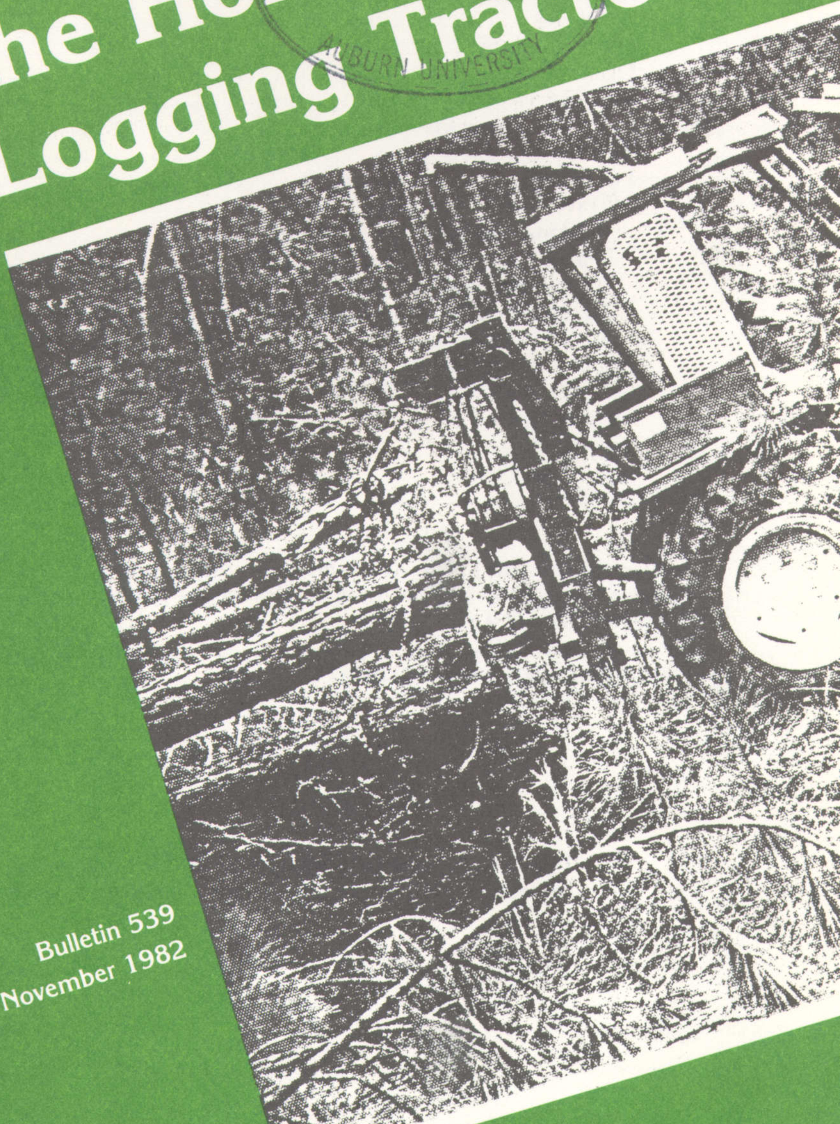
ALABAMA AGRICULTURAL EXPERIMENT STATION
GALE A. BUCHANAN, DIRECTOR
AUBURN UNIVERSITY
AUBURN UNIVERSITY, ALABAMA

Evaluation of the Holder A55F Logging Tractor



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EVALUATION OF THE HOLDER A55F LOGGING TRACTOR

ROY E. HOFFMAN, BOBBY L. LANFORD, and
RONALD H. IFF*

INTRODUCTION

THE NEED FOR SKIDDING VEHICLES better suited to transport small trees on small tracts was the basis for this study of the Holder A55F four-wheel drive logging tractor. This tractor offered promise for thinning in young stands where larger equipment would be uneconomical and could cause excessive damage to the residual stand.

The objectives of the study were to (a) determine the productivity of a Holder A55F logging tractor as a ground skidder, (b) evaluate working environment effects on productivity, (c) investigate alternate hooking equipment and to estimate changes in productivity resulting from the use of alternate equipment, and (d) estimate owning and operating costs for the machine and relate these costs to production.

LITERATURE REVIEW

In the early 1970's, the Forest Research Institute of the New Zealand Forest Service tested a 30-horsepower Holder A.G. 35 logging tractor (18). Muir reported that the A.G. 35 had high production despite a faulty winch and ground conditions unfavorable for traction during the testing. For elements of the productive cycle, Muir found distance traveled had the most significant effect on travel times, and when combined with volume, accounted for 67 percent of the variation in travel time. Travel times were also affected by slope, wet ground conditions, and logs being skidded completely on the ground due to occasional lack of lift. Twenty-four percent of the variation in total skid times was attributable to haul volume. Muir

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*Honors Student and Associate Professor, Department of Forestry, and Research Engineer, Southern Forest Experiment Station, U.S. Forest Service, respectively.

concluded that the A. G. 35 was well suited for low volume thinning of small stems.

Sampson and Donnelly, studying skidder productivity in ponderosa pine selection cuts, showed that the following characteristics must be considered in evaluating skidding tractors: horsepower or pulling power, travel speed in each gear, and percent slippage of wheels or tracks. Important timber characteristics to be considered included the volume per acre, the number of pieces to be skidded per acre, and the density of the residual stand. They also found that three terrain characteristics are important: skidding distance, steepness of slope, and soil surface conditions. The study pointed out that bunching and choking time is affected by the volume per piece and the distance between the felled trees. For cable skidders, the authors stated that unhooking time is a function of the number of pieces skidded and the number of chokers used. Decking time was found to be a function of the volume at the deck and the height of the deck.

The same study also indicated that optimum skidding production is attained when the volume per skidder turn is maximized, not by sacrificing load size to decrease choking time. Even with light loads, the authors noted that the highest theoretical speed cannot be obtained due to acceleration, rough ground, obstacles, and deceleration. Therefore, lower speeds and heavier loads were more efficient. The report stated that heavier loads should not be pursued to the extent that either choking time is wasted searching for the right size logs or the equipment is overloaded (19).

In a time prediction study for rubber tired skidders, Gardner noted that such skidders offered speed, maneuverability, and lower cost not found in most tracked vehicles. He found that smaller skidders, between 10,000 and 12,000 pounds with about 75 horsepower, were not as fast as larger skidders weighing over 14,000 pounds with 100 or more horsepower. The number of logs, weight of the skidder, and total skidding distance were the principal variables found for predicting cycle time (9).

Koger noted that while lower horsepower skidders required more time to skid a 400-board-foot load, they had the same travel empty time as higher horsepower skidders. The overall difference found for total cycle time was so small that the number of cycles per day was barely affected. Koger, in finding that the daily production of lower horsepower skidders is almost the same as their stronger counterparts, realized that due to both lower initial costs and operating costs, the lower horsepower skidders had a much smaller cost per thousand board feet skidded (13).

Analyzing moving costs for various logging systems as a function of investment cost, McDermid showed that moving costs increase as investment increases. The findings were that low investment cost is needed to harvest small tracts competitively (15). Thienpont et al. later verified these findings (20).

MACHINE DESCRIPTION

The Holder A55 F is a rubber tired, four-wheel drive, articulated frame, diesel tractor with 48 horsepower. The tractor weighs 7,200 pounds with overall dimensions of: width, 50 inches; length, 123 inches; and height, 84 inches. The blade used on the study tractor was not designed by Holder, but was manufactured and sold by Indag Iowa Incorporated. A Farmi JL-30 winch, used primarily for skidding with farm tractors, was mounted on the Holder A55F. Technical data on the Holder A55F and Farmi JL-30 winch can be found in Appendix A. Adjustable chain chokers were used to take full advantage of the lift capabilities of the winch.

STUDY AREA

An area of approximately 5 acres in Lee County, Alabama, was the location for the study. The stand was a 22-year-old plantation composed predominately of slash pine. Prior to thinning, the stand averaged 15 cunits (CCF) and approximately 150 trees per acre. About 5 CCF per acre were marked for thinning. The marked trees ranged in diameter breast height (DBH) from 6 to 16 inches, with a mean of 8 inches. The mean height of the marked trees was approximately 55 feet. The ground condition was reasonably dry and favorable for skidding during the study. The slopes for the study site ranged from 0 to 15 percent. There were very few major obstacles to tractor travel on the study site except for thick honeysuckle in one area.

WORK METHODS

All trees were felled with a chain saw; approximately 17 percent were directionally felled. The fallen trees were limbed and topped with a chain saw prior to being skidded to the landing. Trees were hooked at either the butt or the top, as was appropriate to minimize hook-up time. A tractor operator having 1 year experience on similar equipment performed the skidding.

OPERATING SEQUENCE

To assess the productivity of the Holder A55F logging tractor, the skidding cycle was broken into five readily identifiable time elements: travel empty, choking, travel loaded, unchoking, and decking, each of which was timed to within 0.01 minutes for each observation. The travel empty segment of the skidding cycle involved the travel time from the landing to the stems to be skidded. The choking segment of the cycle included the operator getting on and off the machine, pulling out the cable, choking, winching, moving the tractor to other stems for choking, and preparation for skidding. Travel loaded consisted of moving the machine while loaded and any winching necessary for the skidding process. The unchoking segment included unhooking the stems, and the decking segment involved random pushing and adjusting of stems at the landing to create efficient piles of trees.

AVAILABILITY AND UTILIZATION

Delays experienced during the study may not reflect those that could be expected under operational conditions. Also, accurate delay information requires long term data over the life of many machines. For these reasons, delays experienced during the study were ignored and not included as a part of general availability and utilization rates. No data were taken during the study regarding down time (repair), idle time (breaks, under-utilization), or service time. In a similar study on the Holder AG 35, however, productive time was given as 6.5 hours per day *(18)*. In a study by McDermid and Perkins, utilization, or the ratio of productive time over scheduled time expressed as a percent, was measured at 60.9 percent for rubber tired cable skidders. Availability, the percent of scheduled time not consumed by down time, can vary from machine to machine, and utilization from operation to operation, but in general, idle times and other times for the Holder A55F should be similar to those times for other cable type skidders. The production and cost analysis in this study was computed for a range of utilizations, from 50 to 90 percent, so the results will be applicable to a range of owners and operators *(16)*.

STUDY MEASUREMENTS

The measurements taken for each load to use in estimating the total cycle time were: number of trees, average DBH in inches, basal area in square feet, travel empty distance in feet, travel empty slope percent, travel loaded distance in feet, travel loaded slope percent, brushiness, bogginess, and method of felling. Brushiness was separated into four classes based on the distance of unobstructed vision. Class A required good vision for as far as terrain allowed or greater than Class B. Class B required good vision for less than two chains but greater than Class C. Class C required good vision for less than one chain but greater than Class D. Class D required good vision for less than one-half chain. The brushiness conditions on the study site itself included only classes A and B. Bogginess, a measure of soil strength, was divided into four classes. Class A included ground conditions which were dry or wet but firm for excellent traction with sinkage from 0 to 1 inch. Class B included ground conditions which were dry or wet with loose or soft soil but good traction and sinkage of 2 to 6 inches. Class C included slippery ground conditions causing poor traction with sinkage of 7 to 11 inches, while Class D included boggy conditions with very poor traction and sinkage of 12 inches or more. Conditions on the study site reflected bogginess levels equivalent to classes A and B only. The method of felling was simply recorded as to whether or not the trees were directionally felled. All segment times, measurements, and variable values were recorded on standard forms, Appendix B, at the time the cycle was occurring to ensure the accuracy of the data.

ANALYSIS PROCEDURE

While estimation of the total cycle time was one of the ultimate goals, each segment such as travel empty, choking, etc., required separate analysis. It was expected some environmental factors and work methods would affect particular time segments but not others. By analysis of each segment separately, sensitivity to these various controlling factors would be increased. Least squares regression methods were used to estimate regression coefficients which are used to estimate productivity rates for the Holder (6, 7).

Various procedures have been devised to employ least squares regression in the analysis of data; each has its merits. The goal of these methods is to arrive at a model which accurately represents the relationship between influencing and estimated values. Factors which have little or no effect should be discarded, and those that do should be included. In this study, segment times per cycle were the dependent variables which were modeled, and measurements such as skidding distance, slope, brushiness, and bogginess were the controlling factors or independent variables which might affect these times.

Frequently, one or possibly two independent variables explain a majority of the variation found in the dependent variable. Other independent variables, even though statistically significant, may only add a small amount to the explained variation. The procedure used in this analysis involved selecting the independent variables which were intuitively expected to explain the largest portion of variation and developing a foundation or basic model. Other less important variables were ignored during this phase of the procedures. If necessary, transformations to the independent variable were made to improve the fit which was checked through an analysis of residuals.

Graphic representation usually aids in examining a regression model. By plotting dependent variables over independent variables, possible transformations are suggested from the pattern of the points. After regression estimates have been calculated using the individual observations, the plots can be used again to examine how well the estimates "fit" the actual data points. Points that are averages of observations within classes of the independent variables tend to show data patterns more clearly than plots of individual observations. Plots of individual observations are useful too in identifying extreme data points which may be in error.

To test for homogeneity of variance, which is important when dealing with forestry data, the standard deviation of the dependent variable was calculated for classes of the independent variable. These values were plotted and the plots examined ocularly to determine whether or not the variance was homogeneous. If the plot of standard deviations paralleled or nearly paralleled the x-axis, weighting was not needed. If the variance was determined to be heterogeneous, a weighting function could be determined from these same plots.

After a basic model had been determined, the significance of other independent variables was tested by including them in the regression model. Each new variable, or transformation thereof, was tested singly, in association with the basic equation and if found significant was set aside for further tests. Once each of the new variables had been tested, the significant variables were tested in various logical combinations. Attention was given to the possible interaction of the variables. New regression models were plotted with the actual data to check the accuracy of the fit.

For each time segment, the final regression model included the independent variables from the basic equation plus those found significant in subsequent individual and group variable tests. The plot of the actual data values and the regression estimate for classes of an appropriate independent variable were analyzed to ensure the adequacy of the model.

The dummy variable technique, as discussed by Cunia and Kmenta, was used to analyze variables for which the intervals between classes could not be quantified such as brushiness, bogginess, and directionality of felling. This technique allowed qualitative variables to be analyzed along with quantitative ones (5, 12).

PRODUCTIVITY ANALYSIS RESULTS

Based on the analysis procedures as defined above, each individual segment of the total cycle (turn) time was analyzed separately. It was expected that different types of models would be needed for each segment.

Travel Empty Segment

The basic equation found for estimating travel empty time per cycle involved the distance traveled. A straight line relationship between time and distance traveled was calculated as shown in figure 1. Based on travel empty distances ranging from 20 to 275 feet, the basic equation for estimating travel empty time was:

$$\mathrm{TE} = b_0 + b_1 (\mathrm{TEDIST})$$

where TE equals the estimate of travel empty time per turn and TEDIST equals the travel empty distance.

When testing other variables for improvement to the travel empty time model, only slope was found to be significant along with distance. The travel empty slope values for the test site ranged from minus 15 percent to plus 5 percent. Downhill slopes hastened travel empty time while uphill slopes had the opposite effect. From a theoretical point of view, slope was expected to affect the travel empty time in an exponential way, that is, as the slope became increasingly steep, the travel time was expected to increase sharply. However, since the ground conditions did not include extreme slopes, this exponential relationship was not exhibited by the data. A straight line relationship between the slope and travel empty time was found to be the strongest, but when tested in association with the basic equation including travel empty distance, the individual slope term was not found to be significant. Only the travel empty distance term and the term for interaction between slope and distance were

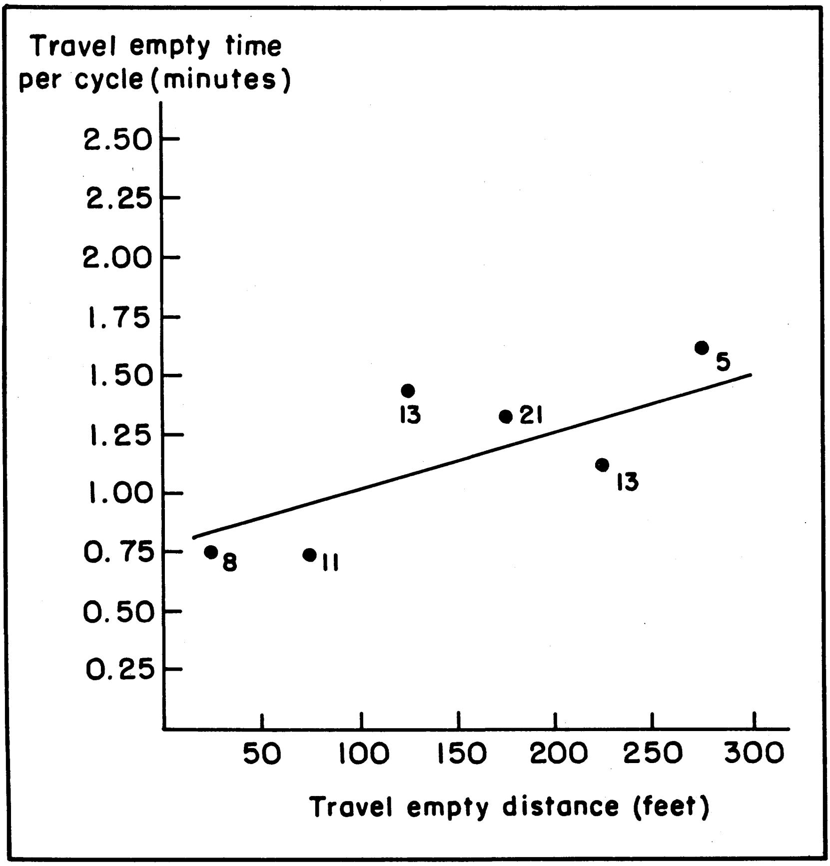

FIG. 1. Travel empty time as a function of distance traveled with weighted data points.

significant giving the following model:

$$TE = b_0 + b_1 (TEDIST) + b_2 [(TEDIST) \times (TESLOPE)]$$

where TESLOPE equals travel empty slope. The analysis of variance (ANOVA) table showing the significance of the slope and interaction terms may be found in Appendix C.

Dummy variables indicating brushiness and bogginess were not significant. Only two classes of brushiness and bogginess were observed. With this limited range, differences in travel empty times were not detected.

With all variables tested, the model was examined for improvement. The intercept was not significant after slope was included and since the intercept's exclusion was not illogical, it was dropped from the final model. All other terms were highly significant taken by themselves with all other variables included. The final model to predict travel empty time was:

$$TE = 0.0052\ (TEDIST) - 0.0005\ [(TEDIST) \times (TESLOPE)]$$

with TE in productive minutes per turn, TEDIST in feet, and TESLOPE in decimal representation of percent. This equation accounted for 81 percent of the variation in travel empty time with the mean effect included.

Choking Segment

In estimating choking time, the most significant factor was expected to be the number of trees. However, a straight line relationship between choking time and the number of trees was not expected. For a one tree load, choking time included time walking from the tractor to the tree, actually choking the tree, and returning to the tractor. For a load having two or more trees, the choking time included those activities for a single tree load spent walking from the tractor plus walking to and choking the second and subsequent trees. On multiple tree loads less time is spent for the additional trees. Therefore, the choking time per tree is greater for a one tree load than for larger loads, and the relationship between the number of trees and choking time appeared to assume the shape of the natural log function as can be seen in figure 2. The data included loads ranging from one to five trees. The basic equation for estimating the choking time of each cycle was found to be:

$$CHOKE = b_0 + b_1\ [\ln(TREES)]$$

where CHOKE equals the choking time per turn estimate and TREES is the number of trees choked during the turn.

The method of felling was also significant in the estimation of the choking time per cycle. Directional felling, when the trees were oriented toward the landing, was found to reduce the choking segment of each cycle. The directional felling reduced the amount of time spent in wasteful repetitions, such as: choke, winch, move, choke again, winch again, etc. Directional felling also reduced the moving time spent preparing for the initial choking and moving time prior to the travel loaded segment. The equation for estimating

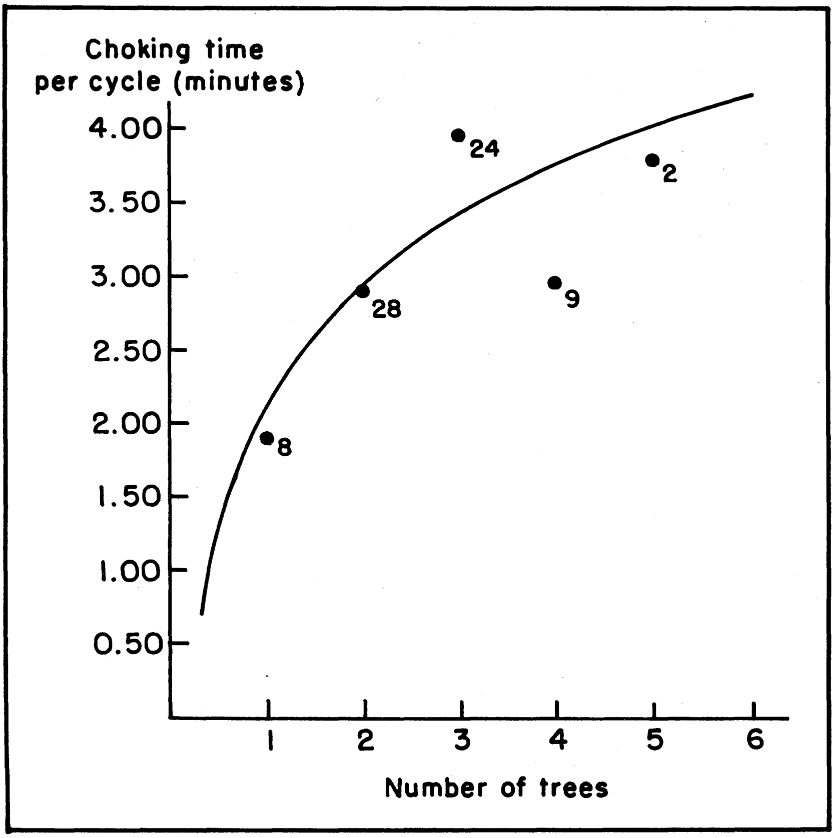

FIG. 2. Choking time per cycle as a function of number of trees with weighted data points.

choking time based on the natural log of the number of trees and directional felling was of the form:

$$CHOKE = b_0 + b_1 [\ln(TREES)] + b_2 (d_f) + b_3 [\ln(TREES) \times (d_f)]$$

where d_f equals zero for directional felling and one otherwise. The ANOVA table showing the significance of the method of felling variable and the interaction term can be found in Appendix C.

Several other variables were tested and found not significant in estimating choking time. Average DBH was one of these. While the DBH of the trees ranged from 6 inches to 20 inches, few diameters were less than 7 inches or greater than 12 inches. When combined into an average DBH per turn, the variation was even less. The small number of DBH classes represented along with a fairly even distribution of diameters over these few classes failed to demonstrate a significant effect in estimating choking time. The basal area per turn data were similar to the average DBH data in their narrow range and even distribution, and therefore were not significant. The effect of slope was tested and was not found to be significant. As with travel empty time, brushiness and bogginess showed a nonsignificant effect which could have resulted from the narrow range of data.

The final equation for the estimation of choking time was:

$$\text{CHOKE} = 2.2597 + 0.6530\,[\ln(\text{TREES})] - 1.5674\,(d_f) + 5.2657\,[\ln(\text{TREES}) \times (d_f)]$$

where CHOKE is in productive minutes, and TREES and d_f are as defined earlier. All terms, including the intercept, were highly significant when taken by themselves with all other variables included. R^2 was 83 percent uncorrected for the mean.

Travel Loaded Segment

A number of variables were tested in estimating travel loaded time for each cycle. The distance traveled was expected to be a major factor in estimating travel loaded time. Having found the straight line relationship for distance to be most appropriate in estimating travel empty time, the same function was tested for travel loaded.

As noted in other studies, load size was also expected to influence travel loaded time along with distance traveled. Load size was most accurately reflected by basal area of the turn rather than the number of trees in the load for estimating travel loaded time. It was hypothesized time would increase exponentially with increasing basal area of the load. The additional weight, as represented by basal area, would expend the power of the machine rapidly causing reduced travel speed compounded by additional hangups and more winching. At some increase in basal area, the machine's speed would be reduced to zero. Figure 3 bears out this hypothesis. Basal area proved to be the strongest estimator of travel loaded time per turn and was highly significant in combination with distance.

As with travel empty time per turn, slope significantly affected travel loaded time. Brushiness and bogginess were tested and found nonsignificant after basal area, distance, and slope were included. After testing all variables with their interaction terms, the best model was:

$$\text{TL} = b_0 + b_1\,(e^{\text{BA}}) + b_2\,(\text{TLDIST}) + b_3\,[(e^{\text{BA}}) \times (\text{TLSLOPE})]$$

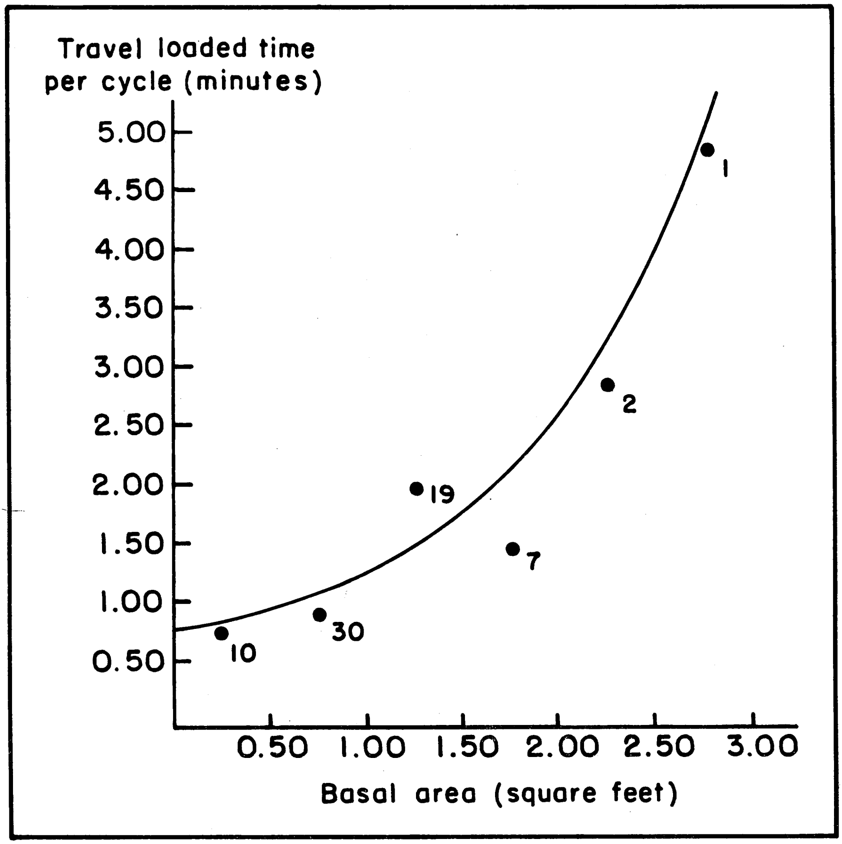

FIG. 3. Travel loaded time as a function of load basal area with weighted data points.

where TL is travel loaded time per turn; BA is basal area of the turn in square feet; TLDIST is travel loaded distance in feet; and TLSLOPE is travel loaded slope in the decimal equivalent of percent.

The equation in this form included a y-intercept, b_0, which was negative, implying that a negative time was possible when the distance traveled was zero. While such a negative time is not possible, the intercept term was highly significant, and for any basal area over 0.7 square feet, the negative intercept was cancelled even when the distance traveled was zero. Therefore, the intercept term was retained in the final equation. The equation for predicting the travel loaded time in productive minutes was:

$$TL = -0.5001 + 0.2890(e^{BA}) + 0.0043(TLDIST) + 0.0331[(e^{BA}) \times (TLSLOPE)].$$

Unchoking Segment

Number of trees was the first variable tested in estimating unchoking time. A straight line model followed the data very closely, figure 4, and yielded the following:

$$\text{UNCHOKE} = b_0 + b_1 \text{ (TREES)}$$

where UNCHOKE equals the unchoking time per turn.

The average DBH and the basal area per turn were each tested in association with the number of trees. Neither were found significant in estimating unchoking time. The lack of extremes in brushiness and bogginess possibly caused these variables to be nonsignificant.

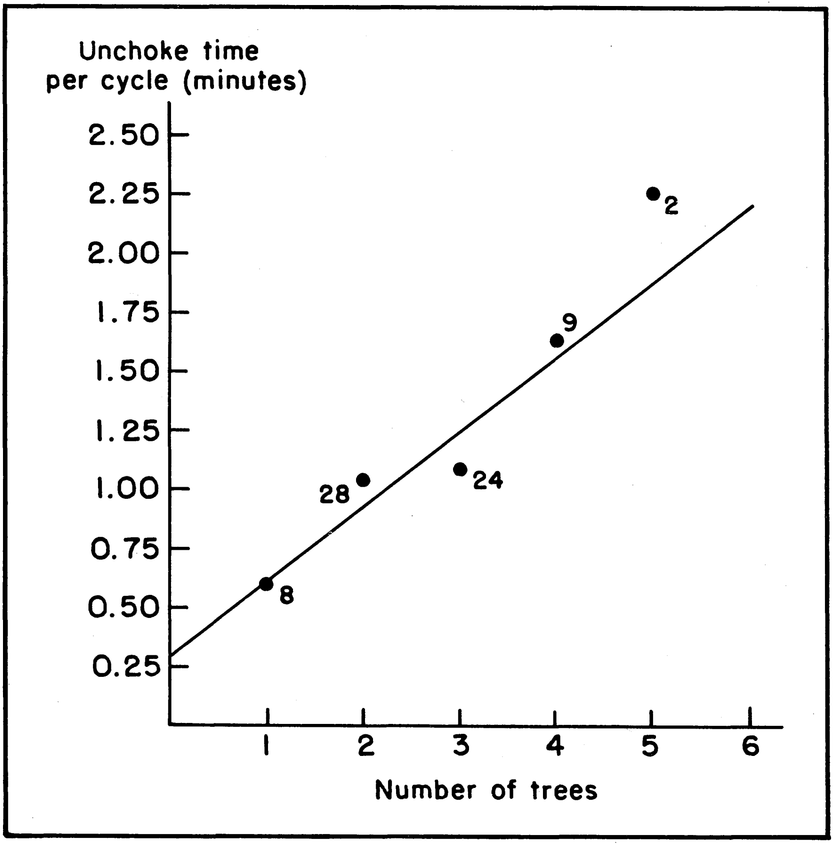

FIG. 4. Unchoke time per cycle as a function of number of trees with weighted data points.

The final regression equation for estimating unchoking time per turn was:

$$\text{UNCHOKE} = 0.2879 + 0.3216\ (\text{TREES})$$

where UNCHOKE is in productive minutes, and TREES is as previously defined.

Decking Segment and Delays

Sampson and Donnelly found that decking time and delay time are subject to increased variability when computed on a per cycle basis since these times do not occur for every cycle. Koger dealt with decking and delay time (as well as choking and unchoking time) as a constant which is simply added to the regression equation for estimating total cycle time (13).

Similarly, the data taken in this study showed high variability for decking and delay times per turn. As mentioned earlier, delay times were introduced through utilization rates and were not estimated from the study data. The decking times from the study were thought to be typical for the Holder A55 F and therefore, were included in total cycle time estimation. None of the controlling factors recorded significantly affected decking time per turn; therefore, it was estimated as a constant:

$$\text{DECK} = 0.87$$

where DECK is in productive minutes. This decking constant is the mean decking time per cycle.

Total Cycle Time

Summing the estimation equations for each segment of the overall cycle yielded the final regression equation for predicting total productive cycle time in minutes:

$$\begin{aligned}\text{CYCLE} &= \text{TE} + \text{CHOKE} + \text{TL} + \text{UNCHOKE} + \text{DECK}\\ &= 0.0052\ (\text{TEDIST}) - 0.0005\ (\text{TEDIST} \times \text{TESLOPE})\\ &+ 0.6530\ [\ln(\text{TREES})] - 1.5674\ (d_f) + 5.2657\\ &\quad [d_f \times \ln\ (\text{TREES})]\\ &+ 0.2890\ (e^{BA}) + 0.0043\ (\text{TLDIST}) + 0.0331\ [(e^{BA})\\ &\quad \times (\text{TLSLOPE})]\\ &+ 0.3216\ (\text{TREES}) + 2.9175\end{aligned}$$

where CYCLE equals the sum of regression estimates for the total productive cycle time. TEDIST equals the travel empty distance in feet, TESLOPE equals the percent travel empty slope expressed in decimals, TREES equals the number of trees in the load, d_f is a dummy variable having a value of zero when directional felling was observed (and a value of one if not), BA equals the basal area of the load in square feet, TLDIST equals the travel loaded distance, and TLSLOPE equals the travel loaded slope. The constant 2.9175 is the sum of the constant terms associated with the choking, unchoking, travel loaded, and decking times.

The overall equation reflects the general relationships evident for the individual segments of the cycle. Travel time increases with distance. A positive slope increases travel time, while a negative, favorable slope can decrease travel time. Figure 5 illustrates the relationship between total productive cycle time and distance traveled and shows the effects of slope on time per cycle. The greater the number of trees choked (and hence, unchoked) for a given cycle, the longer the cycle. Finally, as more basal area is skidded, the total travel time increases.

While seven variables are included in the final equation, TESLOPE is usually the opposite of TLSLOPE, and TEDIST usually equals TLDIST. Though these assumptions are not always valid, they are generally correct, and therefore the final regression equation is essentially a function of five variables: distance, slope, number of trees, basal area, and method of felling.

Several conclusions can be inferred from the overall equation. Avoiding unnecessarily long travel distances can decrease cycle time and thus increase productivity. Avoiding extreme or unfavorable slopes where possible can also have a beneficial effect on cycle time based on this study's slope data which ranged from 0 to 15 percent.

The notion that the reduction in the number of stems skidded per turn, reduction in basal area skidded per turn, or even the reduction of travel distance by making a number of short skids increases productivity is false. The additional cycles required by such practices would be very costly in terms of time and productivity. Instead, every effort should be made to ensure that, within the capability of the machine, the maximum load as governed by weight or basal area should be skidded for each cycle. The skid distances should be based on setting layouts designed to minimize the cost of road building and skid distance.

Finally, the regression equation indicates directional felling should be used whenever possible. Total cycle time is markedly

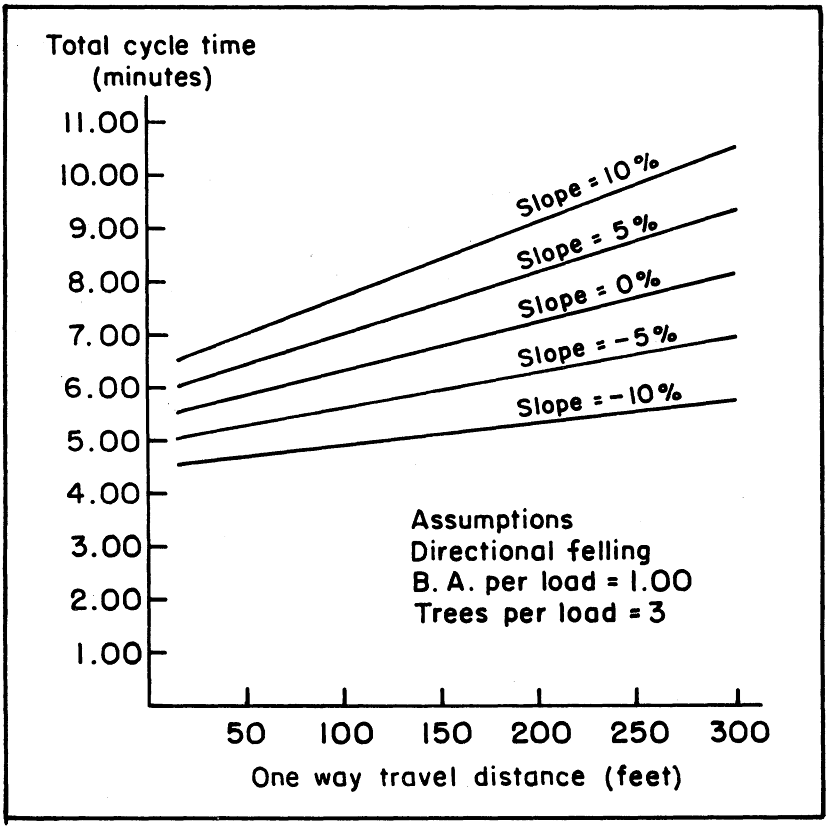

FIG. 5. Total cycle time as a function of distance traveled with slope inbound to landing.

shorter when directional felling is employed, and therefore overall productivity is increased.

The distance traveled per observed cycle ranged from 20 to 275 feet. Observed cycle times ranged from 2.13 minutes to 29.34 minutes, though the latter reflected an extreme case where 18.22 minutes were spent in the decking segment. The mean actual cycle time, including times for all cycles in the data, was 7.65 minutes. By inserting the appropriate variables for each observation into the regression equation, estimates of total cycle time were obtained for each observation and were compared to the actual times in an analysis of residuals which can be found in Appendix D. Forty-five percent of the estimates were within 1 minute of the actual times while over 60 percent of the estimates were within 2 minutes of the actual times. The larger differences between the estimates and the actual times were usually attributable to choking or decking difficulties. For the minimum observed travel distance, 20 feet, the mean regression estimate was 0.15 minute below the mean actual time. For the maximum observed travel distance, the regression estimate was 1.52 minutes below the actual observed time, but the regression equation neither underestimated nor overestimated cycle time consistently.

SKIDDING PRODUCTIVITY

Volume for the "average" tree was derived from stand measurement data. The average total height of the trees in the stand was 55 feet and the average DBH was 8 inches. Average volume per tree of stem wood to a 2-inch top was 6.65 cubic feet (24). Since an average of three stems were skidded per cycle, the average volume per turn was 19.95 cubic feet or 0.1995 cunits.

Estimates of total cycle time combined with production per cycle yielded estimates of production per scheduled machine hour (SMH), see table 1. Assuming 70 percent utilization and an average skid distance of 150 feet, the Holder A55F equipped for cable skidding made 6.17 turns per scheduled hour, skidding an estimated 1.23 cunits or 18.5 trees in a scheduled hour. As a cable skidder, the tractor had an estimated range of cycle times from 6.34 minutes per cycle (1.32 cunits per SMH) at an average skid distance of 100 feet to 10.14 minutes per cycle (.82 cunits per SMH) at 500 feet. Productivity of the Holder A55F equipped as a grapple skidder is addressed later in this report.

TABLE 1. COMPARISON OF PREDICTED CABLE AND GRAPPLE SKIDDING CYCLE TIMES AND PRODUCTION RATES FOR THE HOLDER A55F ASSUMING 70 PERCENT UTILIZATION[1]

Travel distance	Total productive cycle time		Cycles per scheduled hour		Production per scheduled hour			
					Cunits		Trees	
	Cable	Grapple	Cable	Grapple	Cable	Grapple	Cable	Grapple
Ft.	*Min.*	*Min.*	*Cycles*	*Cycles*	*Cunits*	*Cunits*	*Trees*	*Trees*
100	6.34	4.30	6.62	9.77	1.3207	1.9491	19.86	29.31
150	6.81	4.79	6.17	8.77	1.2309	1.7496	18.51	26.31
200	7.29	5.28	5.76	7.95	1.1491	1.5860	17.28	23.85
250	7.76	5.76	5.41	7.29	1.0793	1.4543	16.23	21.87
300	8.24	6.25	5.10	6.72	1.0175	1.3406	15.30	20.16
350	8.71	6.73	4.82	6.24	0.9616	1.2449	14.46	18.72
400	9.19	7.22	4.57	5.82	0.9117	1.1611	13.71	17.46
450	9.66	7.70	4.35	5.45	0.8678	1.0873	13.05	16.35
500	10.14	8.19	4.14	5.13	0.8259	1.0234	12.42	15.39

[1] Assumptions: Average DBH = 8.00 in.; average total height = 55 ft.; volume per stem = 6.65 cu. ft. (U.S. Forest Service, 1929); average number of stems per load = 3.

CABLE SKIDDER COST ANALYSIS

A cost analysis was performed to translate the volume per cycle and cycle time estimates into meaningful cost figures for the Holder A55F logging tractor. This analysis required a number of assumptions:

Machine life:	4 years At 225 work days per year and 8 scheduled hours per day (McMorland, 1977), life of 7,200 scheduled hours.	
Purchase price:	Complete A55F Forestry Tractor	$18,000
	Decking, Frame & Blade/tilt	$ 4,000
	Farmi JL 30 winch	$ 2,000
	Total price (as of January, 1979)	$24,000
Residual value:	10 percent of purchase price (McMorland, 1977)	
Depreciation:	Straight line over 4 years	
Operator wages:	$3.75 per hour (Tufts, 1977)	
Maintenance:	120 percent of purchase price (Caterpillar, 1978) Includes all maintenance, repairs, tires, cable, etc.	
Fuel and lubricant:	0.44 gallon diesel fuel consumed per productive hour (based on study data) $0.92 per gallon diesel fuel Lubricant = 10 percent of fuel costs	

Interest, insurance, taxes:
Insurance = 3 percent of Average Yearly Investment
Interest = 12 percent of Average Yearly Investment
Taxes = 0 percent of Average Yearly Investment
Total = 15 percent of Average Yearly Investment (21).

Based on these assumptions, the depreciation per scheduled machine hour (SMH) was $3.00. Interest, insurance, and taxes, as a percent of the average yearly investment, varied by year. The total ownership costs also varied, ranging from a high of $4.78 per SMH in year one to a low of $3.43 per SMH in year four as can be seen in table 2.

TABLE 2. OWNERSHIP COSTS FOR THE HOLDER A55F LOGGING TRACTOR EQUIPPED WITH A FARMI JL-30 WINCH

Year	Costs per scheduled machine hour		
	Depreciation	Interest and insurance	Total
	Dol.	*Dol.*	*Dol.*
1	3.00	1.78	4.78
2	3.00	1.33	4.33
3	3.00	0.88	3.88
4	3.00	0.43	3.43

Operating costs for the tractor included $3.75 for wages and $4.00 for repairs per SMH. The fuel and lubricant costs varied by the level of utilization from a high of $0.40 per SMH at 90 percent utilization to $0.22 per SMH at 50 percent utilization, as can be seen in table 3.

Assuming year two to be an average year in terms of expenses in the life of the machine, and assuming an average utilization of 70 percent, the total ownership and operating cost per SMH was $12.39. The total ownership and operating costs ranged from a high of $12.93 to a low of $11.40 per SMH, as shown in table 4. For a given level of utilization, there is an approximate 3.7 percent drop each year in total costs per SMH. Also, for any given year, the total ownership and operating costs rise approximately 0.4 percent for each 10 percent increase in utilization.

Combining productivity rates as shown in table 1 with machine rates of table 4 produced the cost rates displayed in table 5. It was assumed the trees were directionally felled, slope was zero, and the number of trees was three amounting to 19.95 cubic feet or 1.00 square foot of basal area. Distances traveled were varied from 100 feet to 500 feet to obtain a cost per cunit for various average skidding distances.

The average skid distance on the study site was 150 feet. For this distance, the cost per cunit was $10.07 assuming an average utilization of 70 percent. Based on 70 percent utilization, the cost per cunit varied from $9.38 for a 100-foot average skid distance to $15.01 for a 500-foot average skid distance.

Reductions of up to 16.3 percent in cost per cunit for an average skid distance can be obtained by increasing utilization just 10 percent (i.e. by reducing idle time, down time, or service time). When utilization is increased by 20 percent, the cost per cunit can be reduced up to 28 percent. As the utilization becomes higher, the additional reduction in costs derived from increased utilization is decreased.

TABLE 3. OPERATING COSTS FOR THE HOLDER A55F LOGGING TRACTOR EQUIPPED WITH A FARMI JL-30 WINCH

Utilization	Costs per scheduled machine hour			
	Wages	Maintenance	Fuel and lubricant	Total
Pct.	*Dol.*	*Dol.*	*Dol.*	*Dol.*
50	3.75	4.00	0.22	7.97
60	3.75	4.00	0.27	8.02
70	3.75	4.00	0.31	8.06
80	3.75	4.00	0.36	8.11
90	3.75	4.00	0.40	8.15

TABLE 4. OWNERSHIP AND OPERATING COSTS FOR THE HOLDER A55F LOGGING TRACTOR EQUIPPED WITH A FARMI JL-30 WINCH

Utilization	Cost per scheduled machine hour			
	Year 1	Year 2	Year 3	Year 4
Pct.	*Dol.*	*Dol.*	*Dol.*	*Dol.*
50	12.75	12.30	11.85	11.40
60	12.80	12.34	11.89	11.44
70	12.84	12.39	11.94	11.49
80	12.88	12.43	11.98	11.53
90	12.93	12.48	12.03	11.58

TABLE 5. TOTAL COST PER CUNIT FOR THE HOLDER A55F LOGGING TRACTOR EQUIPPED WITH A FARMI JL-30 WINCH[1]

Utilization	Cost per cunit								
	Average skid distance								
	100'	150'	200'	250'	300'	350'	400'	450'	500'
Pct.	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*
50	13.03	13.99	14.98	15.94	16.93	17.89	18.88	19.85	20.86
60	10.90	11.70	12.53	13.33	14.16	14.97	15.79	16.60	17.45
70	9.38	10.07	10.78	11.47	12.18	12.87	13.58	14.28	15.01
80	8.23	8.84	9.46	10.08	10.70	11.30	11.93	12.54	13.18
90	7.34	7.89	8.44	8.99	9.54	10.08	10.64	11.19	11.76

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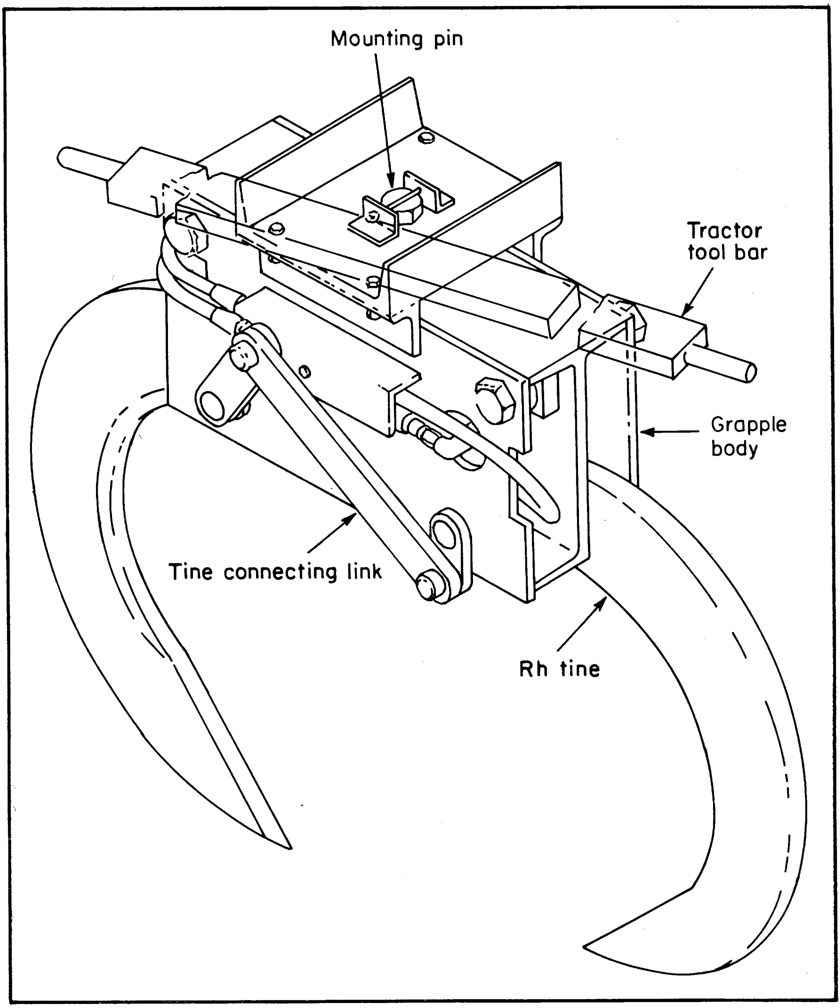
[1] Cost assumptions: Second year of machine life, straight line depreciation. Production assumptions: Zero percent slope, three trees per cycle, 1.00 square foot of basal area per cycle, directional felling.

GRAPPLE OR WINCH?

One of the objectives was to evaluate the changes in productivity and costs associated with the use of alternate hooking equipment on the Holder A55F. The use of a grapple of the type studied in *Power Tine Grapple* was hypothesized (3). This grapple was designed to reduce the choking and unchoking time on small skidders such as two-wheel drive farm tractors or as in this case, the Holder. The grapple can be attached to any tractor with a three-point hitch, see illustration.



(Reprinted from *Power Tine Grapple* (Blonsky, 1970) page vi.)

McDermid and Perkins compared productivity of cable and grapple skidders operating under similar conditions and found grapple skidders took less time than cable skidders in the choking and unchoking segments of the cycle but more time in the traveling portions. Their report includes the percentages of time spent in each segment of the skidding cycle (16).

These percentages coupled with cycle times determined a ratio of grapple skidder to cable skidder times. Ratios were calculated for travel empty, travel loaded, unchoking, and choking times per turn. Decking time was assumed the same regardless whether it occurred for a cable or grapple skidder. This gives the following:

$$\begin{aligned}\mathrm{CYCLE_G} = {} & (\mathrm{TE} \times 1.0202) + (\mathrm{CHOKE} \times 0.6759) + (\mathrm{TL} \times 1.0255) + \\ & (\mathrm{UNCHOKE} \times 0.1259) + \mathrm{DECK}\end{aligned}$$

where $\mathrm{CYCLE_G}$ is the total productive cycle time per turn for a grapple skidder, and TE, CHOKE, TL, UNCHOKE, and DECK have been defined earlier for choker skidders.

Table 1 shows that for a 150-foot average travel distance, the total productive cycle time estimated for the cable skidder was 6.81 minutes; whereas, the estimate for the grapple skidder was only 4.79 minutes. At each distance between 100 and 500 feet, the estimate of total productive cycle time for the grapple skidder was approximately 2 minutes below the estimate for the cable skidder. Converting to cycles per SMH based on 70 percent utilization, the estimates revealed that with the grapple, the Holder A55F would make 3.15 more cycles per SMH on average skid distances of 100 feet. The estimates of production indicate that as a grapple skidder, the tractor is capable of producing 1.95 cunits per SMH at an average skid distance of 100 feet, an increase of nearly 50 percent over its production as a cable skidder. Between 9.45 and 2.97 additional trees could be skidded per SMH by the grapple-equipped tractor over the cable-equipped machine assuming three trees averaging 8 inches in DBH could be grappled. Grapple skidding would have a greater advantage over cable skidding on logging operations where the trees are bunched. Since the bunch sizes would be small, they could possibly be constructed even with skilled manual felling utilizing directional felling.

All cost assumptions made in dealing with cable skidding held for grapple skidding, with the exception of the purchase price, which was only $23,400 for the tractor and grapple. The grapple's 1970 cost of $750, when inflated to 1979 by 183 percent, was $1,400, $600 less than the price of the Farmi winch (21). The changed purchase price reduced the depreciation per SMH to $2.93, see table 6, and the maintenance cost per SMH to $3.90, see table 7. Interest and investment, at 15 percent of the average annual investment, also changed as shown in table 6. An additional cost which was not estimated was for additional lifting capacity in the three-point hitch.

TABLE 6. OWNERSHIP COSTS FOR THE HOLDER A55F LOGGING TRACTOR EQUIPPED WITH A POWER TINE GRAPPLE

Year	Costs per scheduled machine hour		
	Depreciation	Interest and insurance	Total
	Dol.	*Dol.*	*Dol.*
1	2.93	1.73	4.66
2	2.93	1.29	4.22
3	2.93	0.85	3.78
4	2.93	0.41	3.34

TABLE 7. OPERATING COSTS FOR THE HOLDER A55F LOGGING TRACTOR EQUIPPED WITH A POWER TINE GRAPPLE

Utilization	Costs per scheduled machine hour			
	Wages	Maintenance	Fuel and lubricant	Total
Pct.	*Dol.*	*Dol.*	*Dol.*	*Dol.*
50	3.75	3.90	0.22	7.87
60	3.75	3.90	0.27	7.92
70	3.75	3.90	0.31	7.96
80	3.75	3.90	0.36	8.01
90	3.75	3.90	0.40	8.05

TABLE 8. OWNERSHIP AND OPERATING COSTS FOR THE HOLDER A55F LOGGING TRACTOR EQUIPPED WITH A POWER TINE GRAPPLE

Utilization	Cost per scheduled machine hour			
	Year 1	Year 2	Year 3	Year 4
Pct.	*Dol.*	*Dol.*	*Dol.*	*Dol.*
50	12.53	12.09	11.65	11.21
60	12.58	12.14	11.70	11.26
70	12.62	12.18	11.74	11.30
80	12.67	12.23	11.79	11.35
90	12.71	12.27	11.83	11.39

TABLE 9. TOTAL COST PER CUNIT FOR THE HOLDER A55F LOGGING TRACTOR EQUIPPED WITH A POWER TINE GRAPPLE[1]

Utilization	Cost per cunit								
	Average skid distance								
	100'	150'	200'	250'	300'	350'	400'	450'	500'
Pct.	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*
50	8.69	9.67	10.67	11.63	12.62	13.59	14.58	15.56	16.53
60	7.27	8.09	8.92	9.73	10.56	11.36	12.20	13.01	13.83
70	6.25	6.96	7.68	8.37	9.08	9.78	10.49	11.19	11.90
80	5.49	6.11	6.74	7.35	7.98	8.59	9.22	9.83	10.45
90	4.90	5.45	6.01	6.56	7.12	7.66	8.22	8.77	9.32

[1] Cost assumptions: Second year of machine life, straight line depreciation. Production assumptions: Zero percent slope, three trees per cycle, 1.00 square foot of basal area per cycle, directional felling.

Some difficulty was experienced during the study with this feature. It is expected this modification would be minor in cost.

Assuming year two to be an average year in terms of expenses in the life of the machine, and assuming an average utilization of 70 percent, the total ownership and operating costs per SMH for the Holder A55F and attached grapple were found to be $12.18 as shown in table 8. Total ownership and operating costs per SMH for the grapple skidder ranged from $12.71 to $11.21.

Productivity and cost figures for the Holder modified with a grapple were combined as for the cable skidder. For an average skid distance of 150 feet and utilization of 70 percent, the cost per cunit for the Holder A55F tractor equipped with a grapple is estimated to be $6.96 as shown in table 10. McDermid and Perkins did find delay times for grapple skidders to be greater by 8.5 percent than for cable skidders, implying lower levels of utilization for grapple skidders (16). However, even at reduced utilization, the estimates of cost per cunit for the grapple-equipped tractor are an improvement over those for the tractor equipped with a winch.

CONCLUSION

Time per cycle can be predicted for the Holder A55F as a function of (a) skid distance, (b) slope, (c) number of trees per cycle, (d) basal area per cycle, and (e) method of felling. Setting layouts which reduce the average skid distance are advantageous for reduced skidding costs. Loading the machine to its capacity reduces skidding costs for all distances. Directional felling improves productivity significantly.

The Holder tractor offers good maneuverability, particularly in dense stands where its smaller dimensions prove advantageous. The tractor's small size and weight lessen the task of transporting the machine from operation to operation. Low fuel consumption on the part of the Holder A55F may improve its cost figures even more relative to other skidding equipment if fuel prices continue to increase more rapidly than other costs. Hypothesizing the use of a grapple for skidding with the Holder A55F indicates production rates and costs per cunit which were much better than those for the same tractor equipped with cable equipment.

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APPENDIX

Appendix A

Technical data: The Holder A55F Logging Tractor

Design:	Frameless unit construction, four-wheel drive, pivotal steering.
Engine:	Holder three-cylinder, four-stroke diesel engine, 2,024 c.c., 48 at 2,400 r.p.m., Bosch fuel injection system and regulator, direct injection, crankshaft on four ball bearings.
Clutch:	Single plate clutch
Gearbox:	Eight forward speeds, four reverse speeds, four-wheel drive via spiral toothed level gears, two differentials, individually operated diff-locks front and rear.
Steering:	Hydromatic pivotal steering
Brakes:	Acting on all four wheels, two independent braking systems, foot and hand brake acting on all four wheels
Tires:	Front and rear 9.5/1 -24 AS
PTO:	Geared PTO with 540 r.p.m. at 2,100 r.p.m.
Fuel tank:	23 litres (6.08 gallons)
Air filter:	Large oilbath air filter
Cooling:	Water cooling with pump and thermostat
Hydraulics:	Holder two-cylinder hydraulics with Bosch pump, lifting capacity 15.00 n (1,600 kp) on field bar
Implement lift:	Standard three-point linkage
Electrical equipment:	12 V system
Wheel base:	57.09 inches
Track widths:	49.21 inches

Technical data: The Farmi JL-30 Winch

Pulling capacity:	6,600 pounds
Drum capacity:	100 feet of 1-inch cable
Winching speed:	100-200 feet per minute
Clutch:	Mechanical friction plate clutch
Power transmission:	Universal shaft from tractor P.T.P.
Mounting:	Tractor three-point hitch
HP requirement:	35 or more
Weight:	400 pounds

Appendix B

FOREST HARVESTING ANALYSIS RECORD

SKIDDER CYCLE REPORT

Page ___ of ___

DATE (MO / DAY / YR): ___/___/___ (1–6)

TIME OF DAY: BEGIN ___:___ (7) END ___:___ (14)

STUDY NO.: ___ (15–17)

LOCATION: COUNTY ___ STATE ___ (18–27)

TS CREW (INITIALS): ___, ___, ___, ___ (28–35)

CONTRACTOR: ___ (36–47)

FUNCTION: ___/___ (48–53)

MACH. NO.: ___ (54–57)

TIME	CODE	DBH	NO. OF STEMS	BUNCH NO.	DIST.	SLOPE %	DIR.	BRUSH	OBSTACLE	BOGGINESS
58 :	62	64		68		75				80
:										
:										
:										
:										
:										
:										
58 :	62	64		68		75				80
:										
:										
:										
:										
:										
:										
58 :	62	64		68		75				80
:										
:										
:										
:										
:										
:										
:										
:										
:										

Appendix C

ANALYSIS OF VARIANCE TABLES

Travel empty segment:

R1: $TE = b_0 + b_1\,(TEDIST)$

R2: $TE = b_0 + b_1\,(TEDIST) + b_2\,[(TEDIST) \times (TESLOPE)]$

Source	*Sum of squares*	*Degrees of freedom*	*Mean square*	*F*
R1	94.3947	2	47.1973	153.30
R2	97.0313	3	32.3438	118.65
Error R2	17.9913	66	0.2726	-
R2-R1	2.6366	1	2.6366	9.67

Choking segment:

R1: $CHOKE = b_0 + b_1\,[\ln(TREES)]$

R2: $CHOKE = b_0 + b_1\,[\ln(TREES)] + b_2\,(d_f) + b_3\,[\ln(TREES) \times (d_f)]$

Source	*Sum of squares*	*Degrees of freedom*	*Mean square*	*F*
R1	701.8150	2	350.9075	96.31
R2	791.2934	4	197.8233	83.15
Error R2	154.6395	65	2.3791	-
R2-R1	89.4784	2	44.7392	18.81

Travel loaded:

R1: $TL = b_0 + b_1\,(e^{BA})$

R2: $TL = b_0 + b_1\,(e^{BA}) + b_2\,[(e^{BA}) \times (TLSLOPE)]$

Source	*Sum of squares*	*Degrees of freedom*	*Mean square*	*F*
R1	153.3286	2	76.6643	75.80
R2	160.5003	3	53.5001	58.28
Error R2	60.5900	66	0.9180	-
R2-R1	7.1717	1	7.1717	7.81

R1: $TL = b_0 + b_1\,(e^{BA}) + b_2\,[(e^{BA}) \times (TLSLOPE)]$

R2: $TL = b_0 + b_1\,(e^{BA}) + b_2\,(TLDIST) + b_3\,[(e^{BA}) \times (TLSLOPE)]$

Source	*Sum of squares*	*Degrees of freedom*	*Mean square*	*F*
R1	160.5003	3	53.5001	58.28
R2	165.4399	4	41.3600	48.31
Error R2	55.6504	65	0.8562	-
R1-R2	4.9396	1	4.9396	5.7692

Appendix D

ANALYSIS OF RESIDUALS

Trave loaded distance	Actual cycle time	Estimated cycle time	Difference = prediction - actual
Ft.	*Min.*	*Min.*	*Min.*
20	3.16	2.24	-0.92
20	8.72	8.25	-0.47
25	4.43	6.12	1.69
26	4.22	5.16	0.94
30	6.75	7.93	1.19
30	7.61	6.51	-1.10
32	10.21	8.20	-2.01
34	2.13	2.42	0.29
40	7.14	7.02	-0.12
43	7.22	6.68	-0.54
60	13.68	8.75	-4.93
60	5.64	5.30	-0.34
66	16.05	9.67	-6.38
72	4.49	6.49	2.00
75	3.15	5.78	2.63
75	5.30	8.84	3.54
80	4.06	6.43	2.37
80	5.38	7.35	1.97
85	3.81	3.31	-0.50
90	6.09	6.25	0.16
90	6.91	7.06	0.15
93	6.38	6.82	0.44
100	9.99	6.31	-3.68
101	10.63	9.08	-1.56
110	7.89	8.16	0.27
120	17.67	12.11	-5.56
120	7.85	8.83	0.98
125	7.58	12.22	4.64
125	4.30	6.37	2.07
125	4.15	6.89	2.74
134	8.25	7.76	-0.49
140	9.28	9.75	0.47
140	5.65	6.09	0.44
150	9.04	9.37	0.33
150	6.43	8.06	1.63
150	7.03	8.42	1.39
152	6.70	7.55	0.85
152	9.32	9.44	0.12
160	4.89	7.14	2.26
163	7.48	6.22	-1.26
168	7.57	7.25	-0.32
171	9.65	9.53	-0.12
175	8.60	12.20	3.60
175	6.54	5.66	-0.88
176	6.33	7.02	0.69
185	9.29	7.18	-2.11
185	9.42	6.57	-2.85
186	6.00	7.25	1.25
190	6.34	7.75	1.41
190	4.51	6.34	1.83
190	10.48	9.25	-1.23
190	29.34	8.43	-20.91
192	7.60	7.82	0.22
194	4.57	9.35	4.78
195	12.54	6.60	-5.94

ANALYSIS OF RESIDUALS (cont.)

Travel loaded distance	Actual cycle time	Estimated cycle time	Difference = prediction - actual
Ft.	*Min.*	*Min.*	*Min.*
199	5.38	9.37	3.99
205	6.75	7.67	0.92
208	8.96	7.49	-1.47
215	8.43	8.53	0.10
215	8.56	7.77	-0.79
220	4.96	8.70	3.74
225	6.12	7.95	1.83
235	7.41	7.47	0.06
240	6.34	7.66	1.32
245	8.63	8.14	-0.49
245	4.77	6.92	2.15
245	8.30	8.20	-0.10
270	8.53	8.54	0.01
275	8.96	7.44	-1.52

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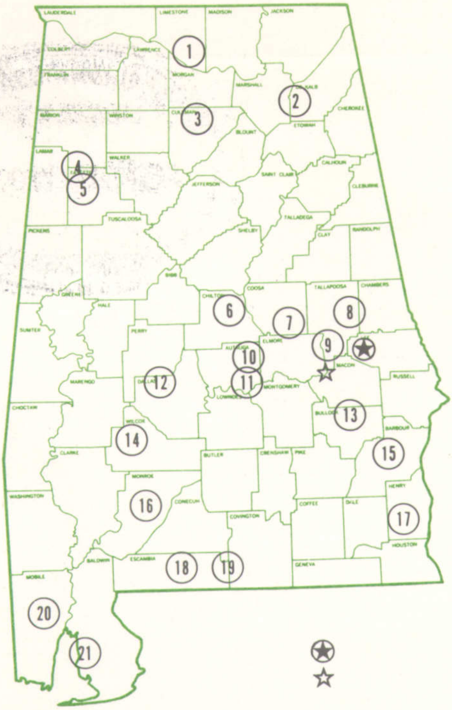
AUBURN UNIVERSITY

With an agricultural research unit in every major soil area, Auburn University serves the needs of field crop, livestock, forestry, and horticultural producers in each region in Alabama. Every citizen of the State has a stake in this research program, since any advantage from new and more economical ways of producing and handling farm products directly benefits the consuming public.



Research Unit Identification

★ Main Agricultural Experiment Station, Auburn.
☆ E. V. Smith Research Center, Shorter.

1. Tennessee Valley Substation, Belle Mina.
2. Sand Mountain Substation, Crossville.
3. North Alabama Horticulture Substation, Cullman.
4. Upper Coastal Plain Substation, Winfield.
5. Forestry Unit, Fayette County.
6. Chilton Area Horticulture Substation, Clanton.
7. Forestry Unit, Coosa County.
8. Piedmont Substation, Camp Hill.
9. Plant Breeding Unit, Tallassee.
10. Forestry Unit, Autauga County.
11. Prattville Experiment Field, Prattville.
12. Black Belt Substation, Marion Junction.
13. The Turnipseed-Ikenberry Place, Union Springs.
14. Lower Coastal Plain Substation, Camden.
15. Forestry Unit, Barbour County.
16. Monroeville Experiment Field, Monroeville.
17. Wiregrass Substation, Headland.
18. Brewton Experiment Field, Brewton.
19. Solon Dixon Forestry Education Center, Covington and Escambia counties.
20. Ornamental Horticulture Field Station, Spring Hill.
21. Gulf Coast Substation, Fairhope.