard	Avg Turn Time (minutes)		# Turns per hour		# Logs per hour	
Dist (ft)	Study	HELIPACE	Study	HELIPACE	Study	HELIPACE
260	1.52	1.97	39.47	30.46	169.7	131.0
325	1.67	1.94	35.93	30.93	154.5	133.0
460	2.02	1.95	29.70	30.77	127.7	132.3
510	2.01	1.94	29.85	30.93	128.4	133.0
705	2.13	1.99	28.17	30.15	121.1	129.6
760	1.98	1.92	30.30	31.25	130.3	134.4
865	2.48	2.05	24.19	29.27	104.0	125.9
870	2.26	2.01	26.55	29.85	114.2	128.4
880	2.26	1.94	26.55	30.93	114.2	133.0
940	2.07	2.07	28.99	28.99	124.7	124.7
1225	2.73	2.06	21.98	29.13	94.5	125.3
1245	2.58	2.04	23.26	29.41	100.0	126.5
1300	2.53	2.20	23.72	27.27	102.0	117.3

Paired-t test based on average turn time

One-Sample Analysis Results

		AVGTURN.study-AVGTURN.helipace
Sample Statistics:	Number of Obs.	13
	Average	0.166154
	Variance	0.0957256
	Std. Deviation	0.309396
	Median	0.14
Confidence Interval for Mean:		95 Percent
	Sample 1	-0.0208603 0.353168 12 D.F.
Confidence Interval for Variance:		0 Percent
	Sample 1	
Hypothesis Test for H0:	Mean = 0	Computed t statistic = 1.93628
	vs Alt: NE	Sig. Level = 0.0767392
	at Alpha = 0.05	so do not reject H0.

Paired-t test based on number of turns per hour

One-Sample Analysis Results

		NUMTURNS.studyturns-NUMTURNS.HELIturns
Sample Statistics:	Number of Obs.	13
	Average	-1.59077
	Variance	19.8205
	Std. Deviation	4.45202
	Median	-1.98
Confidence Interval for Mean:		95 Percent
	Sample 1	-4.28179 1.10025 12 D.F.
Confidence Interval for Variance:		0 Percent
	Sample 1	
Hypothesis Test for H0:	Mean = 0	Computed t statistic = -1.28831
	vs Alt: NE	Sig. Level = 0.221923
	at Alpha = 0.05	so do not reject H0.

Paired-t test based on number of logs per hour

One-Sample Analysis Results

	NUMLOGS.studylogs-NUMLOGS.HELIlogs	
Sample Statistics: Number of Obs.	13	
Average	-6.83077	
Variance	365.947	
Std. Deviation	19.1297	
Median	-8.5	
Confidence Interval for Mean:	95 Percent	
Sample 1	-18.3937 4.73221	12 D.F.
Confidence Interval for Variance:	0 Percent	
Sample 1		
Hypothesis Test for H0: Mean = 0	Computed t statistic = -1.28745	
vs Alt: NE	Sig. Level = 0.222213	
at Alpha = 0.05	so do not reject H0.	

Appendix D - HELIPACE Sale Summary

The HELIPACE sale summary for this sale is shown on the following page. HELIPACE gives the option of computing yarding costs only or yarding with felling and loading included. Since the concurrent study by King (1994) on the same sale provided felling and loading cost estimates more reflective of sale conditions, only yarding costs estimates were determined with the program. The results for the Bell 204 were computed directly by HELIPACE. The results for the S-58T were derived by adjusting the HELIPACE estimates to reflect the higher payload of the S-58T. The average turn on this sale averaged 3,700 pounds compared to the target payload of 3,444 for the Bell 204. The increased payload resulted in less yarding time and lower costs, assuming that the costs per hour are the same for both helicopters. The Aerial Forest Management Foundation estimated that the costs were very similar for the two ships. All attempts to obtain pertinent data to determine accurate costs for the S-58T were unsuccessful.

Table D1 - HELIPACE Sale Summary

Summary for Sale: Wildcat Thin

Unit	Acres	Landing	AYD	Net MBF/Day		Work Days		Net MBF	Net Cost/MBF		Mean Load (pounds)	
				B204	S-58T*	B204	S-58T*		B204	S-58T*	B204	S-58T*
11	11	1	450	32.9	35.8	2.0	1.9	67.0	237	218	3402	3657
12	20	1	1100	33.4	36.0	3.6	3.4	121.8	234	217	3562	3829
2	26	2	800	32.7	35.1	4.8	4.5	158.3	240	222	3441	3699
4	16	3	500	31.8	34.2	3.1	2.8	97.4	245	228	3334	3584
5	2	3	1260	30.7	33.0	0.4	0.4	12.2	254	236	3426	3683
Count	Total		Mean	Mean	Mean	Total	Total	Total	Mean	Mean	Mean	Mean
5	75		775	32.7	35.1	13.9	13.0	456.8	240	222	3444	3701

Cost Recapitulation

	---Extended Cost---		---Cost/Net MBF---	
	Bell204	S-58T*	Bell204	S-58T*
Yarding**	109462.98	101597.42	239.63	222.41
Falling***				
Loading***				
Special Costs				
TOTAL	109462.98	101597.42	239.63	222.41

* S-58T values were calculated from HELIPACE estimates for Bell 204 based on payload difference (3701 lbs for S-58T during this sale compared to HELIPACE target load of 3444 lbs for Bell 204).

** Does not include front-end loader required for yarding system (additional $20.44 per MBF).

*** Option of computing felling and loading cost estimates not utilized.

Appendix E - Helicopter Production and Cost Estimates

Sale Volume Summary

Table E1 summarizes the volumes removed from the Wildcat Thin Sale by helicopter yarding. The scale records were furnished by the purchaser and scaling was by a third party (scaling bureau). Net volume was 87.03% of gross volume resulting in a much higher defect than the 2% anticipated by the Forest Service cruise.

Table E1 - Summary of Scale Records

Species	# of Logs	Gross Volume (MBF)	Net Volume (MBF)
Douglas fir	10060	455.78	397.88
Hemlock	1301	64.43	55.24
Sitka spruce	161	4.69	3.71
TOTALS	11522	524.90	456.83

Determination of Average MBF/Log and Weight/BF

The average MBF per log and weight per board foot were needed to estimate production with the total turn time equation. Since the sale area was homogenous in terms of size and age of timber, the average log size calculated from the scale records was used. The time study data indicated an average turn size of 4.3 logs and weight of 3,701 pounds. With this information, the average gross volume per log was calculated to be 45.56 board feet (net volume was 39.65 BF/log). The estimate of weight per gross board foot was 18.89 pounds (per net BF was 21.64 lbs.). These weights are somewhat high based on most literature (Douglas fir up to 16.5 lbs/BF), but studies normally have not considered the effect of very small timber, large amounts of defect, and the often large amount of logging slash and unmerchantable material yarded. Some individual truckloads from this sale were weighed and resulted in weights as high as 20.50 lbs per gross board foot so the estimate of 18.89 pounds for this sale was reasonable. Calculations of MBF/log and weight/BF are as follows:

From scale records:

Total logs = 11522

Gross scale = 524.90 MBF

Net scale = 456.83 MBF

Average BF/log = 524.90/11522 = 45.56 BF (Gross)

Average BF/log = 456.83/11522 = 39.65 BF (Net)

From detailed time study:

Average turn weight = 3701 pounds

Average logs per turn = 4.30

Gross BF per turn = 4.3 logs per turn * 45.56 BF per log = 196 BF

Weight per gross BF = 3701 lbs per turn / 196 BF per turn = 18.89 lbs

Net BF per turn = 4.3 logs per turn * 39.65 BF per log = 171 BF

Weight per net BF = 3701 lbs per turn / 171 BF per log = 21.64 lbs

<u>Average turn time calculation</u>

The average turn time for the sale units yarded by helicopter was necessary for determining production and cost estimates. The total turn time regression equation developed from the detailed time study was used to estimate an average turn time for the sale, which was the basis for determining an estimate of production. The average yarding distance for the sale and the average number of logs and weight per turn from the detailed time study were used in the equation to represent average conditions encountered on this sale for the independent variables slope yarding distance, number of logs, and weight per turn. The other independent variable (choker delivery) was represented by the value of the percentage of turns for which chokers were delivered to the hook point during outhaul (0.23 or 23% of turns). Since the study areas reflected the overall homogenous sale conditions, the regression equation for total turn time should provide an adequate estimate of average turn time for the sale. The calculation was as follows:

$$\text{Total turn time} = 0.082144 + 0.000917\ \text{SYD} + 0.419075\ \text{Chokers} + 0.092694\ \text{Logs} + 0.000241\ \text{Weight}$$

$$\text{Total turn time} = 0.082144 + 0.000917\ (775) + 0.419075\ (0.23) + 0.092694\ (4.3) + 0.000241\ (3701)$$

$$\text{Total turn time} = 2.18\ \text{minutes}$$

Production estimates

Based on the average turn time and net board feet per turn and effective hour of 60 minutes (7 hours of actual flight time per 10 hour work day), hourly production was calculated for the sale:

60 minutes per hour / 2.18 minutes = 27.52 turns per hour

27.52 turns per hour * 171 BF per turn = 4.71 MBF per hour

Yarding Cost Estimates

Yarding costs were based on production (4.71 MBF per hour) and estimated hourly helicopter costs from the HELIPACE program. HELIPACE is updated annually with current helicopter cost data from Forest Service sales and these costs were used since adequate cost information could not be obtained from the helicopter industry to calculate detailed costs.

HELIPACE costs are presented by four cost groups directly related to the helicopter and a cost for loaders. These cost categories are defined as follows:

Aircraft fixed costs - costs attributable to having a helicopter at the site and which do not vary by number of hours flown each day. Includes depreciation, insurance, mechanics, pilot and co-pilot labor and costs (excluding flight pay), and overhead.

Aircraft variable costs - costs directly attributable to flying the helicopter which vary in direct proportion to flight time. Includes fuel and oil, pilot flight time, maintenance reserves, and parts and supplies.

Ground support costs - cost of all support equipment and supplies excluding labor. Includes auto and truck expense, depreciation on support equipment (except loaders), saws, chokers, misc. expenses such as communications.

Support system cost - cost of sawyers, rigging and landing crew, and ripping.

Loader costs - costs of loaders with operators is included with support costs in HELIPACE but separated on the sale summary printout provided by HELIPACE (as is felling cost). For this study, cost of the loader required for yarding was included in the hourly cost of the helicopter system and the cost for the loader used for loading trucks can be found below under sale loading cost estimates.

The yarding cost per MBF was determined using the hourly helicopter costs from HELIPACE ($1216.67) and the hourly production rate as follows:

$1216.67 per hour / 4.71 MBF per hour = $258.32 per MBF

Sale Felling Cost Estimates

The felling cost estimate ($51.35) was taken from the gross production study by King (1994) for the cable system operation on this same sale. The area harvested with the cable system was basically identical to the area yarded by helicopter so felling costs should be very similar.

Sale Loading Cost Estimates

Loading cost estimates were based on the daily cost of the loader utilized in the King (1994) study with adjustment for the average net MBF loaded per day during the helicopter operation. Daily costs for the loader (excluding labor) were $467.20. The loader was operated by the truck drivers hauling the timber so no labor cost was included since this labor was included in the transportation cost. The sale average was 32.97 MBF being loaded daily. The estimated loading cost per MBF for the sale was:

$467.20 / 32.97 MBF = $14.17 per MBF

Sale Transportation Cost Estimates

Hauling costs were estimated from the Forest Service timber sale appraisal and were adjusted based on the actual net volume removed. The appraisal assumed no defect when in reality there was a large amount (12.97%). The haul cost was increased proportionally to reflect the reduction in net volume hauled per load since the cost per MBF was directly related to volume per load by the appraisal formula. The original appraisal estimate was $26.73 per MBF, but due to the defect, cost was estimated to be $30.71 per MBF based on the actual volume removed (Jeffries, 1994).