PREDICTION EQUATIONS FOR SKIDDING OUTPUT

By

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PREDICTION EQUATIONS FOR SKIDDING OUTPUT

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CHAPTER I

INTRODUCTION

By comparing the logging industry of today with that of thirty years ago, it can be seen that a major push of the industry has been towards complete mechanization. There is a constant effort involved to build new machines to meet the new concepts of logging.

The main objective of logging mechanization is to lower the costs of transporting timber from the area where it is cut to a landing area where it is assembled and transferred to trucks which will carry the logs to the mill.

There are three major ways of accomplishing the process mentioned above: 1) fell the trees and in turn, limb and buck them where they fall and then skid them to the landing; 2) fell the tree and skid the tree, limbs and top to the landing where the limbing and bucking is performed; 3) perform a single machine operation using a machine which cuts, limbs, bucks and stacks the timber in a bunch, with the bunches then being skidded to the landing. In all three systems, it can be noted that skidding of the tree is involved at some time or other.

The Problem

Logging can be defined as a problem in materials handling and transportation, and it is evident that the area of greatest saving on a dollar basis remains in the skidding phase, the initial movement of timber from the stump to the primary assembly point. While much study and experimentation has been done, the skidding of timber still remains most difficult to evaluate in regard to the efficiency of methods and equipment on various types of forests.

Lumber production costs from the standing tree to rough green or dressed lumber indicate that direct costs of cutting and skidding timber amount to about 40 percent of the delivered cost of timber, 30 percent of the rough green costs, and 25 percent of the dressed lumber costs. Cutting and skidding is the largest single cost item in the process of producing lumber, and therefore it presents the greatest opportunity for cost reduction.

There have been many studies in the area of skidding and cost reduction, however, there have been few actual attempts to combine the physical inputs or variables that affect skidding in such a manner as to predict the time that it would take to skid a given acreage or amount of timber.

Objectives

The main thrust of this study will be the development of prediction equations for estimating yield production per hour for several different models of four wheeled rubber-tired skidders.

With the results of this model and the knowledge of the cubic volume to be logged, skidding costs can be estimated with relative accuracy.

Assumptions

There are certain basic assumptions which must be made. The first is that for all of the models constructed, there will be no variation between operators. This assumption is made on the basis that the models were constructed with an average producing operator. The second assumption is that there will be no variation between machines of the same type and make involved in the construction of the models. The basis for this is that the machines used in the model building process were the average of the machines in use.

CHAPTER II

LITERATURE REVIEW

Before a prediction equation or a multiple regression equation can be formed, the dependent and the independent variables must be designated. In this study, the dependent or the output variable will be the amount of wood that is delivered to the landing by the skidder. The major problem is the determination of the independent variables or those factors which directly effect the dependent variable or the output.

In a study of logging systems for northern hardwoods, Gardner [5] stated that skidding and bunching production depends on slope, soil, tree size, stand density, season of the year, distance, amount of brush and down timber, silvicultural requirements, and logging methods. Decking production depends only on the slope of ground, height of piles, and size of timber. He determined that the influences of brush and down timber, silvicultural requirements, and logging methods on skidding production is very difficult to evaluate. Gardner found that bunching and decking times are directly proportional to the number of trees or logs handled per thousand board feet. Bunching times were also directly proportional to the number of trees cut per acre. The most critical evaluation made was that tree-length bunching decreased bunching and decking time per thousand board feet by 12.4 percent as compared to log-length bunching and skidding.

In a study of three different types of skidding operations by Schillings [12], it was found for most operations observed that rubber-tired vehicles were the most economical, assuming equal operator efficiencies, when compared to a shovel logging operation and a high-lead operation. It was noted that there was an increasing use of the rubber-tired vehicles throughout the country. Schillings also felt and pointed out that downtime and operator unfamiliarity with rubber-tired vehicles did not permit them to realize maximum potential efficiency from such skidders. They also preferred crawler tractors because they were needed in other phases of logging operations.

In a related article by Schillings [13], it was noted that to effectively predict costs and efficiency, one must have the following vital information: 1) the approximate distance in feet from the deck to the general area where logs are hooked; 2) the type of terrain in which the crawler must operate; 3) the average slope in percent over the skidding path; and 4) the tractor operator's efficiency.

By comparing the above variables with each other, efficiency and cost ratings were applied to the various types of skidding operations.

McCraw [8] showed the differences in production in cunits per hour of medium (under 75 horsepower) and large (over 75 horsepower) wheeled skidders over the observed range of skidding distances. In Figure (1) the vertical lines show the variation in production at the distances shown and the sloping lines show the average production of the two horsepower classes of wheeled skidders for softwoods in tree-length skidding operations. The difference as shown was due to a number of factors: load volumes per turn, skidding distances and the skill of the crew.

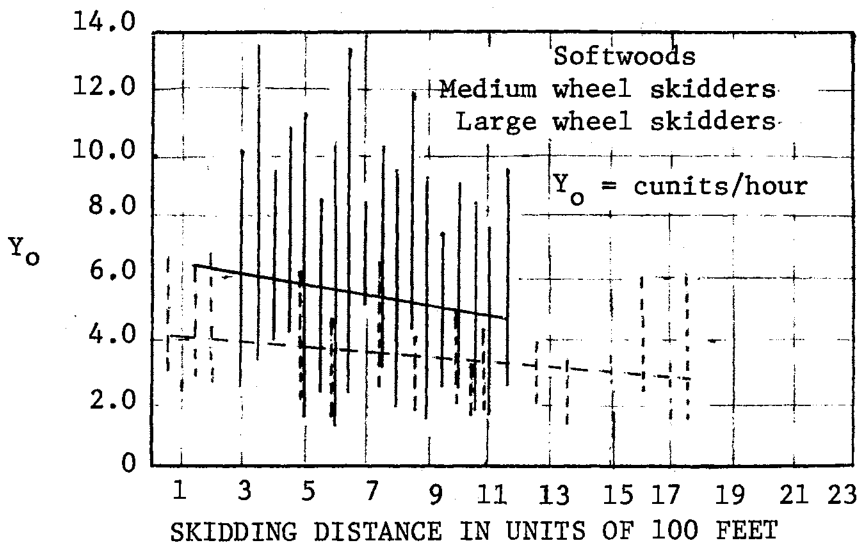

Figure 1. Variations in Skidding Production as Related to Distances.

Source: McCraw, W. E. "How to Profit from Mechanized Logging." Canadian Forest Industries, 1967, Vol. 87(7), pp. 34-38.

Note that these data were obtained by averaging 1400 turns for the medium and large size wheeled skidders.

Figure (2) shows variations in production of medium and large wheeled skidders with distance, in which the volumes skidded per turn were grouped into 30 cubic feet load classes. By taking 90 and 150 cubic feet as representative loads for medium and large wheeled skidders, it was noted that the average production per hour over a skidding distance of 900 feet is 2.7 and 5.6 cunits, respectively, for the two classes of wheeled skidders. This range of production achieved by each wheeled skidder class brings out the importance of optimum loads. It was also noted that the medium sized wheeled skidders on a one-way skidding distance of 900 feet have a range of production of 1.5 to 3.7 cunits per hour with loads from 60 to 120 cubic feet, and the large wheeled skidders show a range of 4.9 to 7.7 cunits per hour between loads of 150 to 200 cubic feet.

McCraw found that although the depreciation of the capital investment for the large wheeled skidder is higher per hour than for the medium wheeled skidder, the greater production per hour of the large wheeled skidder reduced the investment on a per cunit basis to 20 cents compared to 30 cents per hour for the medium wheeled skidder. By this comparison, it can be seen that if the annual depreciation remains constant and the wages of the workers remain relatively constant then increased productivity becomes the major factor in reducing costs.

As a result of analyzing the data, McCraw found that: 1) optimum loads should be skidded on every turn if at all possible to maintain good production with both medium and large wheeled skidders; 2) larger loads permit wider spacing of landings and haul roads as acceptable

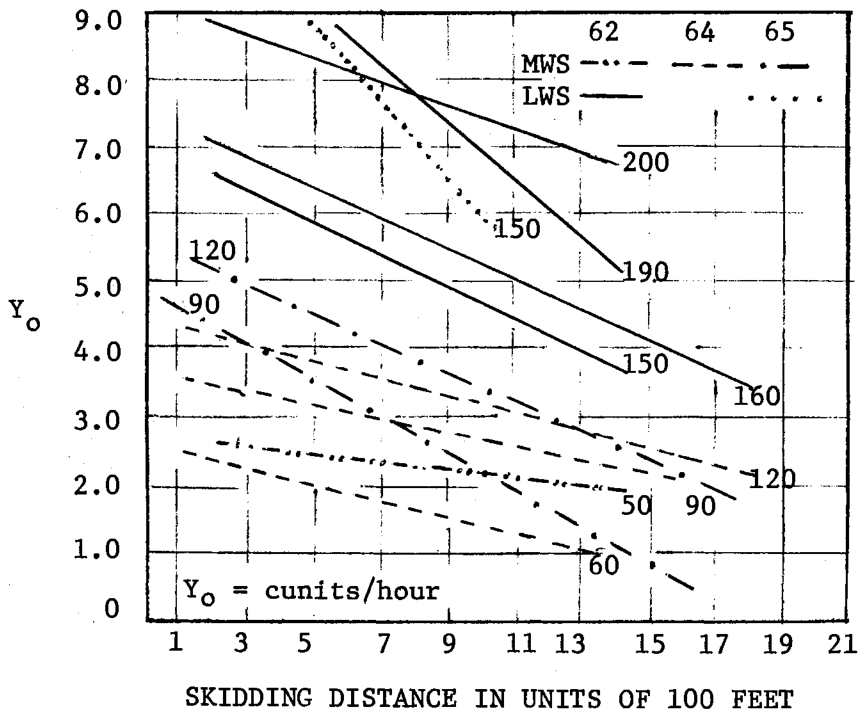

Figure 2. Skidder Output in Cunits per Hour.

Source: McCraw, W. E. "How to Profit from Mechanized Logging." Canadian Forest Industries, 1967, Vol. 87(7), pp. 34-38.

production can be maintained over longer distances; 3) tree-length skidding to a landing reduces manual labor in load handling, insures larger volumes per turn and increases skidding production on a comparative basis; and 4) production can be increased by selecting logging equipment appropriate for the size and weight of the timber being logged.

In a second study by McCraw [9], the determination of an effective prediction equation to forecast the hourly production of four wheeled, rubber-tired, medium horsepower skidders was made. The major factors affecting output were load volume in cubic feet, skidding distance, tree volume in cunits, merchantable, residual, and total number of trees per acre. Soil moisture and a soil trafficability factor were also computed daily.

The data were analyzed using group averaging techniques to determine the basic relationships existing between work elements, productivity and the environmental factors. The determinations made were: 1) whether the relationships were linear or curvilinear; 2) whether the various factors could be combined by multiplication or addition to produce new or more closely related variables; and 3) whether there were any transformations that might be necessary in analyzing the data.

In the analysis, the work elements were separated into five groups:

1. Load handling elements: choking, winching, un-choking.
2. Load moving elements: travel loaded time and travel empty time.
3. Minor work elements: decking, turn, and back.
4. Nonproductive elements: skid trail preparation, wait for timber, etc.
5. Delay elements: mechanical, personal, unnecessary.

After the above elements were separated and classified, an individual prediction equation was found by the stepwise multiple regression technique. The following equations approximate the load handling elements mentioned above where Y is the hourly production in cunits.

Equation 1. Choking: (359 observations)

$Y = -0.270 + 67.19X_1 + 0.0012X_3$;

$\overline{Y} = 12.09$ cunits/hour; $R^2 = 37.0$ percent;

where X_1 = tree length volume in cunits;

X_3 = merchantable volume in cubic feet/acre;

variance: 100.9;

Equation 2. Winching: (359 observations)

$Y = 18.66 + 67.02X_1$;

$\overline{Y} = 28.4$ cunits/hour; $R^2 = 7.8$ percent;

where X_1 = tree length volume in cunits;

variance: 595.3;

Equation 3. Unchoking: (359 observations)

$Y = -13.46 + 248.3X_1 + 0.293X_3$;

$\overline{Y} = 40.2$ cunits/hour; $R^2 = 39.7$ percent;

where X_1 = tree length volume in cunits;

$X_3 = X_4 + X_5$, where X_4 = volume of residual stems/acre, and X_5 = number of tree lengths/load;

variance: 917.1;

Equation 4. Load Handling: (359 observations)

$Y = 0.428 + 28.67X_1 + 0.00225X_3$;

$\overline{Y} = 5.95$ cunits/hour; $R^2 = 36.7$ percent;

where X_1 = tree length volume in cunits;

$X_3 = X_4 + X_5$ as above;

variance: 13.03.

McCraw tested many variables in these equations but only three variables were found to be significant in the turn elements. The non-significant variables were volume of residual stand per acre, number of tree lengths per load, and skidding distance. McCraw also felt that it was necessary to construct another regression equation to predict load volumes in cunits per turn as these were observed to be significant in predicting production.

Equation 5. Factors Affecting Load Volumes per Turn:

(359 observations)

$$Y = -0.1811 + 0.000099X_1 - 0.000769X_2 - 0.0910X_3 + 1.949X_4;$$

$\overline{Y} = 0.63$ cunits; $R^2 = 83.5$ percent;

Symbol (Y_L)

where X_1 = merchantable volume (cu. ft.) acre; X_2 = number of merchantable trees acre; X_3 = number of tree lengths/load; X_4 = tree length volume in cunits;

variance: 0.0203.

It was found that the number of residual trees/acre, skidding distance and total number of trees/acre were nonsignificant factors. He also admitted that the R^2 values were low with the exception of Equation 5 which indicates that even variables included in equations do not explain a great deal of the observed variation in the observed hourly productions.

McCraw also found that there was a general lack of association of travel times to soil types and slopes due to characteristic features of wheeled skidders, particularly the fact that the large low pressure tires absorb ground roughness, resist soft soils and the like, with little apparent loss of speed. Another consideration acknowledged was that the skidders were observed under terrain conditions where horsepower was not a critical factor in determining travel speeds, as the average was 2.85 miles per hour with an observed maximum of 12.0 miles per hour in the 1964 data.

Three more regression equations were formulated using skidding production, travel speeds loaded and travel speeds when empty as dependent variables; load volume, the natural logarithm of the skidding distance, soil trafficability and trail preparation as independent variables to predict the load moving elements.

Equation 6. Factors Affecting Travel Empty Times:

(472 observations)

$Y = 1.072 - 0.117X_1 + 0.220X_4$;

$\overline{Y} = 0.39$ minute/100 feet; $R^2 = 26.0$ percent;

Symbol (Y_{TE});

where X_1 = natural logarithm of skidding distance;

X_4 = soil trafficability factor; non-significant factors; trail preparation and load size;

variance: 0.0335.

Equation 7. Factors Affecting Travel Loaded Times:

(472 observations)

$Y = 1.131 - 0.110X_1 - 0.029X_3$;

$\overline{Y} = 0.43$ minute/100 feet; $R^2 = 15$ percent;

Symbol (Y_{TL});

where X_1 = trail preparation;

variation: 0.060:

Equation 8. Effect of Trail Preparation and Soil Trafficability on Skidding; (472 observations)

$Y = 7.464 + 0.0267X_1 - 1.045X_2 + 0.167X_3$;

$\overline{Y} = 2.610$; $R^2 = 56.9$ percent;

where X_1 = load volume in cunits;

X_2 = natural logarithm of skidding distance;

X_3 = trail preparation and soil trafficability;

variance: 1.010.

It was found as a result of analyzing the above data that skidding distance and volume per turn are the major factors in the movement of timber with trail preparation and soil trafficability as minor factors.

Computing an equation for the minor work elements was found not to be fruitful as these elements are not carried out on all skidding operations. These elements were included in the total cycle time and a mean time per turn for these elements was calculated. The average time per turn for the minor work elements was 1.01 minutes with a standard deviation of $\pm$ 0.69 minutes (Symbol (T_N)).

In computing the nonproductive work elements, it was found that they were similar to the minor work elements. The mean times per turn and the nonproductive times per turn were added to obtain one total time per turn (Symbol (Y_N)).

In computing the delay times, it was noted that delay occurred in 51 percent of all the turns observed, and the mean of total delay times in the turns with delays was 4.45 minutes (Symbol (Y_D)). An interesting feature found in analyzing the delay times was that their occurrence and duration are random. Also, delays are not strongly related to any of the environmental factors measured in the study.

In illustrating his technique, the following data were assumed by McCraw:

	Item	Data
1)	Total stems per acre:	500
2)	Average estimated merchantable tree length volume:	0.125 cunit
3)	Average estimated merchantable volume per acre:	2500 cubic feet
4)	Estimated number of merchantable trees per acre:	200
5)	One way average skidding distance in 100 foot units:	8
6)	Assumed average number of tree lengths per turn:	6
7)	Mean minor work and nonproductive times per turn:	2.0
8)	Mean delay time per turn:	
9)	Predicted production per turn in cunits per hour = $\frac{\text{Load Volume (cu.ft.) x 60}}{\text{Total cycle time (min.) x 60}}$	

where total cycle time = $D(Y_M) + Y_N + Y_D + 60 \times \frac{(Y_L)}{(Y_N)}$

where $(Y_M) = ((Y_{TE}) + (Y_{TL})) \times D$; where D = data.

By substituting in the data into the equations the following equality resulted:

$$Y_T = \frac{60 \times 0.7022}{18.485} = 2.23 \text{ cunits per hour}$$

which completes the prediction process. It is interesting to note that with this process an overall R^2 cannot be given, thus there can be no relation with the original data, only tests with future data can verify the results.

It is equally interesting to note that if the total stems per acre, merchantable trees per acre, and average estimated merchantable volume per acre were omitted, the production in cunits per hour as calculated by the above equation would decrease by only 0.20 cunits per hour with the low R^2 values and the combining of so many equations, this appears to be significant in determining the relative importance of the variables in the prediction model and in the area of expenditures of money in the gathering of data.

The purpose of McCraw's study was to determine the variable factors which need to be measured and those which do not need to be measured in the predicting of logging production. This purpose was accomplished and it seems as though thought could be given to the elimination of a few more.

In a second similar study of skidding machines, McCraw [10] refuted his earlier combination of numerous prediction equations for skidding output per hour for a new single equation which has many features of the equation used in this study. McCraw found that combining numerous equations with varying R^2 values was not accurate in explaining the variance represented by the observations. A new prediction equation was arrived at and was presented in the form of:

$$Y = b_0 + b_1X_1 + b_2X_2 + \ldots b_nX_n = \text{cunits per hour.}$$

The type of skidders involved in the study were apparently of many different makes; however, they were all assumed to be choker type skidders which required manual setting of the chokers. The data was collected over a period of five years in which 3,480 turns were observed.

In the formulation of the equation, Y was the measured output per hour of the skidder which eliminated the necessity of timing each individual turn. Table I indicates the prediction equations found by McCraw. Table II indicates the final equations that were found to be relevant after averaging the values found in Table I.

In a test that was performed by McCraw to determine the accuracy of the equations, the softwood log-length observations or Y_0, not used to produce the prediction equation were used versus the $\hat{Y}$, or the values found from the equation when the independent variables corresponding to each Y_0 value.

The percentage deviation was calculated by using:

$$\frac{Y_0 - \hat{Y}_T}{Y_0} \times 100 = \text{percent}$$

A 'T-Test' was then carried out to determine the validity of the null hypothesis. The expected mean for the null hypothesis was 0 and the test showed that the difference of 0.273 was not significant. The hypothesis was not rejected.

It is significant that all of the literature reviewed agrees that there are certain variables that effect skidding more than others, however, there is little agreement on any one factor which should be included. McCraw seems to be alone with the idea that one can predict future skidding time by combining relevant variables into a regression technique.

TABLE I

PRODUCTIVITY PREDICTION EQUATIONS*

Type	Year	Obs.	R^2	
SWTL	1964	472	0.57	$Y = 7.46 + 2.67X_{16} - 1.04X_{11} + 0.167X_{12}$
SWTL	1967	113	0.51	$Y = 5.40 + 3.54X_{16} - 0.816X_{11} + 0.818X_{15}$
SWTL	64-67	383	0.57	$Y = 4.65 + 2.42X_{16} - 1.08X_{11} - 0.24X_{13} + 2.47X_{17}$
HWTL	1965	201	0.56	$Y = 7.01 + 2.74X_{16} - 1.20X_{11} - 0.46X_{14}$
HWTL	1967	102	0.56	$Y = 5.93 + 1.46X_{16} - 0.680X_{11} + 0.45X_{14} - 1.33X_{15}$
HWTL	65-67	455	0.50	$Y = 5.90 + 2.00X_{16} - 0.79X_{11} + 0.44X_{14} - 0.247X_{19}$
SWLL	1965	83	0.55	$Y = 8.94 + 1.95X_{16} - 1.467X_{11} + 0.668X_{13}$
SWLL	1967	25	0.62	$Y = 7.94 + 4.36X_{16} - 1.244X_{11} + 0.10X_{15}$
SWLL	65-67	56	0.64	$Y = 8.79 + 2.00X_{16} - 1.042X_{11} - 0.389X_{8}$
HWLL	1965	158	0.57	$Y = 3.95 + 2.06X_{16} - 0.596X_{11} + 0.158X_{15}$

Identification of Variables

Y = productivity, cunits per hour
X_8 = crew rating (code)
X_{11} = natural logarithm of skidding distance
X_{12} = trail preparation (code)
X_{13} = stoniness (code)
X_{14} = brush density/height (code)
X_{15} = windfalls (code)
X_{16} = volume per load (cunits)
X_{17} = wage payment system (code)
X_{19} = slope (code)
SWLL = softwoods log length
SWTL = softwoods tree length
HWLL = hardwoods log length
HWTL = hardwoods tree length

*From a study by McCraw [10] of the Department of Fisheries and Forestry, Canadian Forestry Service.

TABLE II

RECOMMENDED PREDICTION EQUATIONS*

Basis
Softwood Tree-Lengths
787 obsn. $\bar{Y} = 3.85$; $R^2 = 0.61$; $Y = 5.96 + 2.96X_{16} - 1.127X_{11} + 1.460X_{17} - 0.745X_{19} + 0.028X_3$
Softwood Log-Lengths
56 obsn. $\bar{Y} = 3.51$; $R^2 = 0.64$; $Y = 8.79 - 2.00\ X_{16} - 1.042X_{11} - 0.389X_8$
Hardwood Tree-Lengths
558 obsn. $\bar{Y} = 3.497$; $R^2 = 0.50$; $Y = 5.69 + 2.17X_{16} - 0.587X_{11} + 0.347X_{14} - 0.753X_{19}$
Hardwood Log-Lengths
143 obsn. $\bar{Y} = 4.17$; $R^2 = 0.46$; $Y = 5.33 + 1.85X_{16} - 0.4208X_{11} - 0.129X_{15} - 0.487X_{19}$

Identification of Variables

Y = cunits per hour
X_3 = merchantable volume per acre (cunits)
X_8 = crew rating (code)
X_{11} = natural logarithm of skidding distance
X_{14} = brush density/height (code)
X_{15} = windfalls (code)
X_{16} = volume per load (cunits)
X_{17} = wage payment system (code)
X_{19} = slope (code)

*From a study by McCraw [10] of the Department of Fisheries and Forestry, Canadian Forestry Service.

CHAPTER III

METHODS AND PROCEDURE

Study Area

The logging area studied is located in McCurtain County, east of Broken Bow, Oklahoma, in the vicinity of the Craig Plyboard Plant. The average annual precipitation is 46-50 inches, and is usually evenly distributed; however, severe summer droughts are common. Frost free days for the area range from 220 to 240 days. Temperature ranges are from 15° in winter to 110° in summer. The topography in the area studied is level to very gently rolling with slopes rarely exceeding ten percent. The elevation of the area is from 300 to 500 feet above sea level.

In the study area described above, the primary species harvested are Shortleaf Pine (Pinus echinata), Loblolly Pine (Pinus taeda), and a mixed hardwood understory. The primary silvicultural method practiced in the area is the clear-cut method. This is a new type of logging for the area and was instituted in 1969 by the Weyherhaeuser Corporation.

Field Data Collection

Data collection began in January, 1972, and continued for two weeks at which time it was terminated. Collection began again on March 20, 1972, and was terminated eight days later. The final phase began May 27 and continued until August 29, 1972.

Data was collected on many skidders; however, the following seven general types or models predominated:

1. Franklin Fixed Grapple Skidder
2. Franklin Granny Type Skidder
3. Clark Fixed Grapple (medium horsepower)
4. Clark Fixed Grapple (large horsepower)
5. Clark Swinging Boom Grapple
6. Clark Choker Skidder (five cables)
7. Timberjack Choker Skidder (five cables)

For brevity, this study deals only with the Clark Fixed Grapple (medium horsepower), the Franklin Fixed Grapple, and the Clark Choker Skidder (five cables).

In evaluation and analysis of the data, the machine operators are considered to be typical or average and the three different machines are presumed to have been operated in an average manner. The above assumptions were set forth in the introduction of this study. All of the skidders were owned and operated by the Weyherhaeuser Company and were operated by the regular Weyherhaeuser personnel.

The operators were fully aware that data were being collected. However, the data collectors had worked on the same logging site on several different occasions and were considered as part of the crew by the working men and operators. Thus it is felt by the researchers that personnel awareness did not overly bias the information collected.

Daily Records

Data were taken on each operator and machine for a 10-turn period. A turn (Figure 3) started as the skidder began its forward motion towards

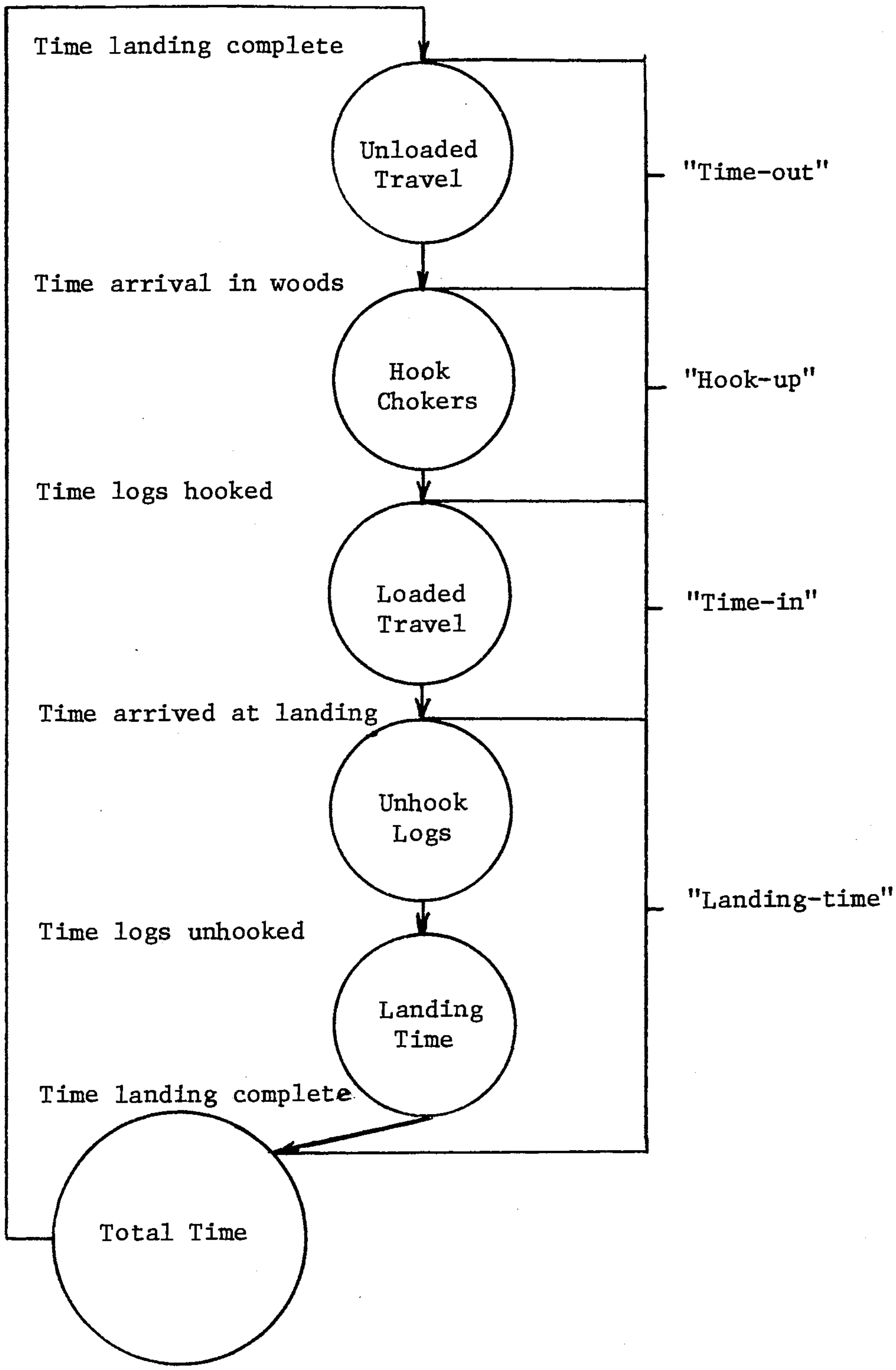

Figure 3. Flow Diagram of Cycle Time Elements.

the hooking area after it had dropped the logs from the previous turn at the landing. This first time measurement, "time-out," continues until the skidder stops its forward motion and begins to back up to the logs that are bunched and awaiting skidding. The time elapsing from the initial backward movement until the logs are hooked and forward motion starts again is called "hook-up time," a second time measurement. The time elapsing from the moment the skidder starts its forward motion with the load of logs to the moment when it drops the logs at the landing is considered "time-in," a third time measurement. The final time measurement, "landing time," occurs from the time the skidder either stops its forward motion on the landing or releases the load of logs until the forward motion to the hook-up area commences.

Data were recorded in small notebooks for ease of handling, and was later transferred to modified fortran programming sheets. A sample of the three fortran programming sheets is furnished in Appendix A. As these sheets would be usable in the field, their adoption would provide for significant time savings in future data collections. If data were recorded directly upon the data sheets, the sheets could be directly sent to the data processing center without the usual delay and possible errors of transferring data to programming sheets.

Information recorded on each turn included the following:

1. Date.
2. Skidder type and number.
3. Quarter day; 8:00-10:00 was recorded as Q.D.1; 10:00-12:00 was recorded as Q.D.2; 12:30-2:30 was recorded as Q.D.3; 2:30-4:30 was recorded as Q.D.4.

4. Temperature; recorded as Hot, Warm, Cool, Cold, and coded in the final equations as Hot=3, Warm=2, Cool=1, and Cold=0.

5. Ground conditions; recorded as Dry, Intermediate, Wet, and coded in the final equations as Dry=2, Intermediate=1, and Wet=0.

6. Type of cutting; recorded as being cut with the feller-buncher or a sawer, the cutting in all the observations taken was accomplished by the feller buncher.

7. Silvicultural method; recorded as either clear-cut, selective cut, or seed tree cut. All observations used were from clear-cut areas.

8. Driver's initials.

9. Turn number.

10. Number of logs per turn.

11. Type of log; recorded as either softwood (S), or hardwood (H).

12. Mid-diameter and length of log.

13. Time-out, Time-in, Hook-up time, and Landing time measured in seconds.

14. Type of delay; all delay times were incorporated in the four time measurements, but the nature of the delays were recorded and entered on the programming sheets in code form, i.e. Mechanical=9, Personal=5, etc.

15. Distance + deviations; the distance was recorded as the length from the mid-point of the landing to the mid-point of the plot where the logs were being hooked. The deviations were either long or short distances ($\pm$) recorded depending

upon where the skidder stopped to hook the logs, i.e., (400' + (-50)) = Dist. = 350 feet.

Log Measurements

The length and mid-diameter were recorded for each log. In the computer program, the formula for determining the cubic volume was:

$$A = \pi \times \left(\frac{\text{mid-diameter}}{2}\right)^2 \times L = \text{cu. ft. wood/tree}$$

where A = cubic volume of wood per tree in feet, $\pi = 3.14$, L = the length of the tree.

Personnel Duties

Initially, two men were used in data collection, a woodsman and a deckman or landing man.

The woodsman was responsible for measuring the cycle time or the times involved in a single turn. All of these times were taken by a stop-watch.

The deckman was responsible for recording the number of logs per turn and the measurement on each log.

Near the end of the skidding study, both duties were accomplished by one man. This proved quite satisfactory if the distance involved in the skidding did not exceed 400 feet.

During the entire observation period, there were 134 plots observed and the total number of turns observed was 1,234. In the analysis of the prediction equations the number of observations used were 77 for the Clark grapple skidder, 81 for the Clark choker skidder, and 108 observations for the Franklin grapple skidder.

The Model

After the data were transferred to the data processing sheets, the information was punched on cards for computer processing on the Oklahoma State University Computer, an IBM 360 Model 65.

Before the final prediction equations were prepared, a trial run was made with the Clark grapple skidder to determine what effect each independent variable had on the dependent variable, cunits/turn, and what shape the independent variables should take on in the final equations (linear, quadratic, or cubic).

The computer program used for the trial run was the multiple regression technique presented in the S.A.S.II Manual [15].

The general form of equation used was:

$$Y = b_0 + b_1X_1 + b_2X_2 + \ldots b_8X_8:$$

where:

X_1 = Ground type

X_2 = Weather

X_3 = Quarter day

X_4 = Number of logs/turn

X_5 = Time-out/100 feet

X_6 = Hook-up time

X_7 = Time-in/100 feet

X_8 = Landing time

Y = Output (cunits/turn)

N = 44 observations

R^2 = 17 percent.

After the trial run was accomplished, the residuals from the observations were plotted against each individual independent variable and from this it was determined the form the variables should take in the final prediction equation. The shape exhibited by the plotting was found to be of a quadratic form for time-in, time-out, and the number of logs per turn. A cubic shape was formed by the hook-up time. The interaction terms used were the number of logs per turn by hook-up time, number of logs per turn by time-in, distance by time-out, and distance by time-in.

After the first trial run, it was found that a second trial was needed to incorporate the ten new independent variables that were determined from the first trial. Another change that was made as a result of the first trial was the changing of the time-out/100 feet and the time-in/100 feet to the actual times recorded. This was done because it was felt that the original form would make future computations more difficult. An R^2 value for the second equation was found to be 49 percent. The changes in the input or independent variables were:

$X_9 = X_4 \times X_6$

$X_{10} = X_4 \times X_7$

$X_{11} = X_7 \times X_7$

$X_{12} = X_6 \times X_6$

$X_{13} = X_6 \times X_6 \times X_6$

$X_{14} = X_5 \times X_5$

$X_{15} = X_4 \times X_4$

X_{16} = Distance + Distance Deviation

$X_{17} = X_{16} \times X_5$

$X_{18} = X_{16} \times X_7$

These changes incorporated the interactions and the shape the variables exhibited when graphed against the residuals found with the first trial run.

Upon obtaining the results of the second trial run, it was then determined to proceed with the final equations. For the final equations, two additional variables were added to incorporate the interaction of temperature by the number of logs per turn, and the group type by the time in. The identification of the variables used are:

$X_{19} = X_1 \times X_7$

$X_{20} = X_2 \times X_4$

For the final prediction equations, it was conceded that an equation with 20 independent variables would prove to be somewhat lengthy for future computations. The maximum R^2 improvement (MAX R^2) technique was then used to obtain prediction equations based on a fixed number of the original 20 variables being employed. The MAX R^2 technique is included in the Statistical Analysis System [15] of statistical programs. The technique is a sequential one which begins by determining the one variable resulting in the "best" one-variable model; that is, best in the sense that the prediction equation obtained is the one having the largest R^2 value among all one-variable models. The model selected is also the one for which the estimated variance about the regression line is smallest among all one-variable models.

Next the MAX R^2 technique proceeds to determine the best two-variable model. From among all possible pairs of variables the procedure selects the pair for which the resulting prediction equation gives the largest R^2 value. The procedure also enumerates all pairs of variables which give a larger R^2 value than the best one-variable model and prints out the R^2 value which would result for each pair enumerated. A complete analysis, however, is given only for the best two-variable model.

The third step selects from all possible combinations of three variables the one combination which gives the best three-variable model; that is, the one with the largest R^2 value. Again, a complete analysis is given of this "best" prediction equation along with an enumeration of all three-variable combinations with their R^2 values which provide a larger R^2 value than the best two-variable model. Each succeeding step is performed in a similar manner. The user has the option of stopping the procedure at any step. If it is later determined that more steps are needed the procedure may be restarted at the point where it was terminated earlier.

The MAX R^2 technique is considered to be superior to the stepwise regression technique and almost as good as calculating regressions on all possible subsets of independent variables.

The MAX R^2 procedure was applied to the data collected from each of three types of skidders. The command was given for the procedure to terminate after step ten; that is, after the best ten-variable model was determined. The three ten-variable prediction equations obtained follow.

Clark grapple skidder:

$$Y = -18.6337 + 0.00436X_{11} + 77.45269X_4 - 8.98583X_{15} - 0.20791X_{16} + 0.00094X_{17} - 0.33367X_{10} - 0.04759X_9 + 12.25447\text{TempC} + 0.001278X_{18} - 0.009754X_8;\ R^2 = 44.7 \text{ percent.}$$

Clark choker skidder:

$$Y = 48.4599. + 10.05235X_{15} - 0.001464X_{14} - 0.000739X_{12} + 0.89754X_{7} + 0.27812X_{6} - 32.11758X_{4} - 0.001803X_{18} + 0.11907X_{16} - 14.89458GrdtyX - 7.37231TempC; R^2 = 78.9 \text{ percent.}$$

Franklin grapple skidder:

$$Y = 115.39088 + 12.83987GrdtyX + 0.32096X_{10} + 0.00783X_{8} - 0.18006X_{9} - 0.81850X_{7} + 0.001468X_{12} + 0.000848X_{18} - 0.27578X_{16} + 0.002868X_{17} - 0.00652X_{14}; R^2 = 39.4 \text{ percent.}$$

These three equations were found to explain the effects that each variable had on each individual skidder. Upon analyzing the MAX R^2 equations, it was found that by the time the best ten variable model had been found, there were in some cases variables in one equation that did not appear in the others. That is, a variable that explained a large amount of variation in one skidder did not do so in another. It was determined therefore, that the contribution that the MAX R^2 equations could lend would be to aid in the determination of the variables that would appear in the final multiple regression prediction equations.

Table III was constructed to obtain the frequency of appearance of each variable in the ten steps leading to each MAX R^2 equation. These frequencies were summed and the ten variables appearing most frequently over the determination of all three equations were used in the final multiple regression equations. The selection of X_6 and X_{12} over X_9 was done because X_6 appeared solely in the Choker skidder equation as well as X_{12}, however, X_{12} did appear in the Franklin grapple equation. It was felt that with the exclusion of these two variables for X_9 would create a poorer equation for the Clark choker skidder. In order to keep the final equation at the ten variable

TABLE III

THE FREQUENCY OF APPEARANCE OF THE INDEPENDENT VARIABLES IN THE MAX R^2 EQUATION

Variables	Clark Choker	Clark Grapple	Franklin Grapple	Total	Variables Used in the Final Equations
TempC (coded) X_1	1	3	0	4	*
GrdtypX (coded) X_2	2	0	9	11	
X_3 , Quarter Day	0	1	0	1	*
X_4 , Number of logs/turn	6	9	2	17	
X_5 , Time-out	0	0	0	0	
X_6 , Hook-up time	5	0	0	5	*
X_7 , Time-in	7	6	6	19	*
X_8 , Landing time	0	2	3	5	
X_9 , $X_4 \times X_6$	3	4	4	11	
X_{10}, $X_4 \times X_7$	1	7	9	17	*
X_{11}, $X_7 \times X_7$	0	2	0	2	
X_{12}, $X_6 \times X_6$	5	0	2	7	*
X_{13}, $X_6 \times X_6 \times X_6$	1	0	0	1	
X_{14}, $X_5 \times X_5$	8	2	4	14	*
X_{15}, $X_4 \times X_4$	10	8	0	18	*
X_{16}, Distance + Deviations	3	4	6	13	*
X_{17}, $X_{16} \times X_5$	0	3	3	6	
X_{18}, $X_{16} \times X_7$	3	4	5	12	*
X_{19}, $X_1 \times X_4$	1	1	0	2	
X_{20}, $X_2 \times X_7$	0	1	1	2	

level, X_9 was eliminated. This procedure allowed comparing skidders on a common basis whereas a collective evaluation could not have been accomplished with the MAX R^2 technique because of the differences in the independent variables. On the other hand, the MAX R^2 equations are an invaluable asset in the determination of the amount of effect each independent variable has on each individual skidder. The effect can be determined for each skidder by taking the ten best variable equations and determining the contribution each variable makes by testing each coefficient as to whether it equals 0 or not. Another evaluation that could be made would be to examine each equation individually (the best one-variable, the best two-variable, etc.) and determine the order in which the variables are added to produce the highest R^2 value. The complete evaluation of these equations would lead to the determination of the importance and necessity of certain variables which in turn would allow more accurate data collection techniques.

The three equations giving output per turn for each skidder using the ten variables appearing most frequently are:

Clark choker skidder:

$$Y = 40.37702 - 17.51094 GrdtX - 36.67089X_4 + 0.27856X_6 + 0.872368X_7 + 0.000012X_{10} - 0.000761X_{12} - 0.00138X_{14} + 10.557X_{15} + 0.125719X_{16} - 0.00175X_{18};\ R^2 = 78.5 \text{ percent.}$$

Clark grapple skidder:

$$Y = -13.63339 + 2.12683 GrdtyX + 77.04196X_4 - 0.1066X_6 + 0.48024X_7 - 0.3235X_{10} + .000029X_{12} + 0.00275X_{14} - 9.41735X_{15} - 0.16939X_{16} + 0.00175X_{18};\ R^2 = 42.6 \text{ percent.}$$

Franklin grapple skidder:

$$Y = 111.39315 + 12.51269GrdtyX - 15.9837X_4 - 0.12474X_6 + 0.89307X_7 + 0.31773X_{10} + 0.00040X_{12} + 0.00070X_{14} + 0.2750X_{15} - 0.11769X_{16} + 0.00110X_{18};\ R^2 = 31.5 \text{ percent.}$$

Instead of individual tests for significance of each coefficient, the "F" value arrived at for the whole equation was used in order to justify building an equation. The "F" values and their significance levels were:

Skidder	"F" values	Prob > F
Franklin grapple	4.45067	.0001
Clark grapple	5.18972	.0001
Clark choker	24.1637	.0001

This analysis shows that there was a significant contribution by all of the variables in the model and that the whole equation was significant in explaining the variation of the observations and each of the three equations were significant at the .0001 level.

Table IV indicates the statistics of the individual Beta coefficients which can be used for the purpose of ordering the importance of the variables in each equation.

A comparison of the R^2 statistic from the MAX R^2 equations and the multiple regression equations just given showed very little decrease in the amount of variation explained. The decrease was brought about by the exclusion of some of the variables that contributed to the explanation of the variance in the MAX R^2 equations.

TABLE IV

PROBABILITIES FOR EACH COEFFICIENT > |T|

Source	Franklin Grapple		Clark Grapple		Clark Choker	
	T for HO: B=0	Prob > |T|	T for HO: B=0	Prob > |T|	T for HO: B=0	Prob > |T|
Intercept	3.93008	0.0004*	-0.32939	0.7419	1.50918	0.1322
GrdtyX	2.14888	0.0321*	0.34314	0.7323	-1.85521	0.0646*
X_4	-0.73144	0.5269	4.22327	0.0002*	-3.15981	0.0027*
X_6	-0.61027	0.5502	-0.72882	0.5246	2.87855	0.0055*
X_7	-3.78412	0.0005*	0.70176	0.5078	4.59956	0.0001*
X_{10}	3.42633	0.0013*	-1.73129	0.0840*	0.00023	1.0000
X_{12}	0.47489	0.6413	0.07840	0.9357	-4.89648	0.0001*
X_{14}	0.80243	0.5701	1.71785	0.0865*	-3.51661	0.0011*
X_{15}	0.05817	0.9525	-2.44388	0.0162*	6.71442	0.0001*
X_{16}	-2.58752	0.0108*	-2.08894	0.0380*	2.91621	0.0050*
X_{18}	3.26778	0.0019*	1.80075	0.0725*	-3.16996	0.0027*

*Significant at the .10 level.

Equation Application

To compare the three skidders on a realistic basis, a hypothetical situation was set up and the prediction equations were utilized. In the test situation it was assumed that the volume to be logged was 5000 cunits, the number of logs per turn was fixed at three, the skidding distance was fixed at 500 feet, and the ground type was presumed to be dry.

To equate each system on its own merit, striaght-line regression analysis was applied to the individual variables that were used in the final equations. This was done in order to obtain valid numbers for application in the equations. Numbers needed were for hook-up time, time-out, and time-in. Hook-up time was found by using the number of logs as the independent variable and hook-up time as the dependent variable. Time-out was determined by using distance as the independent variable and time-out as the dependent variable. Time-in was found by first fixing the number of logs carried at three (the number used in the prediction equation) and distance as the independent variable and time-in the dependent variable. Table IV shows the equations found for each variable. The data used to obtain each equation was taken from the original data used in determining the MAX R^2 and multiple regression equation.

The values found by the regression equations in Table V were then entered into each of the three prediction equations.

The average number of turns per hour were also computed from the original data and are presented in Table VI. The average turns per hour

TABLE V

REGRESSION EQUATIONS FOR THE INDIVIDUAL VARIABLES

Skidder	Hook-up Time/Log	Number of Obsn.	Variables Identification
Clark grapple	$Y = 15.9552 + 19.0920X$	81	Y = Hook-up time
Clark Choker	$Y = -4.3739 + 75.6663X$	77	X = Number of Logs
Franklin Grapple	$Y - 45.9301 + 14.6183X$	108	
Skidder	**Time in by Distance (fixed at 3 logs)**	**Number of Obsen.**	**Variables Identification**
Clark Grapple	$T_i = -58.5291 + .2495D$	48	T_i = Time in
Clark Choker	$T_i = 62.3478 + 1496D$	46	D = Distance
Franklin Grapple	$T_i = 12.6732 + .1738D$	35	
Skidder	**Time Out by Distance**	**Number of Obsen.**	**Variables Identification**
Clark Grapple	$T_o = 32.5784 + .0568D$	81	T_o = Time out
Clark Choker	$T_o = 42.9873 + .0341D$	77	D = Distance
Franklin Grapple	$T_o = 30.6852 + .0566D$	108	

TABLE VI

AVERAGE TURNS PER HOUR

Skidder	Time Out (sec)	Hook-up Time (sec)	Time In (sec)	Landing Time (sec)	Total Time (sec)	Num. Obsn.	Avg. Turns/ Hour
Clark Choker	95.676	273.699	123.117	162.516	654.998	77	7.053
Clark Grapple	70.431	90.216	89.952	214.501	465.100	81	10.450
Franklin Grapple	109.631	119.152	126.601	240.531	595.915	108	10.874

were arrived at by summing all four measured times and dividing by the number of observations.

With cunits per turn obtained from the prediction equations and the average number of turns per hour, production per hour can then be found by multiplying the two values together.

Once production per hour has been found, the number of machine hours needed for each model to harvest the entire 5000 cunits can be computed simply by dividing the total number of cunits by the value that was arrived at by multiplying cunits per turn and average turns per hour. The total cost of the skidding was accomplished by obtaining the cost of operation per hour for each skidder and multiplying that value by the number of hours needed to log the area. Cost tables and computations are presented in Appendix B through Appendix E.

CHAPTER IV

RESULTS AND DISCUSSIONS

Upon entering the independent values found by the regression equations presented in Table V into the three separate prediction equations determined for each skidder, output per turn was found. The number of logs per turn used were three logs, the average skidding distance was 500 feet, and the ground type was presumed to be dry. The amount of cunits to be logged was 5,000. The area was not fixed in this study because the individual dimensions of each log per turn were not considered as a factor which affected the number of logs carried on each turn. In order for a complete evaluation with the equations, an actual area should be considered and the average sized log in the area should be calculated.

The results found by using the skidding prediction equations are presented in Table VII. As can be seen from Table VII the Franklin grapple skidder requires only 38 percent as much time as the Clark choker skidder and only 65 percent as much time as the Clark grapple skidder to move the same amount of logs.

The estimated total cost of operation for the Franklin grapple skidder was 40 percent of that for the Clark choker skidder and 63 percent of that for the Clark grapple skidder.

It was found that additional study needs to be conducted on the best size of log and number of logs per turn for each skidder in conjunction with the skidding times involved. This analysis could not only lead to a better machine mix for a given area, but also to determining the location or geographic sector in which each type of skidder could perform best.

TABLE VII

RESULTS OF SKIDDER PREDICTION EQUATIONS

Skidder	Predicted Cunits/ Turn	Computed Turns/ Hour	Computed Cunits/ Hour	Computed Total Hours	Cost* Per Hour	Computed Total Cost
Clark choker	.76873	7.053	5.4220	1014.386	$9.2	$9374.96
Clark grapple	.80044	10.450	8.3646	597.757	$9.8	$5855.63
Franklin grapple	1.18670	10.874	12.9042	387.470	$9.6	$3724.36

*From Tables VIII, IX, X

Other areas of interest that could be developed would be the analysis of the MAX R^2 equations and the independent variables therein. Analysis of the effects that each variable plays in the final equations would be important in determining which factors are important on which skidder.

The major objective of this study was building a prediction equation for skidding equipment and Table VII reports the results that can be obtained from using the equations. As previously pointed out, there were many avenues of research touched upon in the development of these equations. These need to be explored fully before the area of skidding and skidding cost analysis can be utilized for all combinations of skidders and forest types. With appropriate additional research it might be possible to make several easily taken measurements and determine: 1) the best mix of skidder types to use; 2) the cost of doing the entire job; and, 3) how long the job is going to take. Studies attacking problems of these types should be made in conjunction with other studies on skidding such as bunching systems and bunch sizes, trucking distances and other related problems.

CHAPTER V

SUMMARY

Prediction equations for skidding output were established for three different models of skidders. Development was accomplished by first performing a multiple-linear regression equation technique with the eight direct variables measured in the skidding operation. From this equation the shape that each variable should take in the final equations was determined by graphing the residuals from each observation against the variable itself. The shape (linear, quadratic, or cubic), the interaction present, and the linear values of the variables were then entered into the stepwise MAX R^2 regression equation technique in the SAS II system. The three equations obtained from the MAX R^2 technique indicated the relative importance of each variable in each equation. The relative frequency of each variable in each equation was then determined and the variables that appeared most for each equation were selected to appear in the final prediction equation. For the final equation, ten variables were used which equated the three skidders on the same basis.

By entering the corresponding values for the ten variables into the prediction equations, a final value (cunits/turn), can be determined. The measurements needed are: 1) number of logs per turn; 2) time-out; 3) hook-up time; 4) time-in; 5) ground type; and, 6) skidding distance. The two final values needed for the determination of the total time and total costs are the average turns per hour for the machines and the cost of operation for one hour. With the use of the equations in this manner, a total cost and a total time for skidding a given amount of wood can be determined.

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APPENDIXES

APPENDIX A

FORTRAN FORMS FOR DATA COLLECTION

Card Number

Plot Number

Month

Day

Quarter Day

Starting Time
Use 24 hour clock

Weather

Ground Condition

Slope/Rockiness

Setting Number
Side Foreman

Silvic. Method
Felling Method
Pattern
Limbing, Bunching, Piling Methods

Skidder Make, Type, Size and Number

Driver's Initials

Turn Number

Number of Logs

Species S,H

Diameter-Inches

Length-Feet

Diameter-Inches

Length-Feet

Diameter-Inches

Length-Feet

Initials R.M.

Initials FOR

Project Number

Year

Card Number

Plot Number

Diameter-Inches

Length-Feet

Diameter-Inches

Length-Feet

Diameter-Inches

Length-Feet

Diameter-Inches

Length-Feet

Diameter-Inches

Length-Feet

Diameter-Inches

Length-Feet

Diameter-Inches

Length- Feet

Diameter-Inches

Length-Feet

Diameter-Inches

Length-Feet

Diameter-Inches

Length-Feet

Diameter-Inches

Length-Feet

Diameter-Inches

Length-Feet

Initial's R.M.

Initial's FOR

Project Number

Year

Card Number

Plot Number

Time Out in
Min. & Sec.

Hook-Up Time in
Min. & Sec.

Time-In in
Min. & Sec.

Landing Time in
Min. & Sec.

Distance From
Mid.Pt. to Landin

Long or Short
Distance +-

Lateral Distance
Left or Right

T
H
I
L
Delay Codes

Initial's R.M.
Initial's FOR

Project Number

Year

APPENDIX B

COST ANALYSIS FOR MACHINES

TABLE VIII

MACHINE RATE CALCULATIONS FOR A CLARK CHOKER SKIDDER

Fixed Costs	Cost/Hour	
Depreciation	$3.282	
Insurance, taxes, interest, etc.	1.313	
		$4.595
Variable Costs		
Operator	2.75	
Fuel	.50	
Oil and Lube	.085	
Tires*		
Repairs	1.312	
		4.647
Total Cost		$9.242 15.4¢ /minute .257¢ /second

Assumptions

Initial cost (C)	$25,000
Salvage (R)	9,000
Years in use (N)	3
Operating hours/year	1,625
Number of men: operator at $2.75/hour	1
Gallons fuel/hour @ 25¢/gallon	2
Oil - 10 quarts/month @ 50¢/quart	
Lube - 3 gallons/month @ $2.00/gallon	
Repairs - 40% of depreciation	
*Tires not replaced in 3 years	
Average annual investment = $\frac{(C-R)\ (N+1)}{2N}$	
Interest, taxes, insurance, etc. = 20% of average annual investment	

TABLE IX

MACHINE RATE CALCULATIONS FOR A FRANKLIN 170 SKIDDER

Fixed Costs	Cost/Hour	
Depreciation	$3.487	
Insurance, taxes, interest, etc.	1.395	
		$4.882
Variable Costs		
Operator	2.75	
Fuel	.50	
Oil and Lube	.085	
Tires*		
Repairs	1.395	
		4.73
Total Cost		$9.612
		16¢ /minute
		.267¢/second

Assumptions

Initial cost (C)	$27,000
Salvage (R)	10,000
Years in Use (N)	3
Operating hours per year	1,625
Number of men: operator at $2.75/hour	1
Gallons fuel/hour @ 25¢/gallon	2

Oil - 10 quarts/month @ 50¢/quart

Lube - 3 gallons/month @ $2.00/gallon

Repairs - 40% of depreciation

*Tires not replaced in 3 years

Average annual investment = $\frac{(C-R)(N-1)}{2N}$

Interest, taxes, insurance, etc. = 20% of average annual investment

TABLE X

MACHINE RATE CALCULATIONS FOR A CLARK GRAPPLE SKIDDER

Fixed Costs	Cost/Hour	
Depreciation	$3.589	
Insurance, taxes, interest, etc.	1.436	
		$5.025
Variable Costs		
Operator	2.75	
Fuel	.50	
Oil and Lube	.085	
Tires*		
Repairs	1.436	
		4.771
Total Cost		$9.796 16.3¢ /minute .272¢ /second

Assumptions

Initial cost (C)	$28,000
Salvage (R)	10,500
Years in use (N)	3
Operating hours/year	1,625
Number of men: operator at $2.75/hour	1
Gallons fuel/hour @ 25¢/gallon	2
Oil - 10 quarts/month @ 50¢/quart	
Lube - 3 gallons/month @ $2.00/gallon	
Repairs - 40% of depreciation	
*Tires not replaced in 3 years	

Average annual investment = $\frac{(C-R)(N+1)}{2N}$

Interest, taxes, insurance, etc. = 20% of average annual investment

APPENDIX C

COMPUTATIONS FOR CLARK CHOKER

COMPUTATIONS FOR THE CLARK CHOKER SKIDDER

1. Cunits per hour with 3 logs/turn fixed using the prediction equation. .76873 cunits/turn x 7,053 turn/hour = 5,422 cunits/hour.
2. 5000 cunits to be logged.

   @ 3 logs/turn = $\frac{5000}{5.422}$ = 1014.386 hours.
3. Fixed costs = 1014.386 x 4.595 = 4661.104
4. Variable costs = 1014.386 x 4.647 = 4713.850
5. Total cost for 5000 cunits = $9374.96.

APPENDIX D

COMPUTATIONS FOR CLARK GRAPPLE SKIDDERS

COMPUTATIONS FOR THE CLARK GRAPPLE SKIDDER

1. Cunits per hour with 3 logs/turn fixed using the prediction equation. .80044 cunits/turn x 10.45 turn/hour = 8.3646 cunits/hour.
2. 5000 cunits to be logged.

   @ 3 logs/turn = $\frac{5000}{8.3646}$ = 597.757 hours.
3. Fixed costs = 597.757 x 5.025 = $3003.73
4. Variable costs = 597.757 x 4.771 = $2851.90
5. Total cost for 5000 cunits = $5855.63

APPENDIX E

COMPUTATIONS FOR FRANKLIN GRAPPLE SKIDDER

COMPUTATIONS FOR THE FRANKLIN GRAPPLE SKIDDER

1. Cunits per hour with 3 logs/turn fixed using the prediction equation. 1.1867 cunits/turn x 10.874 turns/hour = 12.9042 cunits/hour.
2. 5000 cunits to be logged.

   @ 3 logs/turn = $\frac{5000}{12.9042}$ = 387.47 hours.
3. Fixed costs = 387.47 x 4.882 = $1891.628
4. Variable costs = 387.47 x 4.73 = $1832.733
5. Total costs for 5000 cunits = $3724.36

VITA

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Candidate for the Degree of

Master of Science

Thesis: PREDICTION EQUATIONS FOR SKIDDING OUTPUT

Major Field: Forestry

Biographical:

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