AN ABSTRACT OF THE THESIS OF

John Charles Balcom for the degree of Master of Science in Forest Engineering presented on April 28, 1983. Title: COMPARISON OF SKYLINE CARRIAGES FOR SMALLWOOD HARVESTING.

Abstract approved: ______________________

Eldon D. Olsen

Three skyline carriage types are analyzed on the basis of their operating characteristics and limitations. Their effect on productivity is expressed as cubic feet per hour yarded to the landing. These carriage types, tested as part of Oregon State University's School of Forestry Smallwood Harvesting Research Program represent those which are especially suited to thinning smallwood stands. The three types are distinguished by their clamping mechanisms: 1) skyline stop 2) self-clamping hydraulic and 3) self-clamping mechanical. The clamping mechanism is the means by which the carriage is secured to the skyline during the lateral inhaul element of the yarding cycle. Since data from the individual studies are not all comprehensive, five carriage studies are used for the analysis of the three carriage types. The Maki and Christy carriages represent the skyline stop carriages. The Koller 1.0 and 2.5 carriages represent the self-clamping hydraulic carriages and the Wyssen 2.5 represents the self-clamping - mechanical carriages.

The operating characteristics which proved to be most important are the ability to throw slack in the mainline, adaptability for use with sliding chokers, spotting ability and carriage delays. The skyline stop carriages tend to throw slack in the mainline when they hit the skyline stop at the end of outhaul (which aids in the lateral outhaul of the mainline). The Koller

carriages, representing the self-clamping hydraulic carriages, cannot be used with sliding chokers without modification, since the load hook is part of the release mechanism. This effect, along with the effect of throwing slack, was not quantified. The Wyssen carriage was observed as having a greater capacity to be spotted at an exact location on the skyline for the lateral yarding sequence than any of the other carriages. This resulted in a lead angle standard deviation of only 17.7 degrees. A similar standard deviation of 16 degrees was observed for the Koller 1.0. The Christy carriage resulted in a larger standard deviation of 24 degrees. Lead angle data was not available for the Maki and Koller 2.5 carriages. The importance of spotting is that either the logs can be yarded laterally to lead or the best extraction path can be choosen for a turn. Both of these advantages serve to reduce resets and minimize stand damage.

Carriage delay analysis indicated very little difference between the time required to move the skyline stop calculated on a per turn basis and the time required for the self-clamping carriages to cycle every turn. With operational delays added in, the carriage delays for the skyline stop carriages is 0.2678 minutes per turn and for the self-clamp mechanical is 0.2625 minutes per turn. This information was not available for the self-clamping hydraulic carriages, but is probably greater than the self-clamping mechanical type and may be greater than the skyline stop type.

The three carriage types were compared on a productivity basis. No conclusive differences were found since factors not accounted for in the individual studies tended to mask the affects of the different carriage types. The differences in productivity due to carriage types appear to be small in comparison to such factors as crew selection, stand conditions and site conditions.

Comparison of Skyline Carriages for Smallwood Harvesting

by

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Special recognition is due four people, not mentioned in the thesis, yet who made major contributions in its behalf. Loren Kollog, for soliciting the use of the Wyssen 2.5 Automatic carriage and eventually its donation to the Oregon State University School of Forestry. Jacob Wyssen, for traveling from his home in Switzerland in order to instruct us about the use of the carriage and to the Wyssen family for their generous involvment in this research project. Nathan Putman, for sharing with me, the arduous task of data collection. Eldon Olsen, for the many hours spent reviewing and revising the thesis and for the sound advice, "Don't expcet to write the final draft the first time around."

DISCLAIMER

The names Maki, Christy, Koller 1.0, Koller 2.5 and Wyssen 2.5, used throughout the text of this thesis, are name brands of skyline carriages. All five were selected as representative of a skyline carriage type. For the sake of clarity, the carriages were referred to by their names instead of the skyline type they represented. The results contained herein do not take into account the unique characteristics of the brand of carriage provided it is not a characteristic unique to the carriage type it represents. As a result, comparisons presented represent carriage types, not carriage brands.

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I. INTRODUCTION

Since the summer of 1972, Oregon State University's School of Forestry has been involved in the development and testing of methods for harvesting timber of small diameter. The research has taken the name "Smallwood Harvesting Research." Concentration has been on commercial thinnings in Douglas-fir stands with average DBH (diameter breast high) less than 20 inches or less than 100 board feet per log.

The smallwood harvesting research, which began with a comparison of ground skidding verses skyline yarding, has since addressed itself to such other concerns as; 1) Prebunching verses full-cycle yarding 2) Gravity (shotgun) outhaul of carriages verses haulback assisted outhaul 3) Effect of felling pattern 4) Effect of presetting chokers and 5) Effect of "swinging" from the landing. In all of these research areas, time study analysis was used to quantify the relationships between those characteristics unique to that project and the production rate or cost effectiveness of that yarding system.

As a result of these studies, and partly by design, eight different skyline carriages have been used. In five of the studies, observations were made to qualify the modes of operation and to quantify the effect of the carriage on the productivity of the skyline system being tested. Three types of carriages, classified according to their skyline clamping mechanism, were represented within those five studies. These initial observations indicated that the type of carriage may affect the productivity of the system. Therefore, further study is warranted to distinguish those affects.

Certainly, one way of studying the effects of the three different carriages types would be to run a full scale test in which the same stand is yarded three different times under exactly the same conditions varying only the skyline carriage. Such a scheme, though certainly providing excellent data, would be very costly since a large number of turns must be yarded in order to provide statistical validity to the findings.

Another scheme would be to utilize the existing research. If the five research projects mentioned as involving observations of the three carriage types could be used in the analysis, considerable savings of time and money could be realized. The limitation of this scheme however, is that all five projects were not carried out in the same stands or under exactly the same conditions. As a result, differences in productivity are not necessarily attributable to the skyline carriage.

The third option is to use the previous research to compare those fuctions which the individual studies were able to quantify such as cycle times and delays, and look for observations or descriptions of functions which are unique to that carriage type and appear to affect the productivity of the carriage. In addition, the raw data from each study could be incorporated into a computer analysis scheme in which simulation is used to create a stand and yard it three times under exactly the same conditions, varying only the carriage. This would essentially simulate the first option mentioned. The intent of this paper is to present such a comparison using this third option.

The paper is divided into three sections. The first section contains original testing and analysis of the Wyssen 2.5 multispan skyline carriage. This section provides the comparison data for the third carriage type, represented by the Wyssen, in addition to familiarizing the author and the reader with the productivity analysis of skyline carriages. The second section compares the carriages on the basis of their design and operating characteristics. Design characteristics are such things as size and weight.

Operating characteristics are those functions or characteristics of the carriage observed during rigging and yarding which are either unique to that carriage type or appear to affect the productivity of the skyline system and can be measured directly. In the event that one study contains information that another study of the same carriage type does not contain, both studies will be considered. In the third section, the results of simulation will be used to compare productivity of the three carriage types on a cubic feet per hour basis. Simulation will also be used to test the sensitivity of the different carriage types to those conditions which most strongly influence productivity (i.e. slope and lateral yarding distances).

II. JUSTIFICATION

Two problems serve to justify the analysis of skyline carriages used in smallwood harvesting. The first is the required use of skyline systems in the harvesting of smallwood on steep terrain, and the second is the general decrease in timber size, both of which serve to reduce the profit margin associated with smallwood harvesting.

Smallwood is typically removed either in commercial thinning operations where a skyline system with lateral yarding capability is necessary to minimize site and stand damage or from second growth stands on steep slopes, inaccessible to tractors. The problem is that production costs associated with skyline yarding are higher than those associated with tractor yarding. In a study conducted by Aulerich, et. al. (1975), skyline logging costs were 1.5 to 1.6 times those for tractor logging.

The second problem arises from the general decrease in timber size. In speaking of the decline of timber size in western Oregon between the years of 1975 and 2075, Tedder (1979) states that "the average diameter of trees for all western owner groups will fall from 23 to 14 inches." With the decrease in timber size, the cost of production increases on a per volume basis and in general, the stumpage value decreases. This is a very important point in the justification and is best served by a brief explanation.

The reason for the increase in production costs is the increased cost per volume of handling smaller logs. In the yarding sequence, the time required for outhaul and inhaul of the skyline carriage is dependent on yarder line speeds and the yarding system used, and is relatively independent of the size of the load being yarded. If a system with large payload capacity is being used, the efficiency of the system is greatest when the turn (load of logs being yarded) approaches the payload of the system. If a turn which is much smaller than the payload is yarded to the landing, the same amount of time is spent on outhaul and inhaul of the carriage, but the volume of the turn is small, therefore efficiency is reduced. In order to increase efficiency, the size of the turn would need to be increased. With small logs, this requires extra time to "build" a turn of adequate size, since the number of logs per turn is increased. Once again, the efficiency of the system is reduced as a result of the extra time required to build the turn, guide the turn to the corridor during lateral inhaul and unhook the logs at the landing. The solution to this dilemma seems to be found either in matching the payload capacity of the system being used to the size of the timber being removed, thereby optimizing its efficiency with fewer logs per turn, or decreasing the amount of time spent building a turn of many small logs, yarding them laterally to the corridor and unhooking them at the landing.

These two potential solutions are precisely those which formed the basis for the smallwood harvesting research of Oregon State University's School of Forestry, as will be presented in the literature review section of this paper. The analysis and comparison of skyline carriages is part of this continuing overall investigation.

III. LITERATURE REVIEW

If production costs associated with smallwood harvesting with skyline systems are to be reduced, system efficiency must be optimized, and lateral yarding time must be reduced. Early research at Oregon State University supports this assumption.

In 1974, Aulerich, et. al. published a paper entitled "Tractors or Skylines: What's Best for Young-Growth Douglas Fir." The study was the starting point for the O.S.U. School of Forestry Smallwood Harvesting Research. The study compared a skyline logging system with tractor logging. Results indicated that: 1) The skyline system was more productive than the tractor skidder on steep slopes and less productive on flatter slopes. 2) Skyline yarding costs were 1.55 to 1.66 times higher than tractor yarding. And 3) Lateral yarding with the skyline system was time consuming, accounting for 46 percent of total skyline time. As a result of these conclusions, further research at O.S.U. would address either the development of efficient skyline systems or reduction of the lateral yarding sequence.

Significant work in the development of efficient skyline systems was done in 1978 by Krammer. In Krammer's study, gravity outhaul of the skyline carriage proved to increase the overall system efficiency by 35.5 percent over haulback assisted outhaul. An additional advantage of using a gravity outhaul (shotgun) configuration is that highlead equipment can be modified for use with this system. Whether highlead equipment is modified for use with gravity outhaul or a two drum skyline yarding system is used, these systems meet the requirement for maximizing efficiency, in that they have relatively small payloads with high line speeds. Efficiency is maximized because system payloads can be met with a turn of only a few logs. These systems also tend to have smaller operating and fixed costs associated with them than systems incorporating larger yarders.

Research into the reduction of the lateral yarding time was started by Kellog (1977), in which he used a motorized winch to prebunch logs in the corridor, thereby reducing the amount of skyline time used in the lateral yarding cycle. The prebunched logs were then yarded to the landing using a conventional skyline system. The result was a lower yarding costs per MBF. The portable winch did however appear to be less effective on steep slopes and production of the winch was low enough so as to create difficulty in scheduling the conventional yarder. Keller (1980) analyzed an alternative method in which logs were prebunched using a small yarder at the landing and swinging with a larger machine. Keller concluded that full-cycle yarding with the larger yarder was less costly than prebunching and swinging with two yarders. The reason for the greater cost of the prebunching appeared to be the cost of rigging and unrigging two skyline systems. The potential exists for using the same rigging for both systems, changing only the yarder, but this has not been tested. Both of these studies dealt with reducing the lateral yarding time of a large skyline system.

Another possible means of reducing the lateral yarding time is using haulback assisted slackpulling to reduce the lateral outhaul time. Keller's study (1980) also compared manual slackpulling with haulback assisted slackpulling with the result that no significant difference existed between the two slackpulling techniques.

Another method of reducing lateral yarding time was also tested. Gabrialli (1980) found that flying six chokers was 13 percent faster than flying three. He also found no difference between using ring and toggle chokers and sliding chokers. The ring and toggle had the advantage that the chokers can be preset, but this did not increase production.

The conclusion of these studies is that for the logging conditions studied, a skyline yarding system with gravity outhaul, manual slackpulling and full-cycle yarding with a two drum or small three drum yarder is best suited for thinning small diameter Douglas-fir. With this system, however, the skyline carriage must somehow be secured to the skyline during lateral yarding. If the carriage is not secured to the skyline, the resolution of forces on the carriage during the lateral yarding sequence would move the carriage up the skyline, toward the yarder, and out of position for lateral yarding.

As mentioned in the introduction, the methods by which the carriage is secured to the skyline (skyline clamping mechanism) distinguishes the three types of carriages being compared in this paper. Although other clamping mechanisms exist, the following three show the greates potential for use in small-wood harvesting.

The first type of carriages, are those secured to the skyline by what is called a carriage stop. A carriage stop is any device secured to the skyline but which can be easily moved up or down the skyline by lowering the skyline, loosening the stop, repositioning it, and resecuring it to the skyline. When the carriage strikes the stop during outhaul, the carriage is coupled to the stop via a coupling mechanism. The mainline is then free to move through the carriage during the lateral yarding sequence without moving the carriage up the skyline. The coupling release is triggered when the load hook enters the carriage. The carriage is then free to move up the skyline with the load attached. This carriage type, represented by the Maki carriage, was studied in conjunction with a Schield-Bantam T 350 yarder by Aulerich (1975). A regression equation was developed to predict yarding cycle time based on such variables as number of logs per turn and slope distance. The study indicated that on the average, 0.34 minutes per turn was spent moving the carriage stop. Also of interest was the tendency of the carriage to "throw slack" when it was stopped suddenly by the carriage stop. This proved to be advantageous since less work was required of the choker setters in pulling the mainline laterally to the turn. The Christy carriage, also representing this carriage type, will be considered along with the Maki in this paper. The yarding conditions in the Christy study, Kellog (1980) more closely match those of the studies involving the other carriage types. In addition, the Christy study provides information on lead angles, not accounted for in the Maki study.

The Koller SKA 2.5, studied by Aulerich in 1976, represents the second type of carriage - those which are secured to the skyline by a set of skyline clamps. Skyline clamps are metal "shoes", sized to fit the skyline, which are fixed to the carriage. The clamps secure the carriage to the skyline by locking on to the skyline in opposing directions, with the skyline between them. The frictional resistance created between the clamps and the skyline is sufficient to keep the carriage from sliding up the skyline during the lateral yarding sequence. The normal force on the clamps is provided through hydraulic pressure. The clamps are triggered to lock onto the skyline by a directional change sequence, and triggered to release the skyline when the load hook enters the carriage. The study by Aulerich (1976) indicated a number of delays in production which were uniquely attributable to this type of carriage. A study by Lucas (1983), involving the Koller SKA 1.0, a similar but smaller carriage, provides additional data on lead angles and delays associated with this second carriage type.

The third type of clamping mechanism is the hydraulically activated mechanical skyline clamp. This carriage type uses hydraulics only as part of a timing mechanism which activates the mechanical clamping device. The clamps are similar in operation to those of the self-clamping hydraulic carriage type, with the exception that the normal force on the clamps is supplied through mechanical means instead of hydraulics. Although this carriage appears to be very similar to the second carriage type, the increased control and reduced cycling time show promise of affecting delay time, lead angle and productivity. This third type of carriage is represented by the Wyssen 2.5 multispan carriage. The Wyssen carriage was studied by Hensel, et. al. (1979) in conjunction with the Wyssen W-90 Yarder rigged in the standard Wyssen configuration where the logs were yarded downhill with the Wyssen yarder at the top of the skyline road. Comparisons of productivity and logging costs were made between the Wyssen system, the Idaho Jammer, a live skyline and a running skyline. Although this study presented useful observations of the Wyssen system and indicated that the cost per MBF of this system is comparable to that of the other systems, no observations were recorded as to the function of the carriage itself. To be of greatest use in carriage analysis, a separate study must be conducted in which the Wyssen carriage is used under conditions similar to those in the other carriage studies with particular attention directed toward observing and recording cycles times, operational delays, lead angles and general operating characteristics. Such a study was conducted by this author, the analysis of which is presented in the following sections of this paper.

IV. OBJECTIVES

The objectives can be summarized as follows:

1. Perform production study on the Wyssen 2.5 multispan carriage in order to develop regression equations which predict cycle time based on such variables as slope distance and number of logs per turn.

2. Compare the design and operating characteristics of the three carriage types based on previous field studies.

3. Compare the productivity (cu. ft. per hour) of the three carriage types using the existing simulation model THIN.

V. PRODUCTION ANALYSIS OF THE WYSSEN 2.5 MULTISPAN SKYLINE CARRIAGE

In the summer of 1981 Oregon State University's School of Forestry undertook the production analysis of the Wyssen 2.5 multispan skyline carriage as part of the summer's smallwood harvesting research. The description of the study along with the analysis and conclusions are presented in this section of the paper and in part, in the appendices.

A. Area and Stand Description

The area chosen for the study is located on Oregon State University's Paul Dunn Forest section 15, T. 10S., R. 5W., Willamette Meridian, Benton County, Oregon (figure 1.). The stand consists mostly of 32 to 40 year old Douglas-fir (Pseudotsuga menziesii (Harlow, et. al.)) with a minor component of Bigleaf Maple (Acer macrophyllum (Harlow, et. al.)), Grand Fir (Abies grandis (Harlow, et. al.)) and Madrone (Arbutus menziesii (Harlow, et. al)) present. Mean stand volume is 3211 cubic feet per acre of which 82 percent is Douglas-fir, 9 percent is maple and 9 percent is Grand Fir and Madrone. The mean diameter of the Douglas-fir is 12.7 inches with about 185 trees per acre.

The area is laid out along the 210 road and accesses a continuous 21.5 acres along the east side of the road with an east northeast aspect. The upper boundary is the 210 road and the small drainage at the bottom of the slope is the lower boundary. The slope throughout the area is generally concave with the first 400 feet at 15 to 20 percent slope and 20 to 40 percent beyond.

B. Unit Layout and Assignment

The 5 corridors, shown within the unit boundary in Figure 1, were approximately 190 feet wide and 900 feet long. Dimensions similar to those used in previous smallwood harvesting studies were sought for the sake of comparison. Each thinning unit was laid out with the skyline corridor running the length of the unit, with the landing at the 210 road and the tailtree at the down hill boundary. Three of the five tailtrees were located just up the opposing slope to gain deflection, but with the exception of only a few logs, none of the land beyond the drainage was logged. A description of the skyline payload analysis as well as an example of a typical profile are given in appendix A under "Skyline Payload Analysis."

C. Harvesting

The timber fallers were instructed to remove 40 to 50 percent of the merchantable stems (about a 12 by 12 foot spacing). The objective was to thin the canopy leaving only the healthy, dominant, merchantable species with their crowns open. The fallers were instructed to fall the trees in a herringbone pattern at a 45 degree lead to the direction of the skyline corridor and with the tops falling away from the corridor (figure 2). Those stems which were hung-up were to be flagged and left with as much of the stem severed at the stump as possible. Those stems successfully brought down were limbed and bucked to mill requirements.

These conditions (timber stand, corridor length and width, ground slope and harvesting method), serve to match as closely as possible, those conditions found in other carriage studies. The purpose of matching the conditions is to reduce the source of differences when comparing the productivity of different carriages by normalizing the yarding parameters, and to insure

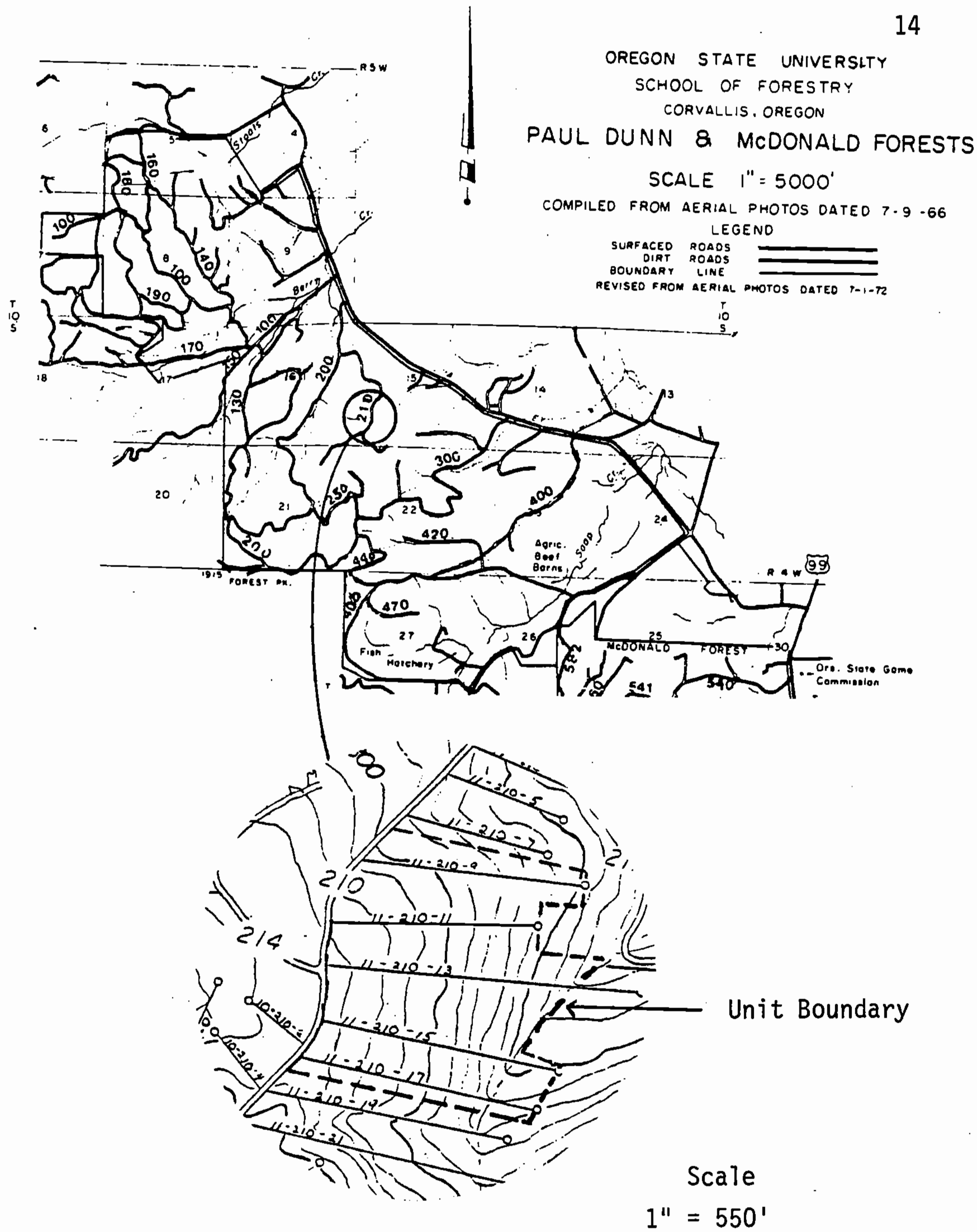


Figure 1. Location of Study Area and Unit Layout

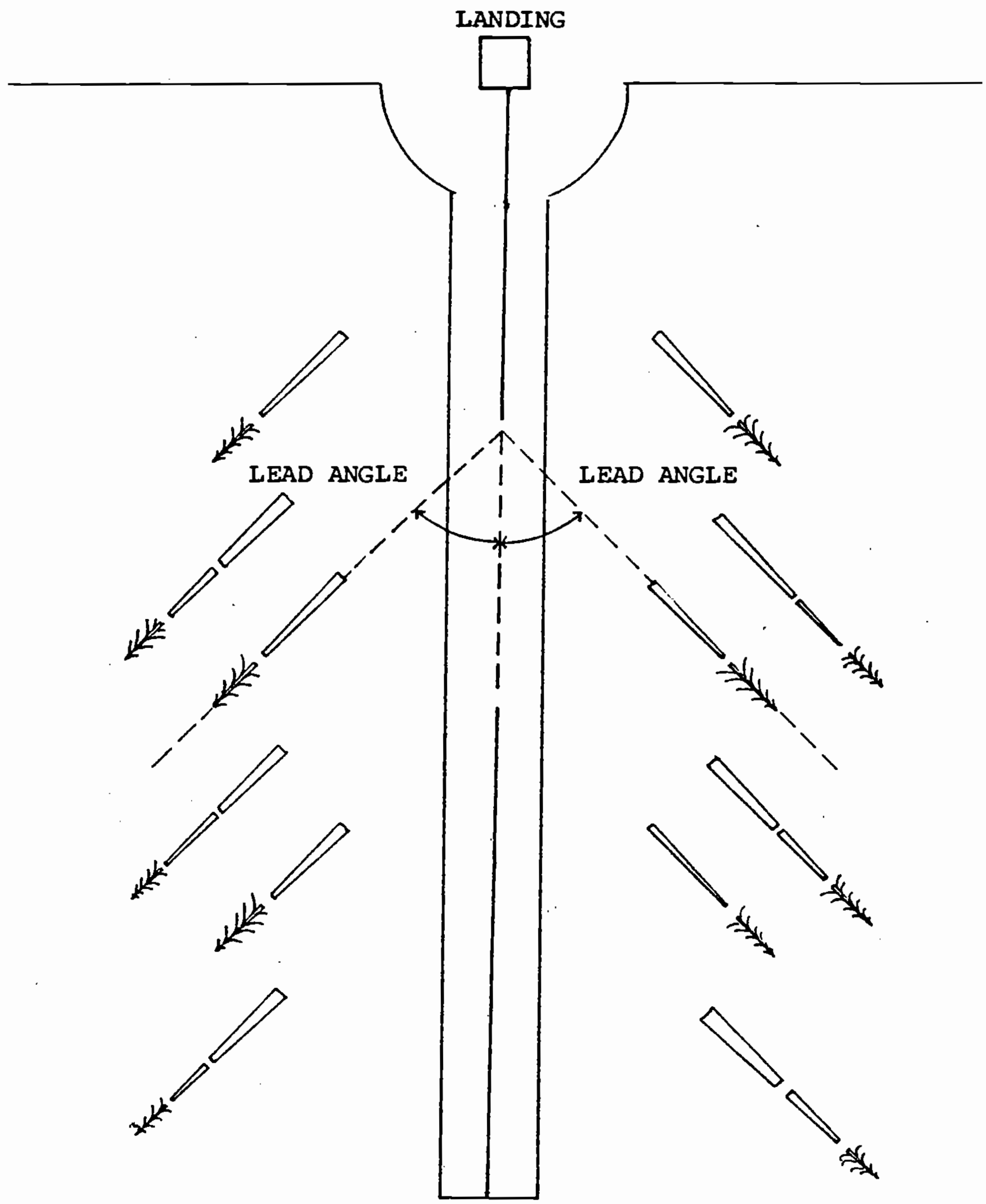


Figure 2. Felling Pattern

that each carriage is tested over the entire range of limits (i.e. slope distance, lead angles) that the other carriages were tested over. This last provision insures that if a carriage proves to have a critical limit (a limit where production drops off sharply with only a small change in the variable), the other carriages will also have been tested at the same limit or their respective limits determined and compared.

The Wyssen 2.5 ton, multispan, self-clamping carriage used for the yarding (figure 3) was rigged in the shotgun configuration as shown in figure 4. For multispan capacity, the Wyssen intermediate support jack was used. Three sliders and chokers were used on the mainline. When only one or two logs could be hooked in a single turn, the remaining choker(s) was removed and preset on one of the logs in the next turn.

The yarder used was a Schield-Bantam T 350. The yarder, along with its specifications is shown in figure 5. At the landing a John Deere 440 rubber-tired skidder with chokers swung the logs from the yarder deck, sorted them according to species and size, and redecked them along the side of the road. This greatly facilitated the loading of the logs with self-loading trucks.

A crew of five men was used for the yarding: 1 yarder operator, 1 skidder operator, 1 chaser and two choker setters. When any prerigging was done, it was done by the foreman.

D. Time Study Method

The completion times for seven full-cycle elements were measured for their response to change in twelve independent variables. A detailed time study using the "snap back" method of timing was used to obtain the yarding production data. The elapsed time in decimal minutes (0.00) was recorded for each activity. The watch ran continuously, so that no gaps in recorded time existed. The independent variables were observed or measured, and recorded for every turn. A detailed description of the time study method along with definitions of all dependent and independent variables is presented in appendix B.

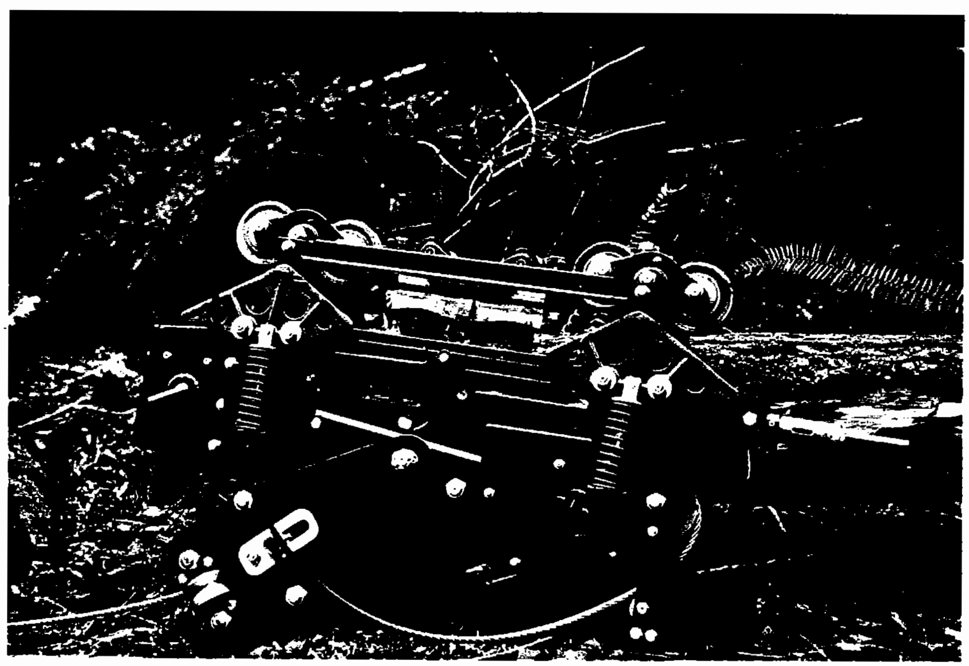


Figure 3. Wyssen 2.5 Multispan Skyline Carriage and Skyline Clamp

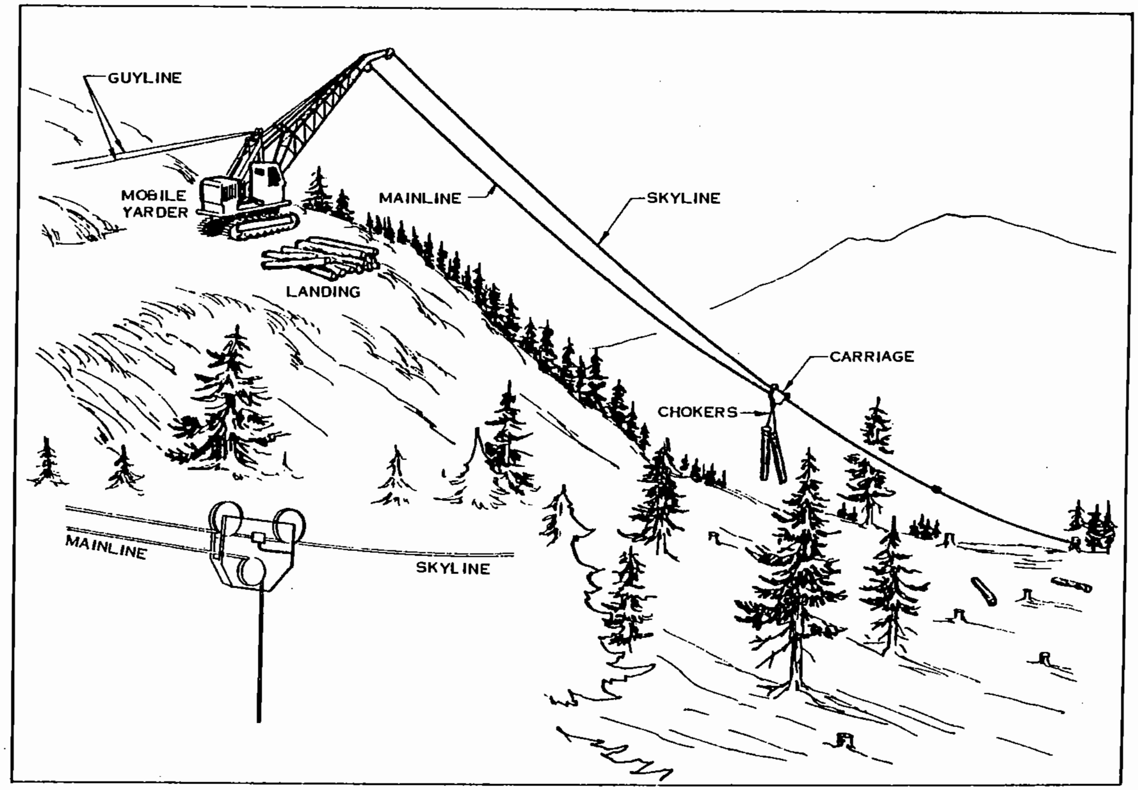
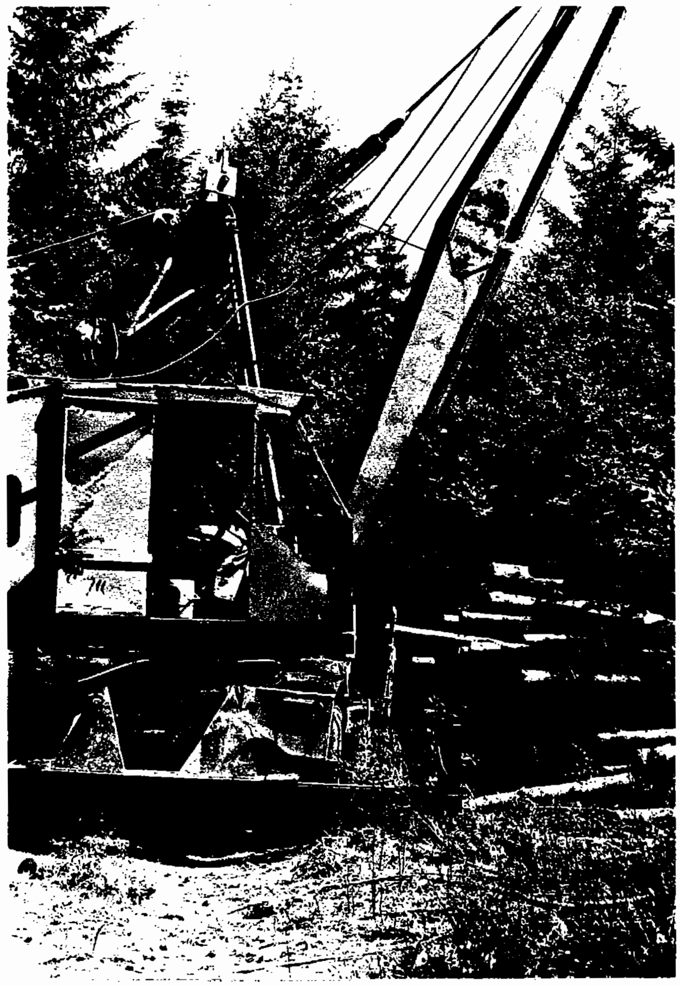


Figure 4. Gravity Outhaul (Shotgun) Yarding Configuration
(Adapted from Binkley, 1974)



Engine 453 Detroit diesel
Rated Engine Horsepower 90 at 2100 RPMs
Drum Capacity

Skyline	1000	feet of 3/4-inch
Mainline	900	feet of 5/8-inch
Haulback	1600	feet of 3/8-inch

Tower height 35 feet
Swing capacity 180 degrees

Figure 5. Schield Bantam T350 (converted loader) Yarder

E. Data Analysis

1. Post Thinning Assessment

Prior to thinning, the merchantable volume per acre was 3211 cubic feet. Tabulation of the volume per turn indicated that 758 cubic feet per acre had been removed. The percent volume removed therefore, was 23 percent. A post thinning cruise indicated that the actual percent stem removal was 32.2 percent.

2. Independent Variables

Table 1 summarizes the range of the independent variables. Correlations were run between all the independent variables. With the exception of Carriage Height and Slope Distance, Table 2 shows that only Number of Logs per Turn and Lateral Yarding Distance have a correlation greater than 25 percent. This indicates that as the lateral distance increased, the choker setters choose to build a full turn of at least three logs. The importance of this correlation is that productivity differences attributable to increased lateral yarding distance may partially be due to the increase in the number of logs per turn. Neither of these two interactions affected subsequent regression analysis.

3. Dependent Variables

Table 3 summarizes the yarding element times and their percentage of the total delay free cycle time. Delay free cycle time is the amount of time spent in the yarding cycle that is free of all resets and delays. This can also be considered as the pure yarding cycle time.

In Table 3, the percentage of time taken up by the UNHOOK element appears to be quite high. As mentioned in the discussion of delays in the appendix, the yarder operator and chaser took personal breaks and adjusted the deck and yarder most frequently during this cycle element. Because both time keepers were positioned in the woods with the choker setters, short delays at the landing went undetected and were attributed to the UNHOOK element.

Table 1. Independent Variables

INDEPENDENT VARIABLES	AVERAGE	MINIMUM	MAXIMUM	STANDARD DEVIATION
Slope Distance (ft.)	326.00	0.00	800.00	206.00
Lateral Distance (ft.)	62.58	0.00	250.00	40.11
Number of Logs Per Turn	2.05	1.00	5.00	0.80
Lead Angle (deg.)	* 56.73	0.00	90.00	17.73
Log Angle (deg.)	38.13	0.00	90.00	27.91
Volume Per Turn (cu.ft.)	29.25	4.00	91.10	14.14
Ground Slope (%)	19.28	12.00	26.00	4.18
Carriage Height (ft.)	12.98	0.00	60.00	10.63

* This value does not include logs yarded from the corridor.

TABLE 2. Intercorrelation of Independent Variables

	SLOPE DIST.	LATERAL DIST.	NUMBER OF LOGS PER TURN	LEAD ANGLE	LOG ANGLE	VOLUME PER TURN	CARRIAGE HEIGHT
Slope Dist.	1.000	0.131	-0.109	-.016	-.125	0.039	0.419
Lateral Dist.		1.000	0.428	0.244	0.029	-.125	0.155
Number of Logs Per Turn			1.000	0.051	0.117	0.009	0.021
Lead Angle				1.000	0.069	-.173	0.066
Log Angle					1.000	-.024	-.221
Volume Per Turn						1.000	-.076
Carriage Height							1.000

TABLE 3. Yarding Element Times for the Wyssen

YARDING ELEMENT	MINUTES PER TURN	PERCENT OF DELAY-FREE CYCLE TIME
Outhaul	0.629	17.06
Lateral Outhaul	0.517	14.02
Hook	0.473	12.83
Lateral Inhaul	0.411	11.14
Inhaul	0.759	20.58
Unhook	0.899	24.38
Total	3.688	100.01

F. Regression Analysis

The purpose of regression analysis is to quantify the relationship between the dependent variable and the independent variables. In this study, three regression models were necessary, using the same set of independent variables to describe three different dependent variables: 1) Delay-free cycle time 2) Cycle time with operational delays 3) Delay-free cycle time with interaction terms. Delay-free cycle time, as explained earlier, excludes all operational delays and resets. The second variable, cycle time with operational delays, includes the cycle time elements plus all operational delays and resets. As used here, operational delays are those incurred during, and as a direct result of, the yarding process. This excludes those delays such as the crew starting late or equipment delays, which occurred frequently, but were in no way a direct result of the carriage or the yarding system being used. The third dependent variable is the same as the first with the exception that interaction between variables is tested, allowing for other than linear relationships between the independent variables and delay-free cycle time.

For all of these models, the REGRESS subsystem of the Statistical Interactive Programming System, (SIPS, Rowe, et. al., 1978) was used to generate the models. This system is available on the Oregon State University CDC 3300 computer (Cyber operating system). Using SIPS, the significant variables were added to the models on the basis of their meeting the following three criterion: 1) The adjusted coefficient of multiple determination (R_a^2) was increased by no less than one percent with the addition of a given variable to the existing model. 2) The mean squared error was reduced by adding that same variable to the model. 3) The regression coefficient associated with that same variable was significantly different from zero at the 0.10 probability level given that the model already contains those variables previously added to it under the same criterion. In this third test, the hypothesis being tested was that the coefficient of the variable is equal to zero (Ho: $B_3 = 0$) verses the alternative hypothesis that the regression coefficient is not equal to zero (Ha: $B_3 \neq 0$). If the hypothesis is rejected, then the variable explains a significant portion of the reduction in variance at the 0.10 probability level. The following are general expressions of the F-test used to validate the hypothesis:

If F calculated $<$ F critical Then Ha: $B_3 \neq 0$
If F calculated $>$ F critical Then Ha: $B_3 = 0$

Where:

$$F \text{ calculated} = \frac{SSR\ (X_3 | X_1, X_2)}{MSE\ (X_1, X_2, X_3)}$$

$SSR\ (X_3 | X_1, X_2)$ is termed "extra sum of squares"

$$F \text{ critical} = F\ (1-\alpha;\ 1\ ,\ n-2)$$

For the analysis of delay-free cycle time and cycle time with opertional delays, the following general linear regression model was used:

$$Y_i = B_0 + B_1X_{i1} + B_2X_{i2} + B_3X_{i3} + E_i$$

Where:

B_0, B_1, B_2, B_3 are parameters (regression coefficients)

X_{i1}, X_{i2}, X_{i3} are known constants

E_i are independent with N(0,)

$i = 1,2,\ldots,n$ observations

Table 4 summarizes the regression coefficients for the total delay-free cycles time and the total cycles time including operational delays. Those independent variables which proved to be significant in the prediction of both cycle times are shown to be: 1) Slope Distance 2) Lateral Distance 3) Number of Logs per Turn and 4) Carriage Height. The other independent variable did not explain a significant amount of the error at the significance level choosen. The coefficient of determination (R^2) for the cycle time with operational delays and resets, is much lower than the R^2 for the delay-free cycle time. This suggests that operational delays and resets are randomly distributed and cannot be significantly explained by the independent variables at the 0.01 probability level. The correlations between operational delays and resets, and the independent variables shown in Table 5 supports the conclusion of random distribution with the highest correlation being 19.2 percent between Lead Angle and Resets.

These first two models are first order linear equations and therefore do not explain any of the interaction between variables. For example, at a slope distance of 800 feet, the sag in the mainline may cause pulling the mainline 70 feet to the side to increase the cycle time more than it would at a slope distance of only 200 feet. These interactions, if they do exist, may help to explain some of the variation in the cycle time and better quantify the relationship between the independent variables and the cycle time. To evaluate these possible interactions and their significance, the following general second order regression model was used:

$$Y_i = B_o + B_1X_{i1} + B_2X_{i2} + B_3X_{i1}X_{i2} + E_i$$

Where:

B_o, B_1, B_2 are first order parameters

X_{i1}, X_{i2} are known constants

TABLE 4. Regression Equation Coefficients without Interaction Terms

INDEPENDENT VARIABLE	COEFFICIENT WITHOUT DELAYS	COEFFICIENT WITH DELAYS
Constant	0.744503	0.682674
Slope Dist. (ft)	0.004295	0.004551
Lateral Dist. (ft)	0.009318	0.009795
Number of Logs Per Turn	0.257006	0.437872
Carriage Height (ft)	0.036869	0.035570
R^2	0.6278	0.2904

TABLE 5. Correlation of Delays and Resets with Independent Variables

	OPERATIONAL DELAYS	RESETS
Slope Dist. (ft)	-0.0013	-0.0494
Lateral Dist. (ft)	-0.0944	-0.1602
Number of Logs Per Turn	0.0262	0.0061
Lead Angle (deg)	-0.0600	0.1920
Log Angle (deg)	-0.0669	0.0294
Volume Per Log (cuft)	-0.0163	-0.1026
Carriage Height (ft)	0.1233	0.0130

B_3	is an interaction effect parameter
X_{i1}, X_{i2}	is the product (interaction) of two known constants
E_i	are independent with $N(0, \sigma)$

Table 6 summarizes the regression coefficients for the total delay-free cycle time and the total cycle time including operational delays, both with interaction terms. As with the models not including the interaction terms, the coefficient of determination (R^2) for the cycle time with delays is much lower than the R^2 for the delay-free cycle time. For both cycle times, the models with interaction terms explained more of the variation in the observed dependent variables.

Table 6. Regression Equation Coefficients with Interaction Terms

INDEPENDENT VARIABLE	COEFFICIENT	
	WITHOUT DELAYS	WITH DELAYS
Constant	1.9774	2.4069
Slope Distance	0.0036	-
Lateral Distance	-	-
Number of Logs Per Turn	-	-
Carriage Height	-	-
Lateral Distance x Number of Logs Per Turn	0.0037	-
Lateral Distance x Carriage Height	0.0005	0.0005
Lateral Distance x Slope Condition	-.0036	-
Lateral Distance x Slope Distance	-	0.00001
Slope Distance x Number of Logs Per Turn	-	0.0016
R^2	0.6376	0.2954

G. Model Analysis

After the "best" set of independent variables was chosen for each model, the models were tested to see if the amount of variation they explained was significant. The hypothesis tested was that the population's coefficient of determination was zero (HO:p = 0) verses the alternative that the population's coefficient of determination was not zero (HO:p ≠ 0). If the hypothesis is not rejected, then the amount of variation explained by the model is not significantly different from zero. If the hypothesis is rejected in favor of the alternative hypothesis, then the amount of variation explained by the model is significantly different from zero. The F statistic for this test can be expressed directly in terms of R^2 as follows (Neter and Wasserman, 1974):

$$F = \left(\frac{R^2}{1 - R^2}\right) \left(\frac{n - q - 1}{q}\right)$$

Where:

n = Total number of observations

q = Number of predictor variables

R^2 = Best estimate of p, found in the analysis of variance for the model

F critical = F

The values used in the test are summarized in Table 7. A 90 percent probability level was used. For all four cycle times, the models explained a significant amount of the variation in the observed dependent variables.

H. Delays

As noted in the REGRESSION ANALYSIS, operational delays showed no significant correlation to any of the independent variables and therefore were assumed to be randomly distributed about a mean of 1.0305 minutes per turn. The delays called RESETS (not included in the operational delays), were also checked for correlation with the independent variables with no

Table 7. Direct Test for Significant Relationship Using Coefficient of Determination (R^2)

REGRESSION EQUATION	n	q	R^2	F^*	F	CONCLUSION
Cycle Time (Delay-Free) With Interaction Terms	130	4	0.6376	54.98	1.99	$p \neq 0$
Cycle Time (Including Delays) With Interaction Terms	130	3	0.2954	17.60	2.13	$p \neq 0$
Cycle Time (Delay-Free) Without Interaction Terms	130	4	0.6278	52.71	1.99	$p \neq 0$
Cycle Time (Including Delays) Without Interaction Terms	130	4	0.2904	12.78	1.99	$p \neq 0$

relationships exceeding 21 percent. Based on this evidence, resets are also considered to be randomly distributed about their mean of 0.397 minutes per turn. Operational delays and resets total 1.427 minutes per turn. Adding this additional time to the constant term of the delay-free cycle time produces the regression equations given in Table 8. Two cycle times are presented in Table 8, one with interaction terms considered and the other without. Since both equations have such high coefficients of determination (Tables 4 and 6), the linear model (without interactions), because it is the simpler of the two, will be used throughout the remainder of this paper.

Additional analysis indicates that operational delays consumed 20 percent of productive yarding time. As used here productive yarding time is the time from start up in the morning till lunch break and from the end of lunch break till the end of the day. Major delays not associated with the variables in the study (i.e. repairing the brakes on the yarder) are not included in productive yarding time.

A gross time study of the yarding activities considering the time the crew was scheduled to begin in the morning and the time they quit in the afternoon and the number of turns yarded, indicates that the average time per turn was 7.632 minutes. This suggests that other delays consumed 34 percent of the work day.

Approximately 20 percent of this nonproductive time (other delays), or 6.8% of the work day, was spent learning about or correcting mistakes made with the Wyssen carriage. This time was almost eliminated on subsequent corridors as the crew became familiar with the operation and maintenance of the carriage and had made the necessary modifications. This learning curve effect is evaluated more closely in the discussion of the Wyssen carriage in the Carriage Comparison section.

Table 8. Regression Equations for Cycle Time with Operational Delays and Resets Added in

INDEPENDENT VARIABLE	COEFFICIENT	
	WITHOUT INTERACTION TERMS	WITH INTERACTION TERMS
Constant	2.1722	3.4052
Slope Distance	0.0043	0.0036
Lateral Distance	0.0093	-
Number of Logs Per Turn	0.2570	-
Carriage Height	0.0369	-
Lateral Distance x Number of Logs Per Turn	-	0.0038
Lateral Distance x Carriage Height	-	0.0005
Lateral Distance x Surface Condition	-	-0.0036

I. Sample Size

The minimum number of observations necessary to insure the integrity of the statistical analysis is a function of the precision desired and the inherent variability in the sample population. Had a sample of turns been recorded prior to the study, the number of turns needed for a given precision level could have been determined. Since such a sample was not available the computation of sample size is done here only to indicate whether or not the number of turns sampled was sufficient.

The desired precision for this study was to be 90 percent confident that the mean delay-free turn time was estimated to within plus or minus 5 percent of the observed turn time. The equation used to determine the minimum sample size is (Freese, 1967):

$$n = \frac{t^2 \; S^2}{E^2}$$

n = desired number of observations

t = students at level of probability

= t (1 - 0.10, 313 - 1) = 1.282

S = square root of estimate of mean squared error

= 1.27606

E = $\pm$ 0.05 (Y) = 0.05 (3.61502) = .1807

= specific error

$$n = \frac{(1.282)^2 \; (1.27606)}{(0.1807)^2} = 82 \text{ observations}$$

Based on this analysis, the 313 observations made during the field study constitute an adequate number of observations.

J. Summary of Wyssen 2.5 Study

The regression model which best explains the variation in cycle time is the model for delay-free cycle time, without interaction terms, and with operational delays and resets added to the constant term as an average per turn. This model is summarized as follows:

2.17	constant
0.00429 X	slope distance (avg. = 326 feet)
0.00931 X	lateral distance (avg. = 62.58 feet)
0.2570 X	number of logs per turn (avg. = 2.05)
0.0369 X	carriage height (avg. = 12.98 feet)

The regression coefficients yield cycle time in minutes per turn. The coefficient of determination (R^2), equals 0.6278. This model shows that of the independent variables considered, slope distance is the most significant, increasing delay-free cycle time an average of 1.4 minutes per turn. The other significant independent variables (lateral distance, number of logs per turn and carriage height), each increased cycle time an average of about 0.50 minutes per turn. The independent variables not included in the model (lead angle, log angle, volume per turn and ground slope) failed to explain a significant amount of variation in cycle time at the significance level chosen.

Within the lateral yarding sequence, lateral outhaul, hook and lateral inhaul accounted for almost 38 percent of the total delay-free cycle time. The unhook element accounted for 24.37 percent of delay-free cycle time, but much of this was in undetected personal and operational delays.

Additional summaries of the operation of the Wyssen carriage are presented in the following section of this paper as part of the carriage comparisons.

VI. COMPARISON OF DESIGN AND OPERATIONAL CHARACTERISTICS

Five different carriages representing three types of carriages are compared in this section of the paper. The five carriages are: 1) Maki 2) Christy 3) Koller SKA 2.5 4) Koller SKA 1.0 and 5) Wyssen 2.5. The Maki and the Christy carriages represent those which are secured to the skyline with skyline stop. The two Koller carriages represent those which are secured to the skyline with a hydraulic clamp. The Wyssen 2.5 represents those which are secured with a mechanical skyline clamp.

These five carriages are compared on the basis of their design and operational characteristics. The design characteristics are physical characteristics of the carriage such as size and weight. The following five characteristics are generally available in most of the studies involving the carriages:

1. Size and weight
2. Payload capacity
3. Line sizes
4. Maintenance and care required
5. Options - can be rigged with a haulback line or not, sliding chokers or load hook, etc.

The design characteristics specify the compatability of the carriages to a given yarder and rigging system as well as site and stand conditions. The operational characteristics, as explained in the introduction, include either those characteristics unique to the carriage or those which obviously affected production and could be measured directly. An example of a characteristic unique to that carriage type may be the way it cycles in order to clamp onto the skyline or the way in which it releases the load hook at the landing. Two examples of those characteristics which obviously affect production and can be measured directly are: 1) Delays which occur as a result of the carriage and 2) the tendency to throw slack.

The five carriages mentioned were studied in five different research efforts. Were all five conducted under dissimilar conditions, such a comparison may not be possible. The similarities between the different carriage studies is therefore a very important consideration. Table 9 shows the five studies referred to by the carriage being studied, and their similarities. All but one, the Koller SKA 1.0 used the same Schield-Bantam yarder and the same contract logger and his crew (some of the personnel in the crews were different from year to year). The Koller SKA 1.0 study used the Koller K300 tower yarder and a crew of students plus one experienced logger. Other similarities are listed in Table 9.

The carriages will be presented individually, with comparisons to other carriages included when appropriate. General comparisons are summarized following the review of the individual carriages.

Table 9. Carriage Study Similarities

	MAKI	CHRISTY	KOLLER SKA 2.5	KOLLER SKA 1.0	WYSSEN
Schield Bantam T350 Yarder	x	x	x		x
Koller K300 Tower				x	
Gravity Outhaul	x	x	x	x	x
Multispan Capability			x	x	x
Self-clamping			x	x	x
Carriage Stop	x	x			

A. Maki

The Maki skyline carriage was used in the December 1974 and January 1975 study by Ed Aulerich, designed to develop a regression equation for the Maki and evaluate its performance. The carriage used a 3/4 inch skyline and a 5/8 inch mainline and weighed 300 pounds.

At the landing, both the skyline and the mainline are passed through the carriage. The skyline is also passed through the carriage stop and on down the corridor. To begin the outhaul-inhaul cycle, the carriage stop is positioned on the skyline by the choker setters and clamped either hydraulically or mechanically (figure 6). The skyline is then raised and the mainline spooled out. When the carriage strikes the carriage stop, slack is thrown in the mainline and the chokers drop from the carriage. The amount of slack that is thrown depends on the speed of outhaul and how much of the mainline is dragging on the ground. This slack in the mainline makes pulling line laterally much easier while the slack is being used up. The carriage is released from the stop when the load reaches the carriage and without stopping the mainline, the carriage moves up the skyline. At the landing, the carriage is held in place by the mainline while the skyline is lowered so that the logs can be unhooked.

When all the turns from one carriage stop setting are brought in, the skyline is lowered, and the carriage stop is repositioned. The study by Aulerich indicated that on the average, the carriage stop was moved 35 feet every 5.53 turns with an average time expended of 1.86 minutes. This equals 0.34 minutes per turn or 9.9 percent of the delay-free turn time.

No information was available as to the breakdown of delays for this study.

Figure 6. Skyline Stop

Figure 7. Christy Carriage

B. Christy

During the summer of 1980, the O.S.U. Forest Engineering Depratment's smallwood harvesting research used the Christy carriage (figure 7). Like the Maki, it represents those carriages which are secured to the skyline by a carriage stop. The Christy is similar to the Maki in size, weight (320 pounds) and line sizes. It is also similar in its yarding cycle. The difference is that by adding the haulback, it can be converted to a mechanical slackpulling carriage.

This same 1980 smallwood harvesting study indicated that on the average, the carriage stop was moved 35 feet every 8.93 turns with an average time expended of 2.362 minutes per move. This equals 0.2644 minutes per turn or 5.97 percent of the delay-free cycle time. The Christy data indicates that moving the carriage stop accounts for 42.4 percent of all operating delays, excluding resets or 0.264 minutes per turn. Carriage malfuncitons accounted for only one half of one percent of the operating delay time or 0.0034 minutes per turn.

Also of importance is the lead angle at which the turn is yarded laterally to the carriage. Because the carriage stop is moved only once in every eight or nine turn, the chokersetter may choose a poor lead angle as opposed to moving the carriage stop. Figure 8 shows the distribution of lead angles in which the mean is 59.69 degrees with a standard deviation of 24.07 degrees, or 68 percent of the turns had a lead angle between 35 and 84 degrees.

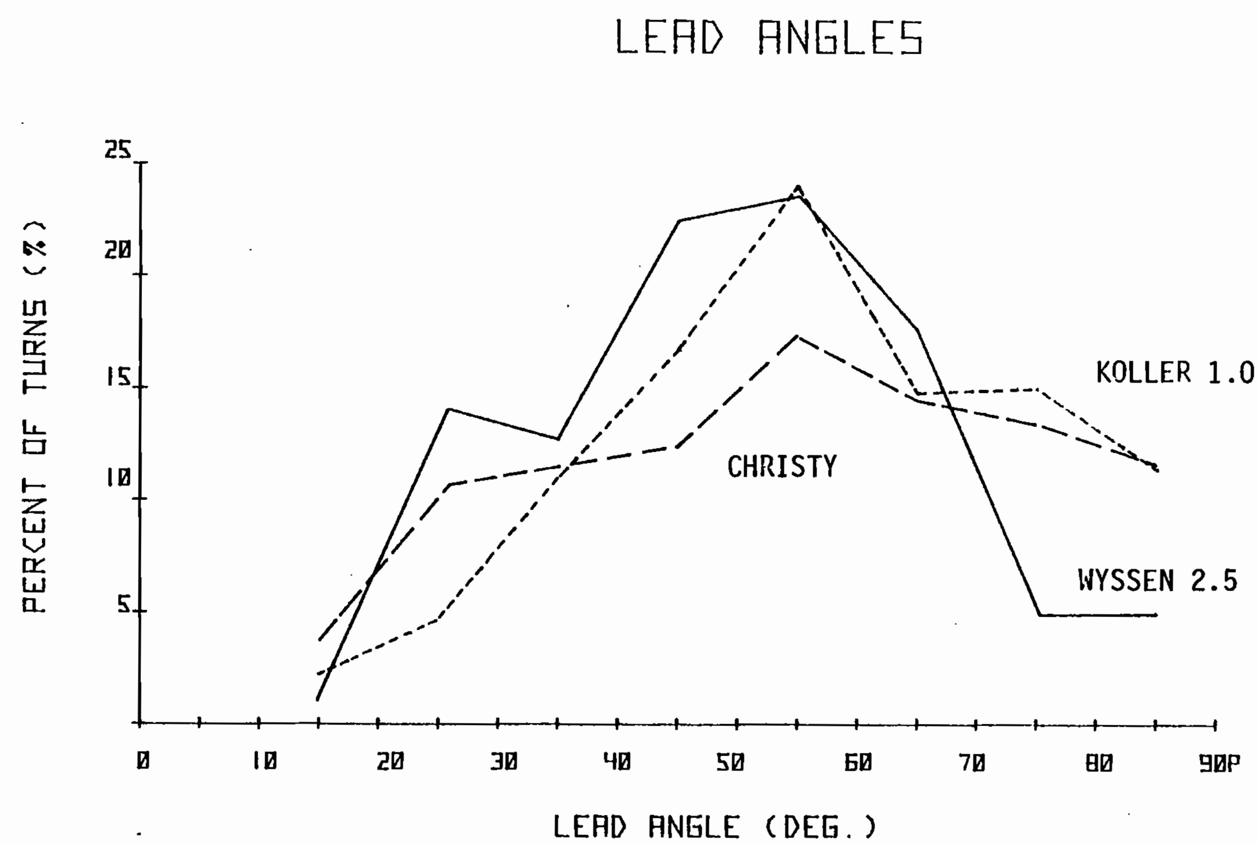


Figure 8. Distribution of Lead Angles

C. Koller SKA 2.5

The Koller SKA 2.5 multispan carriage was tested during the summer and fall of 1976 by the Forest Engineering Department of Oregon State University. During the study, a 3/4 inch skyline and 1/2 inch mainline were used. The carriage is rated at 2.5 kilograms (5500 pounds) payload.

The Koller SKA 2.5 is a self-clamping, hydraulically operated carriage (figure 9). The carriage clamp is activated at the hook point by a directional change. The sequence is as follows. The carriage is lowered to a point 10 feet past the hook point (this distance is adjustable). The mainline is then brought in so that the carriage once again passes the hook point. The carriage is then allowed to drift down the skyline until it clamps to the skyline and the load hook is released. With the turn hooked, the turn is brought to the carriage. When the load hook enters the bottom of the carriage, it locks into place and simultaneously releases the skyline clamps. The mainline is then slacked momentarily and the load is brought to the landing. At the landing, the sequence used at the hook point can be reversed, but this is too time consuming. Two alternative techniques can be used instead. The Koller stop, a clamp with a cushioned plate mounted on the bottom, contacts a release on the carriage and the carriage clamps, releasing the load from the carriage. The load can also be held in place with the mainline while the skyline is slacked. This technique eliminates a clamping sequence but does require lowering and raising the skyline every time a turn is brought in.

Like the Maki and Christy, the Koller SKA 2.5 can be rigged with a haulback for downhill yarding, but cannot be rigged for mechanical slackpulling like the Christy. Also, unlike the Maki and Christy, the Koller carriage is not designed to be used with sliding chokers. The load hook is what triggers the release mechanism on the carriage and must be used for proper operation. Modifications to accomodate the use of sliding chokers may be possible, but the author is not

Figure 9. Koller Carriage

aware of any.

The advantage of the Koller over the Maki and Christy carriages is that as a self-clamping carriage, no time is spent moving a carriage stop. This would eliminate 0.34 minutes per turn in the case of the Maki and 0.26 minutes per turn in the case of the Christy. Time is needed however to cycle the Koller carriage and because of the added mechanical complexity, more repair and maintenance time might be expected.

The data shows that four delays unique to the Koller carriage were incurred. 1) Carriage failed to cycle properly and would not clamp to the skyline. In this particular study, this was due to the fact that the carriage clamps were sized for 7/8 inch skyline and 3/4 inch line was used. This delay would be greatly reduced with proper sizing of the clamps and the line. 2) Carriage stop required adjustment in order to trigger the carriage to clamp at the landing. 3) Load hook hangups occurred when either the carriage would not release the load hook after clamping the skyline at the turn point or when the weight of the load hook was not enough to offset the sag in the mainline. If the carriage was low enough, the load hook could be lowered by hooking the chokers with a stick and pulling them down. If the carriage was too high for this, the skyline had to be lowered. 4) Charging the hydraulics occurred when the reservoir in the carriage, due to loss of hydraulic fluid, could no longer build up enough pressure to secure the carriage on the skyline. The average time per turn consumed by each of the four carriage delays is:

1.	Carriage clamp	0.1269 min./turn
2.	Carriage stop	0.0503
3.	Hook hangup	0.0120
4.	Charge hydraulics	0.0335
	TOTAL	0.2227 minutes per turn

D. Koller SKA 1.0

The operation of the Koller SKA 1.0 is identical to that of the Koller SKA 2.5, with the exception that it is cycled at the landing instead of using a stop or lowering the skyline when unhooking the turn. The Koller 1.0 is smaller and lighter at 330 pounds and can be used with 5/8 inch skyline and 3/8 inch mainline. Of importance here are the delays which showed that carriage malfunctions which includes the carriage cycling, carriage clamp at the landing and hook hangup delays accounted for 0.0382 minutes per turn and charging the hydraulics accounted for 0.0324 minutes per turn or a total of 0.07 minutes per turn. The carriage clamps in this study were properly sized to the line being used and the problems with carriage cycling were greatly reduced. If those delays associated with carriage clamps were not considered in the Koller 2.5 study, the carriage related delays would have accounted for only 0.09 minutes per turn, very close to the 0.07 minutes per turn experienced in the Koller 1.0 study. Neither of the studies accounted for the cycling of the carriage. This was simply included in the outhaul element.

Of additional interest is an evaluation of the lead angles used to bring the logs from the choker point to the corridor. With the option to stop the carriage at any point along the skyline, the data should reflect a smaller standard deviation in the lead angle chosen by the choker setter.

The average lead angle was 49.95 degrees with a standard deviation of 16.30 degrees. As compared with an average lead angle of 59.69 degrees and a standard deviation of 24.069 degrees for the Christy, the choker setters did in fact take advantage of the carriage and used it to select better lead angles. Statistical analysis using student's test confirms the difference in lead angles.

E. Wyssen

The Wyssen, automatic standard, 2.5 ton carriage was studied by the O.S.U. Forest Engineering Department during the summer of 1981. The carriage was designed to be used in conjunction with the Wyssen downhill yarding system, first introduced in the Swiss Alps in 1939 and first used in the Pacific Northwest in 1954. The carriage uses a hydraulically activated mechanical clamping system. One of the skyline sheaves drives an eccentric cam which activates a hydraulic pump. As the carriage is moved either up the skyline with the mainline or down the skyline via gravity, pressurized hydraulic fluid is stored in an accumulator. When the carriage stops moving, fluid is released from the accumulator triggering the mechanical clamping system which clamps the carriage to the skyline and drops the load hook. The advantage of the Wyssen carriage here is that the number of seconds from the time the carriage stops and the time it clamps can be set to best suit the yarding system being used. This timing is set by adjusting the rate at which hydraulic fluid is bled from the accumulator. The faster it is bled off, the sooner the carriage clamps after it is stopped. As long as the carriage is moving fast enough for pressure to be created in the accumulator, the release mechanism is not triggered. Also, the pump must build up a certain amount of pressure before the timing system is activated. The quicker the carriage is set to clamp, the further it must travel to build up the minimum amount of pressure necessary to activate the timing mechanism. Slack is pulled manually for lateral yarding. When the turn is brought up to the carriage, the load hook releases the clamp, using the force of the mainline to reset the mechanical clamping mechanism, and the carriage is returned to the landing with the load hook clamped in place. At the landing, the carriage is stopped, the clamp engaged and the load hook dropped. Old tires or a similar bumper must be placed in front of the boom sheave over which the skyline rides since a crank on the carriage can easily be damaged if it hits the boom. The carriage has several other moving parts outside of the main body. When used in conjunction with the Wyssen yarder system, where the skyline is fixed and ground clearance must be adequate to fly the logs down the skyline, the potential for damaging these exterior mechanisms is very small. When used in conjunction with American systems with live skylines, which have few if any intermediate supports and low ground clearance, these exterior components are easily damaged. A shield (figure 10) was designed during the study to protect the carriage. Most of the damage to the unprotected carriage occurred when it was deflected into the trees along the corridor during lateral inhaul.

The Wyssen carriage offers the choice of several load hooks. Two of the hooks have safety latches to keep the choker eyes in the hook. One of these is too heavy for lateral slack-pulling but is well adapted for swinging with auxillary hooks on the main hook itself for flying additional choker. The other hook, smaller and lighter than the first, is used for lateral yarding and prebunching. The third option is to rig the mainline with a release mechanism and sliding chokers. The advantage here is the lighter weight and the feature of being able to hook scattered logs (more than a choker's length apart) in the same turn.

As with the Koller, the time required for the carriage to cycle was not distinguished, but recorded as part of the outhaul element. This can however, be estimated from the timer used to control the release. In the Wyssen carriage, two timers are set. The first, which ranges from 5 to 120 seconds is the amount of time required before the carriage clamps after it has stopped. During this study, this was set at the minimum of 5 seconds. Once the carriage stops or slows sufficiently such that hydraulic fluid is bled off from the accumulator faster than it is pumped

Figure 10. Shield Constructed to Protect Wyssen Carriage

in, the escaping fluid triggers a release which stops charging the accumulator, thereby initiating the release time. As a result of this procedure, the release time is very consistent. Converted to decimal minutes, this accounted for 0.1667 minutes per turn. The second timer controls a safety system in which once the load hook leaves the pendulum after the carriage has clamped, the carriage will not release if the load hook should snap back up into the pendulum within the time specified. This time can range from 5 seconds to 4 minutes. For the study, this time was set at 15 to 20 seconds. In the case of a turn which was in the corridor and easily hooked, this sometimes caused a short delay.

Due to the intricate mechanisms and important adjustments invloved with the Wyssen, certain delays, many of which required repairs, were a direct result of the inexperience of the logging crew and not of the carriage itself. An example is that when the load hook engages the pendulum, the yarder operator must momentarily (1 to 2 seconds) slack the mainline to allow the skyline clamps to release before inhaul begins. If he failed to slack the mainline, the clamps were wedged tighter due to an intentional design feature intended to hold the carriage more securely as the loads increase. Once the clamps are wedged tightly, they must be opened manually using the hand crank to depress the main spring. Once the yarder operator and choker-setter made the necessary corrections, this delay did not reoccur. These delays, shown in figure 11 as an average time per turn, exhibit a learning curve effect as the number of turns yarded increased. The base line value appears to be 0.0958 minutes per turn. The total average delay from cycling and operation was 0.2625 minutes per turn.

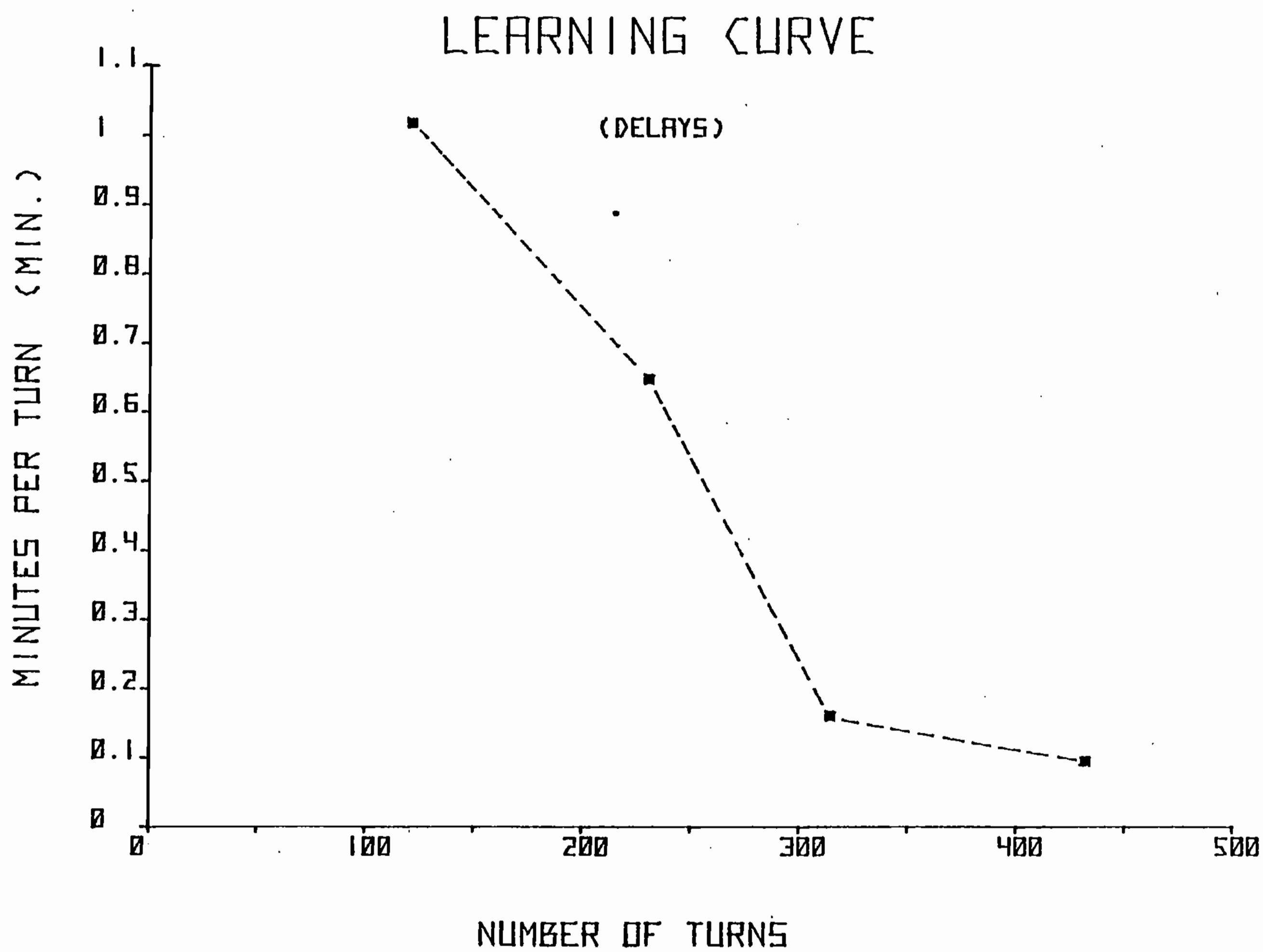


Figure 11. Learning Curve for Operational Delays Unique to the Wyssen Carriage

Table 10 lists the delays unique to each carriage on a minutes per turn basis. The self-clamping carriages, though more complicated, have the lowest delay time per turn.

Lead angles with the Wyssen were also evaluated. With the increased accuracy of picking the carriage location on the skyline, the standard deviation of lead angles using the Wyssen might by expected to be smaller than that using the Maki or the Christy. In fact, the average lead angle was 57.74 degrees with a standard deviation of 17.73 degrees. The comparison of lead angles is shown in figure 8.

TABLE 10. Summary of Significant Carriage Delays

DELAY TYPE	CHRISTY **	KOLLER 2.5 **	WYSSEN **
CARRIAGE MALFUNCTION	0.0034	0.0382	0.0958
CARRIAGE MAINTENANCE	-	0.0324	-
MOVE CARRIAGE STOP	0.2644	-	-
CYCLING	-	*	0.1667
TOTAL	0.2678	*	0.2625

*Accurate estimates are not available

** Decimal minutes per turn

F. Summary of Carriage Comparisons

Figure 8 and Table 10 are especially useful in summarizing the carriage comparisons. From figure 8, the Christy carriage shows a definite peak at about 55 degrees, but with a large deviation, suggesting that a large variation of lead angles was used at each skyline stop. This is to be expected since choosing the same lead angle every turn would require moving the carriage stop almost every turn. The Koller and Wyssen carriages however, have relatively small deviations about their mean lead angles. This suggests that the variation in lead angles is small for each turn.

The author is not aware of any published studies which support the following assumption, but it does seem likely that in a conventional thinning operation in which no thinning pattern is specified, residual stand damage would be minimized with the use of the Koller or Wyssen carriages (self-clamping types). The reasoning is that with directional felling and yarding to lead (mainline and log lie along the same axis), less area is disturbed during the lateral yarding process. Also, the logs being yarded tend to align themselves with the mainline (come into lead) by rotating around and sliding along the residual trees. This causes scarring of the residual trees. With the ability to "spot" the self-clamping carriage types on the skyline, lead angles can be used which will allow the logs to be yarded to the corridor on lead.

Along the same lines, the Wyssen carriage can be spotted with great accuracy since the clamping mechanism is activated by a timing mechanism. Once the carriage stops at the end of outhaul, the choker setter can signal the yarder operator to pull the carriage slowly up the skyline or let it drift down the skyline to the desired spot before the carriage clamps onto the skyline. The choker setters in the Wyssen 2.5 study used this featured extensively by choosing the best extraction path for a turn of logs, then making sure the carriage was on line with their extraction path when it clamped to the skyline. This same procedure is possible with the Koller carriage but since the clamping mechanism is activated by traveling a set distance after a direction change, the accuracy in spotting the carriage is not as great.

In the event that some type of strip thinning is specified, the skyline stop carriages may prove more useful since a large number of turns can be yarded from the same stop position.

The delays listed in Table 10 indicate that the total delay time in minutes per turn is higher for the Christy carriage than for the Wyssen carriage. This is largely a result of the time spent moving the carriage stop. Two other observations can be made regarding Table 10. First, the amount of time spent on carriage malfunctions is very low for the Christy carriage, compared to the Koller and Wyssen carriages. The Christy is mechanically simple and robust compared to the Koller and Wyssen carriages and as a result, incurred fewer malfunctions. Second, the carriage maintenance delay for the Koller resulted from the need to recharge the hydraulics periodically. This is not necessary for the Wyssen since it does not loose hydraulic fluid unless laid on its side.

Finally, the three carriage types represent three levels of mechanical complexity with the Maki and Christy carriages being the simplest and the Wyssen being the most complex. Besides affecting the delays due to carriage malfunctions, this increased complexity also affects the handling and use of the carriage. As mentioned, the Wyseen carriage proved to require extra shielding to protect its exposed mechanisms, great care is required when lowering the carriage to the ground with the skyline for repairs or maintenance and a large number of turns are needed to familiarize the crew with the operation of the carriage unless they are already experienced with the carriage being used. In general, the self-clamping carriages require more care and skill on the part of the crews than do those carriages secured to the skyline via a skyline stop.

The costs of the carriages as surveyed during 1982 are listed by the United States Forest Service, U.S.F.S. (1982).

Christy	-	Regular	$3,845.00
Koller	-	SKA 1.0	$7,500.00
Koller	-	SKA 2.5	$10,000.00
Wyssen	-	2.5 Automatic	$11,000.00

The Maki carriage is not listed in the publication. The prices indicate that the initial investment for the Wyssen 2.5 is almost three times that of the Christy regular.

VII. COMPARISON OF PRODUCTIVITY

In this final section, the objectives are to compare production rates of the carriage types and to quantify the sensitivity of their production rates to such yarding parameters as slope distance and lead angle. The simulation model "THIN" is instrumental in this. The results of this method appear to be conclusive, but they are subject to certain limitations which will be discussed after the description and results of the model are presented.

The intent of this section is not to critique the simulation model as to its validity - substantial testing has been done by the authors of the model, Butler (1980) - but to present its results and to evaluate its limitations in this application.

A. Model Description

THIN, written in FORTRAN IV, combines Monte Carlo and system simulation techniques. It determines production rates based on diameter class, stand densities, yarding efficiencies, external slope and lateral yarding distances and prebunch and swing strategies, Butler (1980). As used in this study, THIN served to distribute the logs over the cutting unit and yard them to a central landing.

The logs were sized and distributed in such a way as to represent those log sizes and spacings actually encountered in the individual carriage studies. The model parameters choosen for this are shown in Table 11. These parameters do not exactly represent any one of the carriage studies, but are considered typical and therefore serve to normalize stand and site conditions. Using these parameters, the exact same stand can be yarded changing only the carriage.

In this simulation scheme, the carriage is varied by inputting the delay-free cycle times from the individual carriage studies.

TABLE 11. Model Parameters for THIN

PARAMETER	MEAN	MAX.	MIN.	STND. DEV.
LOG SIZE (cu.ft.)	17.30	91.1	4.0	13.2
LEAD ANGLE (degrees)	45.0	100.0	0.0	15.0
DENSITY (stems/acre)	200.0	-	-	-
SLOPE DIST. (ft.)	-	1000	-	-
CORRIDOR WIDTH (ft.)	-	300	-	-
GROUND SLOPE (%)	20	-	-	-
CHORD SLOPE (%)	30	-	-	-

The simulated stand is then yarded using the regression equations for cycle time, with THIN choosing the logs in much the same way they would be chosen under actual circumstances. Production rates are recorded as the average over an increment of some parameter (i.e. 0 - 100 feet slope distance). For the purpose of comparison in this study, each simulation was run three times for every carriage, varying the random number seed each time. The outputs were then averaged to find the production rates per increment of indicated variable

B. Simulation Results

The results of simulation are summarized in Figure 12 and Figure 13. In both figures, delay-free cycle times are used with the exception that those operational delays which are unique to the carriages (Table 10) are added in. Resets, non-carriage related operational delays and non-operational delays are not represented in the production rates shown. Where production estimates are carried out past the parameters of the study, productivity is indicated by a dashed line.

The effect of slope distnace on productivity is shown in Figure 12. The three carriages shown represent the three carriage types. The Christy carriage and the Koller 1.0 carriage, although used in the previous comparison, are not represented here for simplicity sake. The figure clearly indicates that productivity decreases as slope distance increases for all three carriages. Also indicated are the relative levels of productivity, with the Wyssen and Koller carriages being more productive than the Maki carriage and the Wyssen being more productive than the Koller.

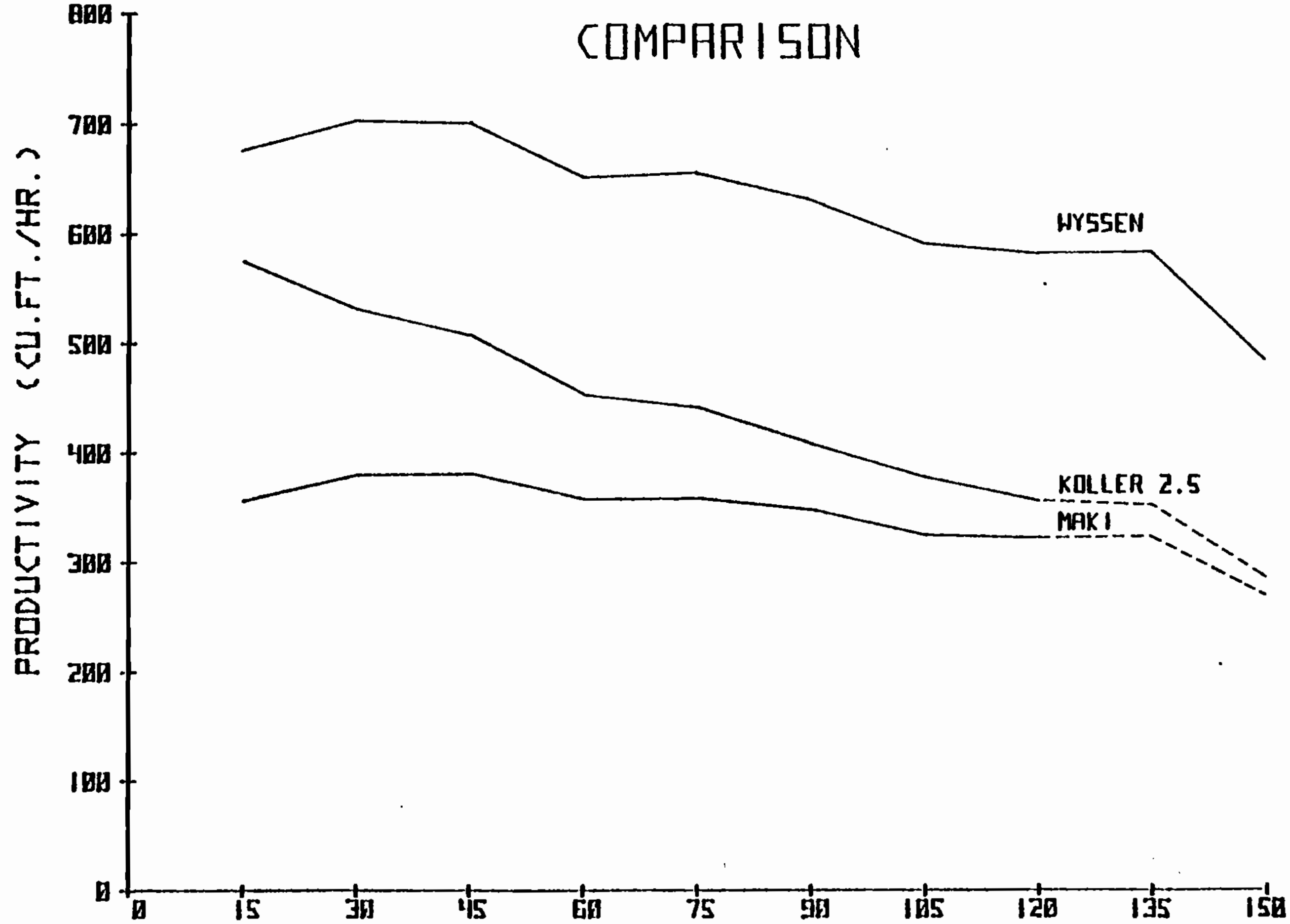


FIGURE 12. Comparison of Productivity as a Function of Slope Yarding Distance

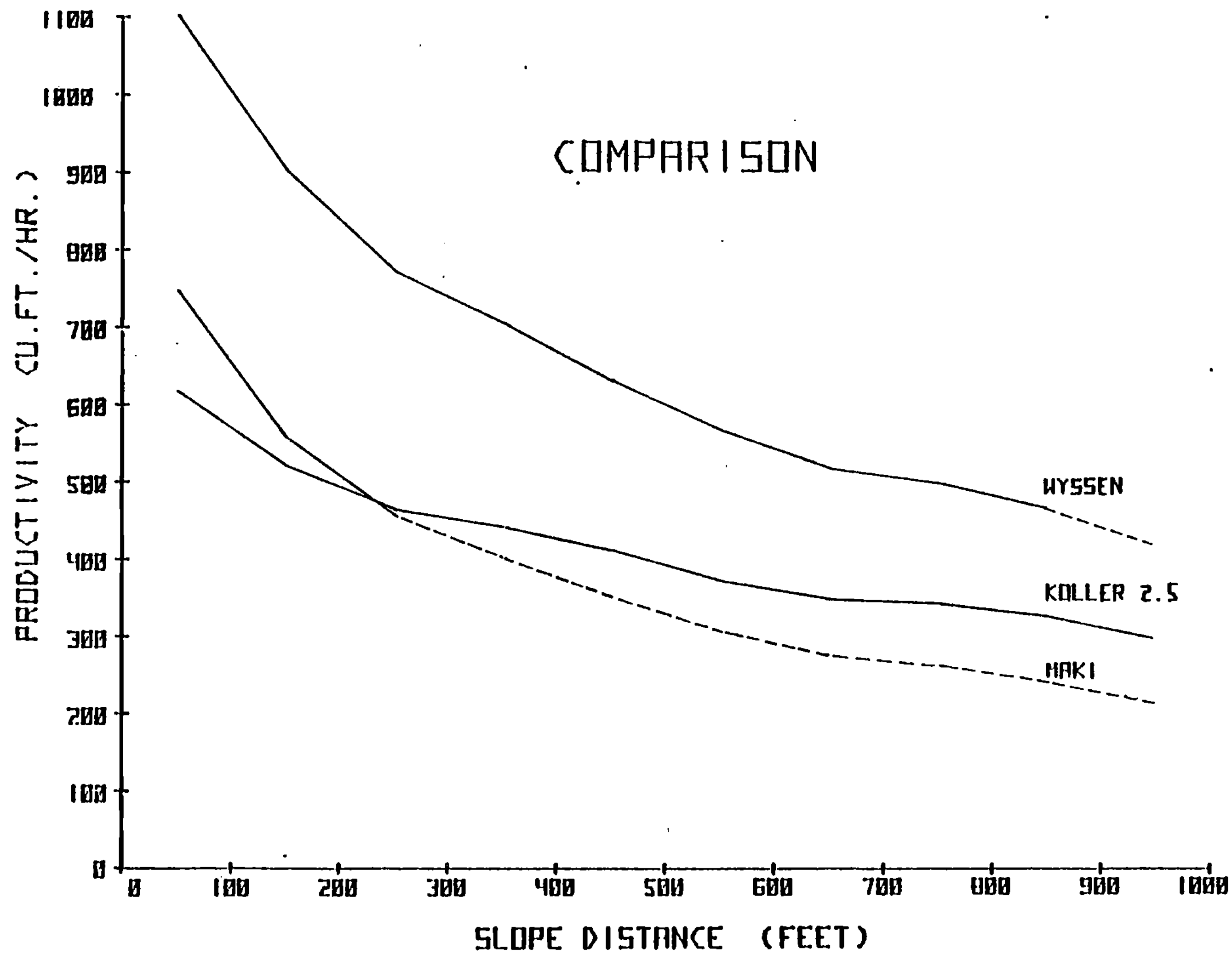


FIGURE 13. Comparison of Productivity as a Function of Lateral Yarding Distance

The same relationship of relative productivity holds true for lateral distance also, as shown in Figure 13. The drop in productivity due to increased lateral distance is not as great as it is due to increased slope distance. The reason that productivity does not decrease rapidly with increased lateral distance may well be that, as was found to be true for the Wyssen study, the choker setters tend to build a larger turn (more logs) as lateral distance increases. This effect, however, would not show up in the simulation results since the regression models do not include interaction coefficients which would account for such a relationship. The only difference accounted for by simulation is extra time required to pull line to the turn and yard the turn as lateral distance increases. Were the interaction between turn size and lateral distance accounted for, productivity would be reduced even less as lateral distance increases.

This limitation of simulation is one of many which serve to reduce the applicability of such a model to this type of comparison. If these limitations can be defined, they may help to validate certain of the results of the simulation. The following paragraphs serve to define these limitations and suggest which of the results of simulation may actually represent the performance of the carriage types.

C. Limitations of Simulation

The results of simulation are only as good as the inputs. If certain variables which affect productivity are not included in the simulation model, the results cannot be expected to accurately predict what actually happens. Such is the case in this comparison. The regression models for cycle time given in the individual carriage studies do not predict a general cycle time, but cycle time for a given site, stand, weather, crew and what ever else might affect cycle time but is not measured. An example of this is reported by Zelinsky (1980), in which the owner of the logging company contracted for the study replaced one of the choker setters for a period of the study. The result was a 50 percent increase in production during that time period. This was not accounted for in any of the variables recorded in the study.

If the assumption could be made that those variables not included in the model are equal for all studies, then simulation could at least be used to compare carriage productivity even though the computed production levels may be wrong. Even this however, is not possible, since very small differences in choker setters, yarder operators, weather, stand or site conditions or any combination of these undoubtedly affects productivity. With the affects of these variables unaccounted for, differences in productivity cannot be attributed solely to the carriage type.

The extent of these differences not attributable to the carriage is illustrated in Figure 14, in which productivity is plotted against lateral yarding distance for the Christy and Maki carriages. Both of the carriages represent skyline-stop carriages and are nearly identical in design and operation, yet the Christy study shows productivity of the skyline-stop carriages to be as much as 57 percent higher than the Maki indicates. In addition, Figure 15 shows the Maki being less productive than the Koller 2.5 and the Christy as being more productive beyond 20 feet. As a result of this paradox, carriage type cannot be considered as accounting for the productivity levels indicated by simulation. Some unaccounted factor or factors appear to have a greater influence and as a result, tend to mask the affects of carriage type.

Other limitations, though not quantified, are the need to compare productivity only within the range of parameters of a given study (i.e. less than 350 feet for the Maki carriage). Comparisons outside the parameters, though desired, may contain an additional source of error since they are inferred. Also, the change in regression coefficients when additional variables are added in to the model would produce different production rates for the same

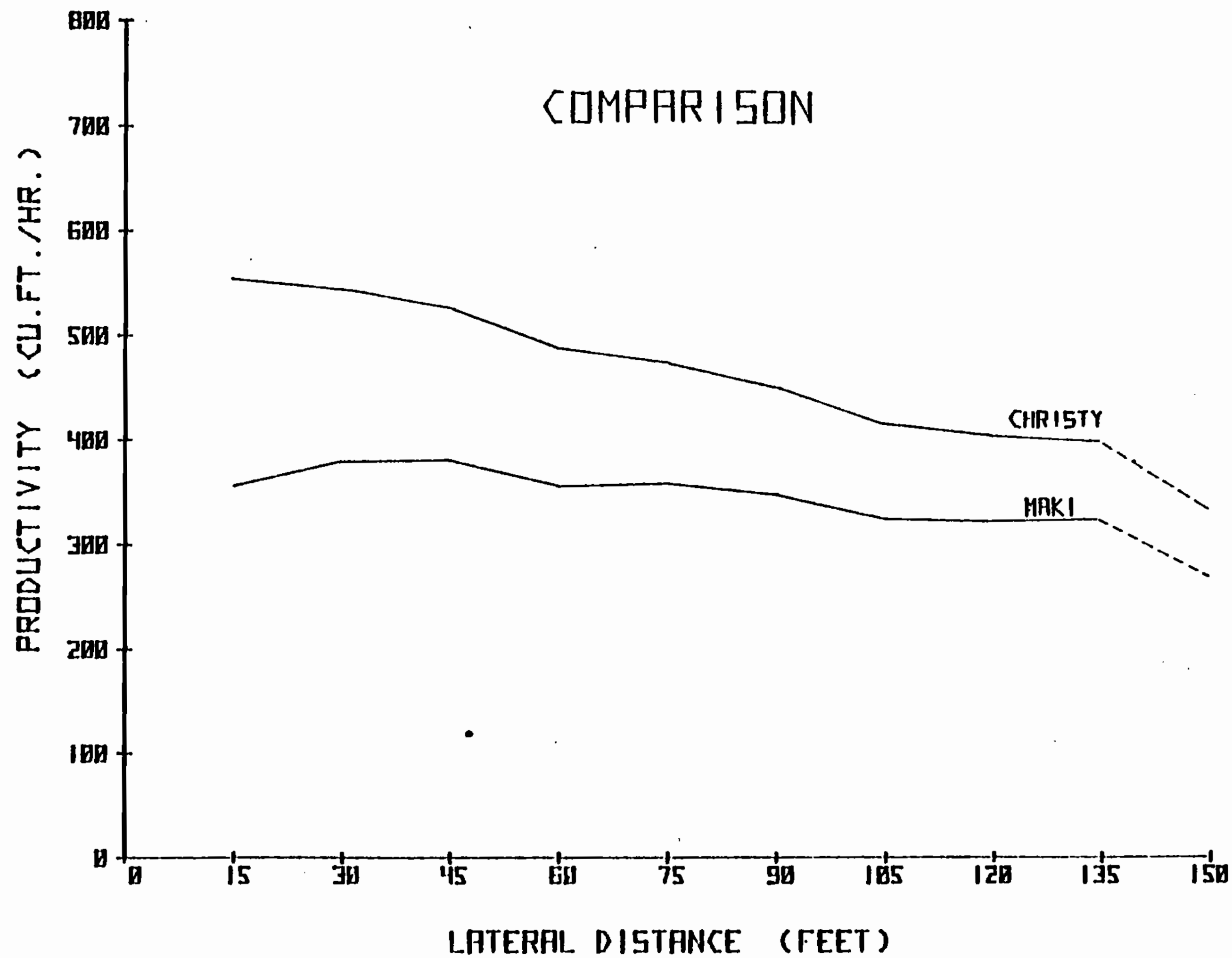


FIGURE 14. Comparison of Productivity of Two Skyline Stop Carriages

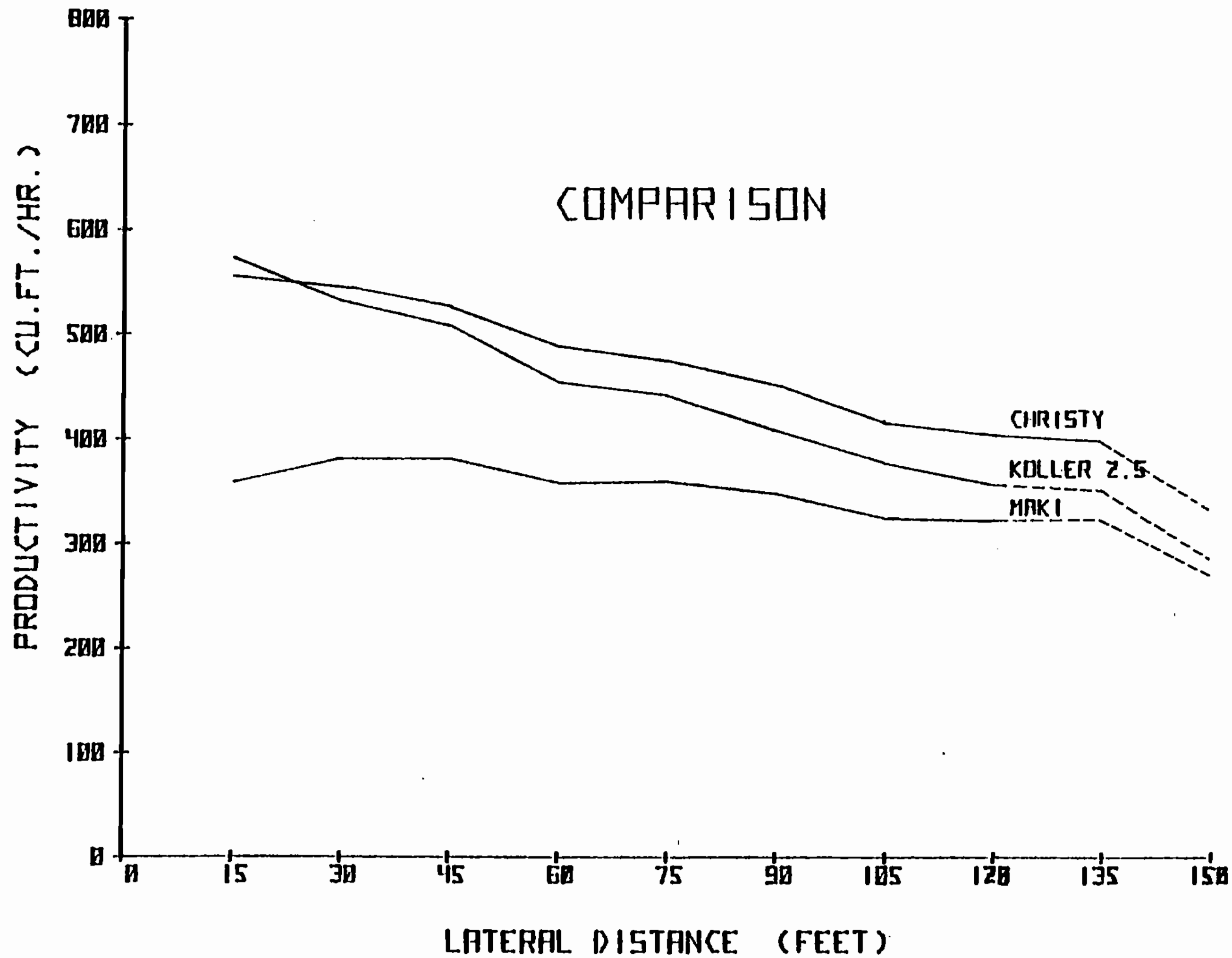


FIGURE 15. Productivity of Two Skyline Stop Carriages Compared to the Self-Clamping Hydraulic Carriage

carriage. This becomes a problem when two carriage study regression models do not include the same variable list. Some of the difference in productivity may be attributable to the difference in variables added to the models.

D. Summary of Simulation

Although the results of simulation, as shown in Figures 12 and 13 appear to be quite conclusive, they are rendered invalid as a result of the limitations of simulation with respect to this sort of comparison. The first objective of this simulation approach was to compare the differences in productivity attributed to the different carriage types. This is not possible since the differences indicated are influenced by factors not accounted for in the regression equations used in the simulation. The second objective, to quantify the sensitivity of productivity to yarding parameters is possible only to the extent that those factors unaccounted for in the regression models are assumed to remain constant throughout the studies and even then only qualitative observations can be made. Quantitative observations such as percent reduction in productivity due to a certain change in one of the parameters is not possible since the levels of productivity indicated are speculative and subject to the limitations mentioned.

VIII. CONCLUSIONS

The initial justification for the comparison of different skyline carriages was founded in the fact that studies involving similar conditions but different carriages showed different productivities. If these differences are to be attributed to the carriage types, then some element or elements of the yarding cycle must be uniquely affected by the carriage type. Therefore, it is necessary to evaluate the cycle elements affected by the carriage types.

Inhaul times are the same since the difference in carriage weights (maximum difference is 250 pounds between the Maki and the Wyssen) is small relative to the payload. The time spent unhooking the logs at the landing is the same for all three carriages also. The lateral yarding sequence however, is different for each carriage type. The Maki and Christy throw slack while the Koller and Wyssen carriages do not and the Maki, Christy and Wyssen carriages can be rigged with sliding chokers while the Koller carriages require a load hook to trigger the release mechanism. In addition, the Wyssen has the greatest spotting capability which allows for the selection ob the best combination of lead angle and extraction path on every turn.

Apart from the lateral yarding sequence, the only other affects on productivity are the delays unique to a carriage type. The following summary of the differences in the lateral yarding cycle and carriage delays points out the sources of differing productivities and serves to conclude the analysis presented here.

THROWING SLACK - In both the Maki and the Christy studies the tendency of these carriages to throw slack in the mainline at the end of outhaul was observed but not measured. As a result, the amount of slack thrown and its affect on reducing lateral outhaul are not known. The effect is however, probably small. As in the Wyssen study, if the average lateral yarding distance is 62 feet and the carriage throws 20 feet of slack, the pulling resistance is reduced for the first one third of the lateral outhaul distance. The average time required for the choker setters to pull the mainline out 62 feet in the Wyssen study was 0.517 minutes per turn. Therefore, one third of this or 0.14 minutes per turn would be affected if the Wyssen threw slack. Even if this affect were a 50 percent reduction, the savings in time would only be 0.07 minutes per turn or a savings of one minute every 14 turns. Also, the ability to throw slack is dependent upon the speed of the carriage when it strikes the skyline stop. Near the top of the corridor, the carriage has not traveled far enough to gain sufficient speed to throw slack and as observed in the Wyssen study, near the bottom of the corridor, both the sag in the mainline and the deflection in the skyline can slow the carriage, even to the point of stopping before it reaches the skyline stop. As a result, maximum slack is thrown only at intermediate slope distances. This further reduces the effects of throwing slack in reducing the lateral outhaul time. The numbers used here are only approximates, but they do serve to illustrate the minimal effect of slack being thrown in the the mainline.

SLIDING CHOKERS - Where sliding chokers are used instead of a load hook lateral yarding time is reduced, however, the amount of reduction has not been measured. In the Wyssen study, with an average of 2.05 logs per turn, the use of sliding chokers reduced lateral yarding time only when the butts of the two logs in a turn were more than two choker lengths apart. Were the load hook to be used in this situation, either one log would be hooked and yarded to within choker's reach of the second log or the second log would be yarded with the next turn. Where more than two logs per turn are hooked on the average, this difference becomes more critical.

SPOTTING ABILITY - As with the slack throwing and sliding chokers, the effect of spotting ability on productivity is observed but not measured. This ability should reduce the number of resets required during lateral inhaul. The average reset time per turn does not strongly support this however, Table 12 shows that the Wyssen, with the greatest spotting ability has only slightly smaller reset time per turn (at a normalized distance of 31 feet) than the Maki, which has the least spotting ability. The Koller carriages however, shows larger variation in average reset time per turn with the Koller 2.5 showing the smallest time of any of the carriages and the Koller 1.0 showing the largest. The choker setters in the Koller 1.0 study were students, not experienced loggers, and may have accounted for the higher reset time. As a result, the differences in resets may be due to factors other than spotting ability. In addition to affecting productivity, the spotting ability effects residual stand damage, but this has not yet been described or measured.

TABLE 12. Comparison of Resets

	RESETS (min. per turn)	AVERAGE LATERAL DISTANCE (ft)	** RESETS (min. per turn)
MAKI	0.2488	31	0.2488
CHRISTY	*	*	*
KOLLER 1.0	0.7658	70	0.3391
KOLLER 2.5	0.180	*	*
WYSSEN 2.5	0.3970	62	0.1985

* Information is not available

** Based on a lateral yarding distance of 31 feet

CARRIAGE DELAYS - Carriage delays (summarized in Table 10) indicate that the carriages differ by only 0.005 minutes per turn with the Christy having the greatest delays. The delays for the Maki and the Christy are largely the result of moving the carriage stop, while the delays for the Wyssen and Koller carriages are largely a part of the time required for cycling. Also of interest is the decreased delay time per turn for the Wyssen as the number of turns yarded increased. The decrease is a result of familiarization with the mechanics and operation of the Wyssen carriage and leveled off after about 400 turns for the study presented here.

In all four of these areas - throwing slack, sliding chokers, spotting ability, and carriage delays - differences in carriage type do not appear to be significant. In every case, unaccountable factors such as crew experience and terrain tend to overshadow the effects of carriage types on productivity. Because of this condition, the individual studies do not contain sufficient data to allow for accurate simulation of productivity as a function of the different carriage characteristics.

Comparison of skyline carriages on a productivity basis is therefore both unwarrented and infeasible. The valuable comparisons are those which have been made with respect to operating characteristics and limitations. Under this comparison scheme, the fixed cost, repair costs and adaptability of a carriage to available machinery become prime considerations in selecting a skyline carriage. Such considerations cannot be generalized, but are operator specific.

IX. FUTURE RESEARCH

The relative differences between carriage types are apparently quite minor compared to other factors which also influence productivity. As a result, further research on skyline carriages would be marginal at best.

Future research on the influence of such factors as crew selection, crew training, and site conditions on productivity may better serve to point out the potential improvements in productivity.

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SKYLINE PROFILE

A typical skyline profile is shown in Figure A-1. Note the change in ground slope at about the intermediate support jack location. This was typical of every skyline profile evaluated. This profile shows the skyline extending to a point on the slope opposite the slope being logged. This was typical of all but one corridor and was necessary in order to gain adequate deflection.

SKYLINE PAYLOAD ANALYSIS

The skyline profile of each unit was analyzed using the Skyline Analysis and Multispan Skyline Analysis programs (FEI 1982) developed for the Hewlett Packard 9830 desktop calculator. The analysis showed that all five units would require intermediate supports to maintain acceptable deflection and ground clearance. The assumptions used in the analysis were:

1. A safety factor of 3.0 was used for the safe working load.
2. A 3/4 inch skyline and a 5/8 inch mainline was used.
3. The height of the yarder tower was 25 feet.
4. The weight of Douglas-fir is 53.7 lbs. ft^3.
5. The weight of the carriage was 550 lbs.
6. The loaded carriage clearance was 10 feet.
7. The block in the tail tree and the jack for the intermediate support could both be rigged at height of 35 feet if necessary.

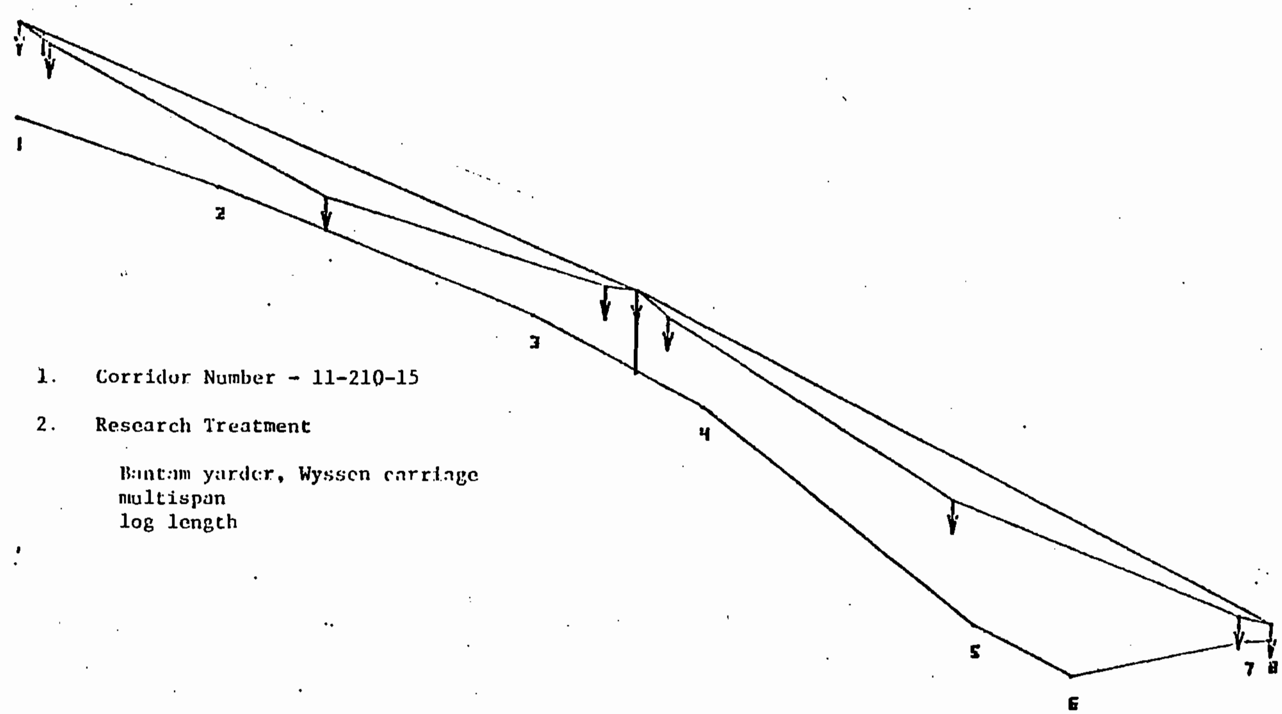
#11-210-15 GROUND PROFILE

<u>Scale</u>

Horiz. - 1" = 100'
Vert. - 1" - 45'

<u>Logging Layout</u>

maximum slope yarding distance	- 882 ft
slope distance - headspar to jack	- 420 ft
chordslope - headspar to jack	- 19%
chordslope - jack to tailspar	- 23%
analyzed inter. support height	- 25 ft
analyzed tailspar height	- 5 ft



1. Corridor Number - 11-210-15

2. Research Treatment

   Bantam yarder, Wyssen carriage
   multispan
   log length

Figure A-1. Example Skyline Profile

RIGGING THE INTERMEDIATE SUPPORT TREES AND TAIL TREES

The support system used for this study was the double tree intermediate support system. It required two sound trees, one on each side of the corridor, two anchor stumps, two blocks and straps and 150 to 200 feet of cable. The straps and blocks were hung about 35 to 50 feet high and the cable hung in the blocks, but not stretched tight between them. With the skyline fastened in the jack, the guys were tightened till the correct configuration was achieved, Figure A-2. The anchor stumps were selected slightly downhill from the support trees. All rigging of the support trees was done in compliance with the specifications of the Oregon Occupational Safety and Health Code, Div. 80, Logging.

All skylines were rigged with a tailtree. The skyline was passed through a lift block and anchored to a tree or stump. This rigging configuration places nearly vertical loads on the tailtree.

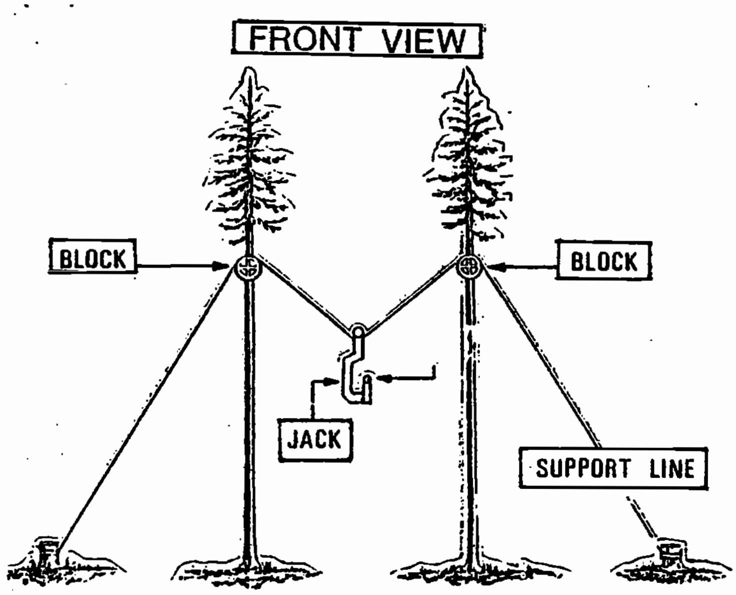


FIGURE A-2. Double Tree Support

APPENDIX B

OVERVIEW

The purpose for the time study in this analysis is to provide the response of seven dependent variables to twelve independent variables. This data forms the basis for predicting cycle times through regression analysis. These variables and their descriptions are presented here in detail.

DEPENDENT VARIABLES

The seven elements (dependent variables) and their descriptions are:

OUTHAUL - This is the time required for the carriage to move from the landing to the carriage-stop location. The activity starts when the carriage moves from the landing and ends when the carriage clamps to the skyline. Outhaul includes carriage cycling time.

LATERAL OUTHAUL - This is the time required to pull the mainline from the skyline corridor to the logs to be hooked. The activity begins when the carriage clamps to the skyline and a choker setter grabs the chokers and begins to pull the mainline laterally away from the corridor. The activity ends when the choker setter reaches the logs to be set. When the logs are scattered and cannot be reached from one location, the time ends when the choker setter reaches the furthermost log to be set.

HOOK - This is the time required to hook a turn of logs. The activity begins when the choker setter reaches the furthermost log to be set. The activity ends when the whistle is blown that indicates the start of the lateral inhaul element.

LATERAL INHAUL - This is the time required to yard a turn of logs from where they are set, to the skyline corridor. The activity begins when the whistle is blown that indicates the lateral inhaul element. The activity ends when the logs reach the corridor and the carriage unclamps from the stop location.

RESET - This is the time required to reposition the choker or lines, rehook a log, or unhook a log so that turn of logs is free to pass an obstacle. The activity starts when the whistle is blown to stop the movement of yarding lines. The activity ends when the turn passes the obstacle and resumes the normal activity (usually lateral inhaul).

Reset includes repositioning the carriage to help clear the obstacle.

INHAUL - This is the time to move a turn of logs from a position at the carriage-stop location to the landing. The activity begins when the carriage is released from the carriage-stop location. The activity ends when the forward travel of the logs stops at the landing. For the time keeper in the woods, this should be indicated by the slacking of the skyline.

UNHOOK - The time required to unhook a turn of logs. The activity starts when the turn of logs is positioned on the log deck and the chaser begins to unhook the logs. The activity ends when the carriage leaves from the landing.

DELAYS

Any interruption which caused a break in the normal sequence of the cycle time elements was noted and recorded as a delay. For every delay, the following information was recorded: 1) turn number, 2) cycle element during which the delay occured, 3) the type of delay, 4) the duration of the delay. All delays were catagorized as either operational or non-operational. Operational delays were those which occured while the crew was in the process of yarding (i.e. lines breaking, refueling the yarder, some carriage malfunctions, etc.). Non-operational delays were those which either caused the yarding to begin late and could have been done before the crew arrived in the morning, or those delays which were directly attributable to the time study itself (tours, discussions of methods, measuring independent variables, etc.). The following is a list and brief description of the operational delays recorded in this study:

PLANNING DELAYS - This is the time used by both the loggers to plan the yarding activities and the time study data recorders to make changes in their methods.

LANDING DELAYS - During many of the turns, the yarder operator or the chaser would make yarder adjustments, reposition logs on the deck, or take personal breaks after a turn is unhooked. Because the data takers were often too far down the corridor to distinguish the exact nature of the delay, it was simply classified as a landing delay.

REPOSITION YARDER - In the event that the deck height became too great, the yarder had to be repositioned to either side of the deck in order to continue yarding. The time required to make this move, was classified as a reposition delay. This delay ended when yarding was resumed with the outhaul of the carriage.

WORKING DELAY - This delay, like the landing delay was used as a catch-all. Any time spent actively getting the log to the landing which was not normally a part of any cycle element and which did not fall under any of the other delays was called a working delay. Examples of this delay would be sawing a downed log which has hung-up a turn, clearing limbs in order to hook the next turn, etc.

HANG-UP DELAY - This includes any time spent in severing a partially cut stump, reseting the choker with an extra wrap to twist the stem off the stump and time spent rehooking a hang-up which has been pulled down.

EQUIPMENT DELAY - Any time spent servicing saws or the swing skidder was classified as equipment delays.

CARRIAGE DELAY - This delay includes any time spent servicing the carriage or correcting a carriage malfunction.

YARDER DELAY - Any time spent repairing the yarder or adjusting the lines on the yarder was catagorized as yarder delays.

RIGGING DELAY - This delay includes any time spent untangling lines, tightening guylines, rerigging tailblocks or intermediate support blocks, etc.

INDEPENDENT VARIABLES

Of the twelve independent variables, five were indicator variables and were simply observed and recorded. The remaining seven were measured and recorded for each turn. The abbreviated forms (mnemonics) which will be used throughout the rest of this report and a brief description of each are as follows:

SLOPE DISTANCE - (SLPD) is the distance in feet from the yarder to the carriage for each turn estimated to the nearest five feet. Before yarding, corridor distances were measured and trees along the corridor were painted with the distance every 50 feet to aid in distance estimates.

LATERAL DISTANCE - (LATD) is the distance perpendicular to the skyline from the center of the corridor to the furthermost log hooked in a given turn.

NUMBER OF LOGS PER TURN - (NLGS) this is the number of pieces hooked for a given turn.

LEAD ANGLE - (LDAL) this is the angle between the skyline and the mainline during the INHAUL element of the yarding cycle (see figure B-1).

LOG ANGLE - (LGAL) this is the angle between the mainline line and the log whose longitudinal axis deviates the most from the direction of the mainline for a given turn (see figure B-2).

TURN VOLUME - (VOL) this is the total cubic foot volume for a given turn.

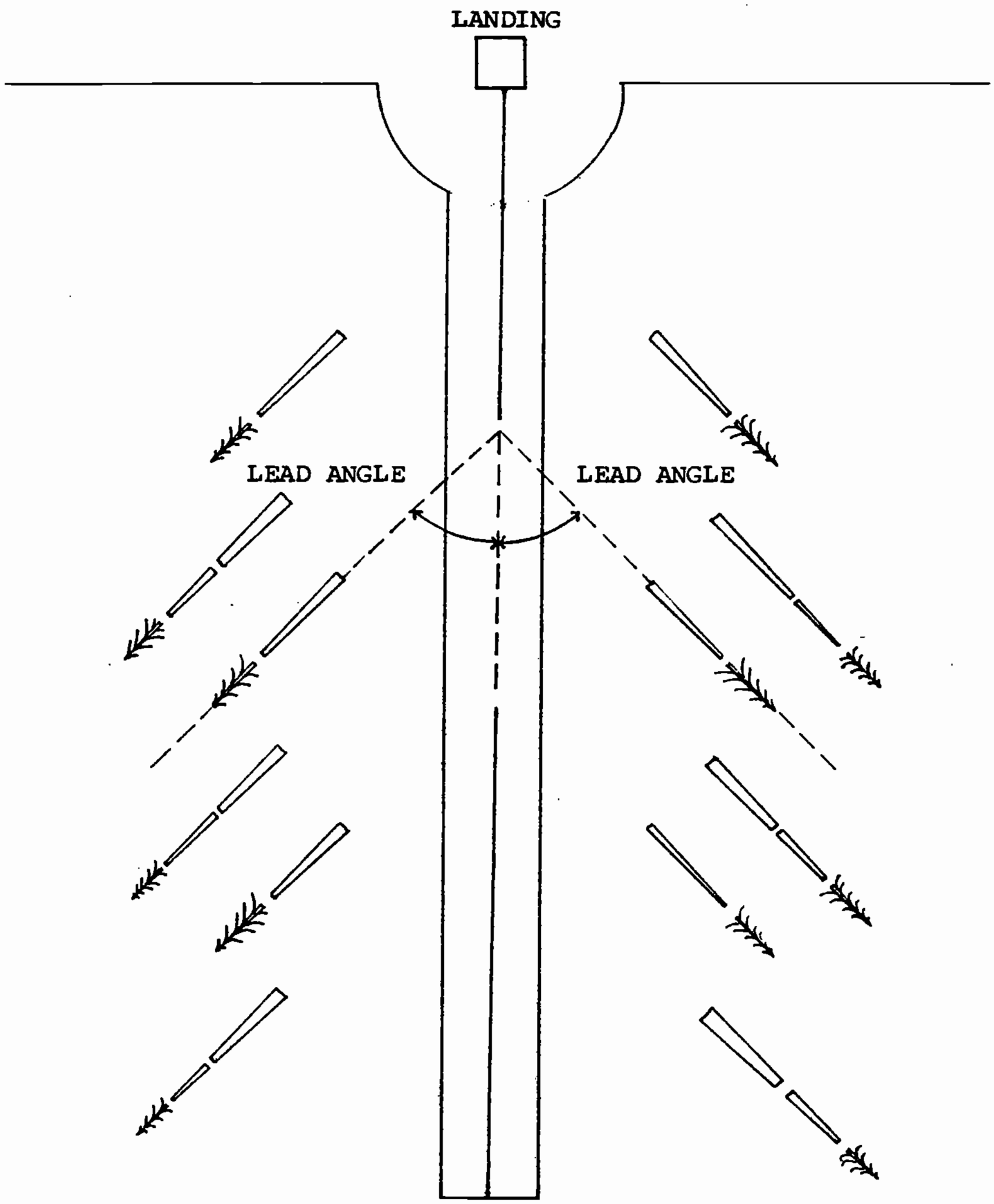


Figure B-1. Definition of Lead Angle

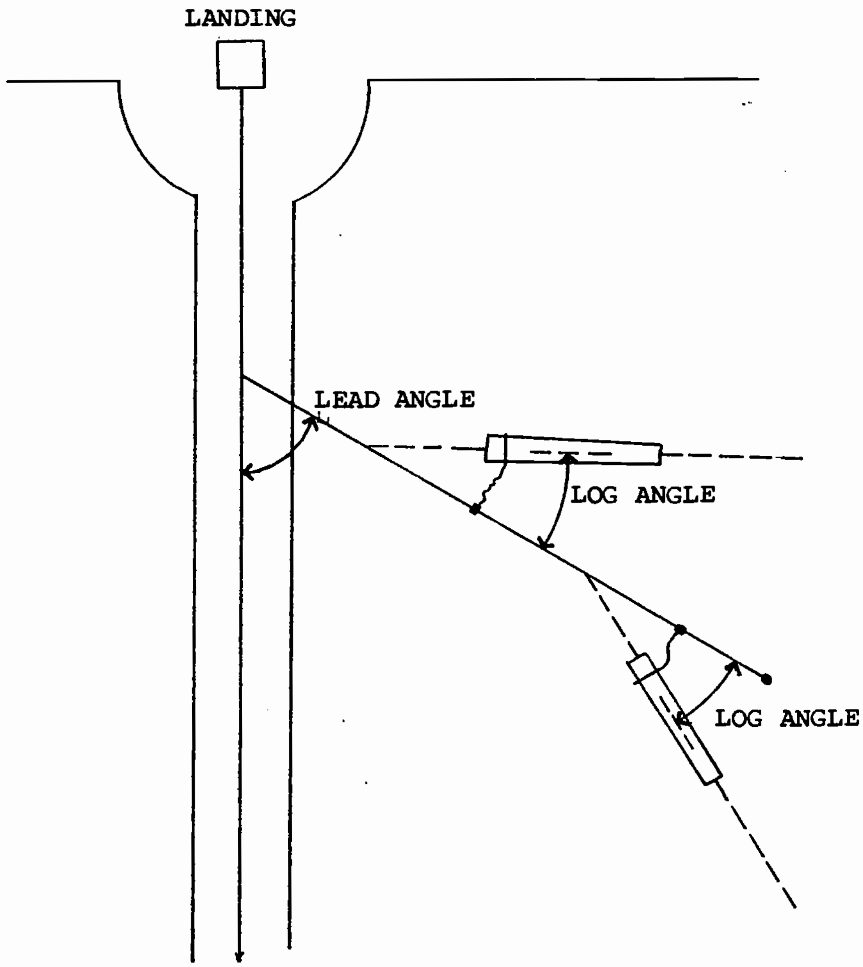


Figure B-2. Definition of Log Angle

CARRIAGE HEIGHT - (CRHT) is the height of the carriage pendulum above the ground during lateral inhaul when the carriage is clamped to the skyline.

LANDING - (LNDG) Landings are rated by estimating the degree to which skidding, yarding, or loading subsystems are effected by landing area characteristics.

Ratings:

1. Spacious landing area. Neither decking nor loading is hampered by any features of the landing.
2. Adequate landing area. Either decking, loading, or both are occasionally hampered to a moderate degree by a small or poorly arranged landing.
3. Limited landing area. Either decking, loading, or both are continually hampered to a high degree by a small or poorly arranged landing.
4. Not applicable to these observations. (For example, landing rating would not be applicable to logmaking subsystems.)

DECK - (DECK) Decks are rated on the effect that the deck arrangement and structure have on decking and loading.

Ratings:

1. Deck has all logs even at the end and parallel to each other. Greater care and time would be required to construct a deck of this type. Such a deck permits the loader to operate with maximum speed in picking and sorting logs.
2. Deck has some uneven log ends and not all logs are parallel. Generally, less time would be consumed in decking, but the loading operation would be slowed somewhat.

3. Deck has practically no log ends even and the logs are jack-strawed. Such a deck is generally the easiest to construct, but the most difficult and time-consuming from which to load.
4. Not applicable to these observations. (For example, deck classification would not be applicable to logmaking subsystems.)

OPERATOR - (OPER) Operators are rated on the basis of observed performance. In a one-man operation, obviously there is only one operator to be rated. In a crew operation, such as a skyline yarding system, the crew performance must be rated collectively. The term "performance" is a combined measurement of motivation, skill and experience.

Ratings:

1. Above average performance. 130%
2. Average performance. 100%
3. Below average performance. 70%

SURFACE CONDITION - (SCND) Surface condition is rated on the degree to which existing surface conditions hamper activity.

Ratings:

1. Soil dry, firm; little or no loss of traction to men or equipment.
2. Soil slightly wet, soft; moderate loss of traction to men or equipment.
3. Soil very wet and muddy, loose; excessive loss of traction to men or equipment.

SURFACE TYPE - (STYP) Surface type is rated on the degree to which surface obstructions hamper activity.

Ratings:

1. Little slash, downtimber, stumps, brush, or rocks; little or no detouring or maneuvering of men or

equipment necessary.

2. Some slash, downtimber, stumps, brush or rocks; moderate detouring or maneuvering of men or equipment necessary. Traverse time is double.
3. Heavy slash, downtimber, stumps, brush or rocks; excessive detouring or maneuvering of men or equipment necessary. Traverse time is triple.

METHODS OF MEASUREMENTS

LATERAL DISTANCE DETERMINATION - What was actually measured was length of the mainline from the carriage to the furthermost log. This line distance recorded represents the hypotenuse of a right triangle such that (line distance) x (sine of the lead angle) = lateral distance. Lateral distance thus determined is the distance line is pulled to the side of the corridor perpendicular to the skyline.

LEAD ANGLE DETERMINATION - For every turn, the azimuth of the mainline from the carriage to the logs was measured with a hand compass and recorded with an accuracy of $\pm$ 5 degrees. The azimuth of the corridor was also measured and recorded sometime during the yarding. When the corridor was finished, the difference between the two azimuths was computed and centered as the lead angle. This method was chosen because of its expediency and accuracy in the field.

LOG ANGLE - The azimuth of the log whose longitudinal axis deviated the most from the azimuth of the mainline was also recorded. This measurement was always taken from the chokered end of the log to the free end. In this way, the difference between the lead azimuth and the log azimuth represents the log angle.

VOLUME DETERMINATION - During the felling study, both the large and small end diameters of the logs were measured in order to compute volume. Using this data, the small end diameter was regressed using the large end diameter as the independent variable. During the yarding, only the large end diameter and the length of the logs were recorded. When the yarding was completed, the small end diameters were predicted using the regression equation and cubic foot volume computed using the Smalian formula described earlier in this report.

TIME STUDY DATA SHEET

The following information must be completed at the top of every data sheet:

Observer - the analyst's name

Comment - brief note on any unusual conditions occurring on that day (crew, equipment, landing, etc.).

Date - Day/Month/Year

Number consecutive pages

Corridor - identification number of the corridor being studied.

Corridor azimuth - measured at the yarder in the direction of the tail tree.

System being used - circle the appropriate one.

TURN NUMBER - In the data section below, the turns for each corridor will be numbered consecutively beginning with the number one (1) at the start of each new corridor.

ELEMENT TIME - For element times, enter three digits representing the time required to perform the element. Enter time to the nearest one-hundredth of a minute. Enter decimal portion to the right of the dashed line; enter whole number portion to the left of the dashed line. If a reading is missed, enter 'M'. If the element does not occur, leave it blank.

FORMAT - The data should be recorded such that for a given turn, the elements and variables (column 1-27 and 39-70) need not be recorded on the same row as the delay (column 28-38) for that same turn. Using this method, one section, elements and variables or delays, may use up all the rows on a data sheet before all the rows in the other section are filled in. In the event that this happens, the time keeper must start a new sheet recording entries from both sections in the first row. Consecutive turn numbers must also be carried over to the new sheet. In the event that Landing, Deck, Operator, Surface Condition, or Surface type do not change through a number of consecutive turns, numbers need not be recorded in the spaces corresponding to those turns. Instead, a vertical line drawn through the rows having the same rating is sufficient.

DELAYS - Delays will cause a break in a cycle element. In order to record the total element time, the elapsed time before the delay must be recorded and the remaining element time after the delay must also be recorded and should be entered in the following row. The turn number and other information need not be copied into this row, since it will be used only as a computational device in determining total element time. The delay must also be recorded. Eleven (11) spaces will be used for delays. The first three (3) are a code describing the type of delay. These codes will be taped to the back of the time keeper's clipboard for easy reference. The next four (4) digits give the turn number and activity (element) number. For instance, a delay during or immediately after the hook element (#3) turn 67 would be recorded as <u>0673</u>. The last four (4) digits are the time in decimal minutes taken up by the delay.

The following delays and their codes were used in this example:

510 Planning Delay
520 Landing Delay
528 Reposition Yarder
570 Working Delay
571 Hang-up
580 Equipment Delay
583 Carriage Malfunction and Maintenance
584 Yarder Adjustment
586 Rigging Gear and Yarding Lines

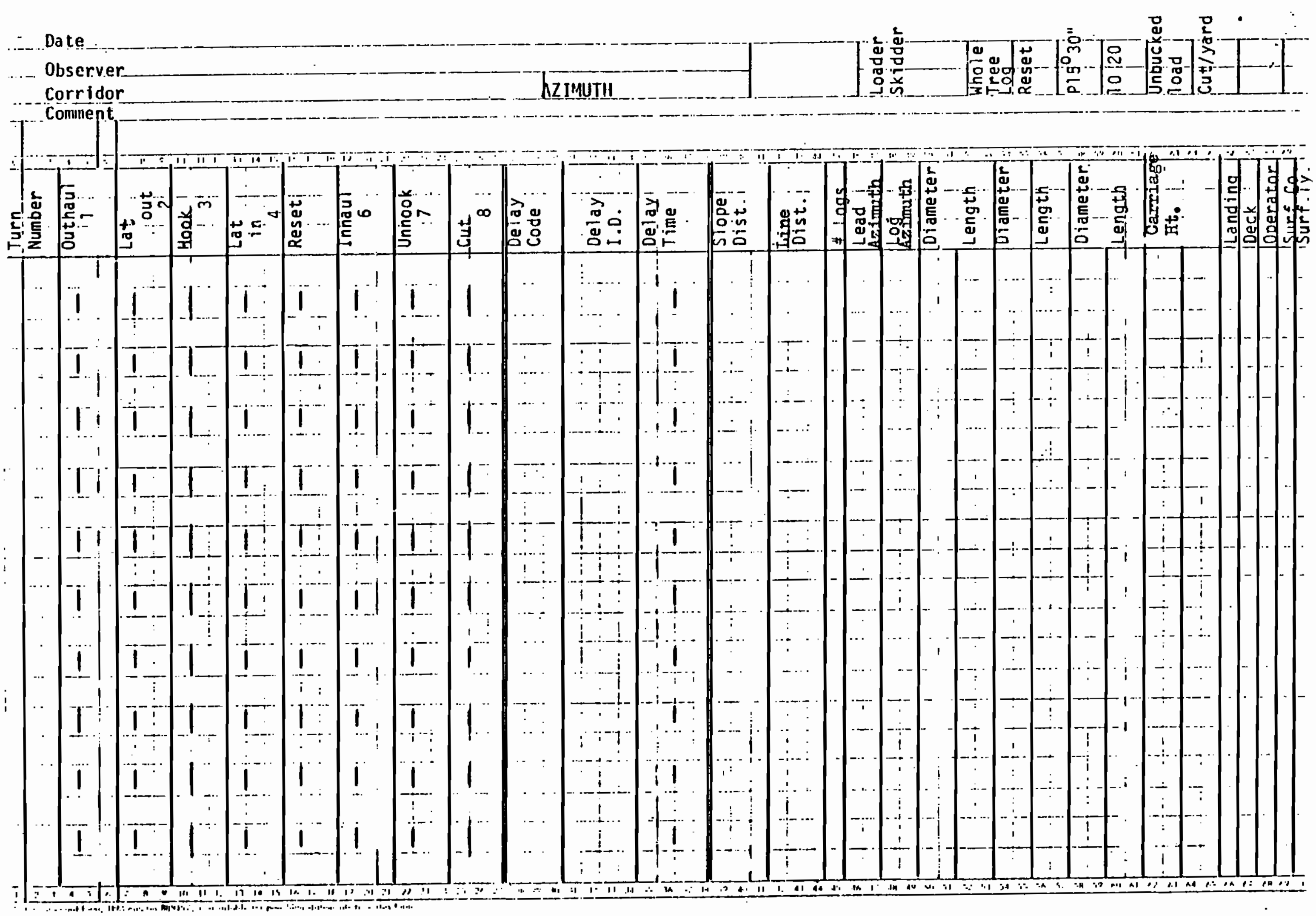


Figure B-3. Field Study Data Sheet